PAKISTAN

WATER AND POWER DEVELOPMENT AUTHORITY

ATTABAD LAKE HYDROPOWER PROJECT

FEASIBILITY STUDY

EXECUTIVE SUMMARY

June 2021

HYDRO PLANNING ORGANIZATION

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EXECUTIVE SUMMARY

S.1 INTRODUCTION

Attabad Lake Hydropower Project (ALHPP) has been identified on Hunza River downstream of Attabad Lake due to creation of dam due to land slide from right bank of Hunza River in January, 2010 20 km upstream of Aliabad, Hunza Valley, Gilgit-Baltistan. ALHPP is proposed on Attabad Lake which has live storage capacity of about 11 million m^3. Project Location is shown in Dwg. No: AFS-GN-101.

On Nov, 2015 Prime Minister announced the construction of ALHPP, Accordingly Ministry of Water and Power, Gilgit-Baltistan undertook its Feasibility Study through Annual Development Program (ADP) for Financial Year 2016-17. In the beginning Feasibility Study of ALHPP was carried out by local consultants, Design man Consulting Engineers (Pvt) Ltd, Islamabad in association with Mountain Infrastructure & Engineering Services, Gilgit, in March, 2017. The Project was finalised with an installed capacity of 32.5 MW and mean annual energy of 255 GWH. On August, 2017, Ministry of Water and Power, Gilgit-Baltistan wrote letter to the Chairman WAPDA to give expert opinion on the Feasibility Study of ALHPP. On July 2019, a meeting was held between Chairman, WAPDA and Chief Secretary, Gilgit-Baltistan. It was agreed that Feasibility Study would be reviewed by Hydro Planning Organization (HPO), WAPDA because of its expertise in the field of Hydropower. Water and Power Development, Gilgit-Baltistan shared the already carried out Feasibility Study with HPO, WAPDA in January, 2020. Feasibility Study has been examined by HPO, WAPDA and found that proposed layout is designed without diversion works and sediment flushing facility which are imperative for Project execution. Therefore, Feasibility Study has been again undertaken by HPO, WAPDA with additional investigation. The Terms of Reference (TOR) set for HPO, WAPDA by Govt. of Gilgit-Baltistan is to review Feasibility Study and preparation and submission of PC-I of ALHPP.

HPO, WAPDA prepared a new Feasibility Study with additional field investigations including topographic and hydrographic survey of Lake, 400 m onshore drilling, neotectonic studies and geological mapping with new layout. It enhanced its capacity to 54 MW with mean annual energy of 374 GWh with an estimated cost of Rs.21,246 million in order to meet the beside requirements of entire Hunza River valley but also fulfil the demand of Gilgit and Ghizar districts with peaking storage facility at Attabad Lake, the installed power of 54 MW can be generated throughout the year during peak hours..

ALHPP has been designed for an installed capacity of 54.0 MW with the design discharge and rated head of 60 m^3/s and 106 m respectively. Project will provide mean annual electricity/energy of 374 GWh by using 3 vertical Francis turbines with a plant factor of 79%.

S.2 PROJECT ACCESS

The Project is accessible from Federal Capital Islamabad connected to Gilgit along the existing N-35 Karakorum Highway (KKH) which leads to Project Area at Attabad Lake near Hunza. The route through KKH can be accessed via Motorways from Islamabad to Burhan Interchange near Hassanabdal (M-1 Islamabad-Peshawar Motorway – 44 km) and from Burhan Interchange to Thakot (M-15 Hazara Motorway – 186 km). From there, the access onward to Gilgit and

Hunza continues as a part of KKH (Thakot to Gilgit– 390 km; Gilgit to Attabad Lake/ Hunza along Hunza River – 120 km). There is another route from Islamabad to Gilgit and Hunza via Babusar Pass, through National Highway (N-15). This route is although shortest than KKH through Besham, to reach upto Chilas but it usually remains closed for six months in a year due to heavy snowfall during the winter season.

Gilgit Airport is the nearest facility to the Project Area which is about 120 km from the Project Site. Domestic flights from Islamabad airport are schedule for Gilgit on daily basis but flight operation depends upon the weather conditions. Recently flights from Lahore and Karachi are also operational to Gilgit Airport.

S.3 TOPOGRAPHIC & HYDROGRAPHIC SURVEYS

To determine the geographical conditions of the Project Area, the topographic survey has been performed by Survey Division, HPO, WAPDA, Peshawar during August & September, 2020. The satellite based survey with two fold approach i.e. Google Earth and Geographical Information System (GIS) has been adopted in addition to the conventional topographic survey. A comprehensive topographic survey of the Project Area has been carried out at a scale of 1:1000 to cover topographic features of ALHPP comprehensively. The topographic survey of the Project Area includes:

- Topographic survey of the Project Area of about 400 hectares, covering 4 km downstream of Weir Site along Hunza River.
- Longitudinal profile along Hunza River, 4 km downstream from Weir Site.
- Topographic survey of 21 valley cross sections along Hunza River, 4 km downstream of Weir Site at an interval of 200 m, covering the main river course and valley slopes (ranging from 175 to 250 m) on either side.

The hydrographic survey of the Attabad Lake has been carried out by International Sedimentation Research Institute (ISRIP), WAPDA, Pakistan during September & October, 2020 using echo sounding equipment. 40 Nos. cross-sections and longitudinal bed profile covering a total lake length of 12,450 m.

The present water surface area of lake at El. 2412 m.a.s.l is 1088.7 Acres (4.41 km^2).The storage capacity at an El. 2412 m.a.s.l comes to be 99,249 Acre Feet (122.42 Mm^3). The comparison of current Hydrographic survey data with previous survey data of year 2011 shows that on an average there is about 30 to 40 m deposition during last 9 years.

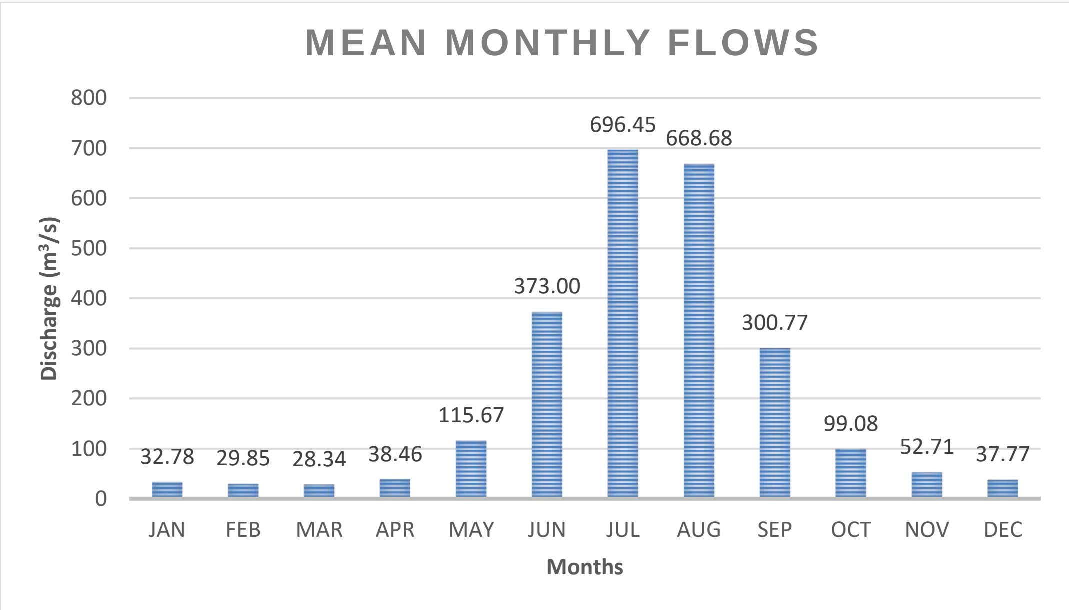
S.4 CLIMATE OF THE PROJECT AREA

The Gilgit Meteorological Station is the nearest station to Hunza Valley that has a sound historical record covering more than five decades. Monthly temperature variations (maximum, minimum and mean) at Gilgit indicate parabolic trend with peak in the month of July. Summer prevails in months from June to August. In July and August, mean maximum and minimum temperatures are normally above 35˚C and 15˚C respectively. The winter is cold and chilly that starts from November and remain still end of March. The lowest temperatures are in the month of January when mean maximum and minimum temperatures reaches below 10˚C and (-) 2˚C respectively.

Precipitation data has not been available to depict the precipitation pattern of the Hunza Basin, therefore isohyetal map used to have a picture of precipitation distribution in the basin. That shows mean annual rainfall of the basin for the last 20 years (2000 – 2019) and the precipitation values vary from 88 to 485 mm.

S.5 HYDROLOGY

The main tributaries of Hunza River are; Chapursan, Kilik, Bola Das joining the Hunza River from the west and Khunjerab along with Ghujerab, Simshal and Hispar Rivers joining river from the east of the valley. There is only one hydrological gauging station on Hunza River at Danyor Bridge being operated by SWHP-WAPDA. This station is located at about 107 km downstream of Attabad Landslide Dam. Therefore, river flows are transposed and estimated from documented discharge data from hydrological station at Danyor. Daily discharge data from 1966 to 2015 is available and processed for the calculations. Average value for mean annual flow has been calculated as 208.36 m^3/s.



Mean Monthly Flows (1966-2015)

Keeping in view the different types flood estimations and generation of high peaks due to GLOFs, it is recommended to adopt design flood of 10,000 years return period at weir site. Therefore, design flood of 3,250 m^3/s at weir site has been assumed for the calculations of design of hydraulic structures.

S.6 SEDIMENTATION

Average value of suspended sediment at Danyor comes out 33.43 MMT with data range 1966-2015 which falls on higher side and also differs from present scenario. To remain on realistic side, we choose the period of 2011-2015 for the calculation of suspended sediment and the average of suspended sediment comes out 20.06 MMT. Bed load has been considered as 20% of the total suspended load. Keeping the trap efficiency in view, reservoir life of the Attabad Lake is about 11 years without flushing.

S. 7 POWER AND ENERGY

Power and energy potential at the site have been estimated on average 10-daily basis using time series data from 1966 to 2015. Keeping in view historic data, optimized design discharge of 60 m^3/s has been selected. Available head across the hydropower facility has been computed keeping in view the minimum and maximum operation water levels i.e. 2,012 to 2,014 m.a.s.l.

In the present study 10-Daily Power Curves, the optimum installed capacity would be 54.0 MW having mean annual energy of 374 GWh. The plant factor has been calculated as 79%. In previous studies, 32.5 MW capacity plant had been proposed for this Project, however, keeping in view the potential of the lake and availability of head, the power and energy optimization have been carried out to size the plant.

S.8 GEOLOGY

Geologically site is located in Karakorum consists mostly of sedimentary, meta sedimentary, igneous and metamorphic rock, bounded by Karakorum Fault in the East, Chaman and Herat Fault in West (Zanchi 1993) ranging in age from Precambrian to Cretaceous. It is glacial originated valley modified later on by river system. Morphologically the valley is lithological as well as structurally controlled.

The site geology unit consists of slided mass and rock. Granitic gneiss and granodiorite rock are exposed which at higher elevations. Geological mapping and 400m drilling have been carried out to evaluate the surface and subsurface foundation conditions of main weir, under sluice/sediment flushing channel, power house and tailrace. 10 test pits have been excavated to analyze the slope and barrow area material to be used for construction material. Samples from bore holes, test pits and barrow area have been tested from CMTL, Lahore to find out the engineering properties along with their suitability to be used as construction material.

Being disastrous slided area due to active tectonics, neo-tectonics studies have been conducted to assess the operational active forces and distortion/deformation in recent sediments (0.1 Ma). Attabad slide commenced as a result of active deformational force, therefore, 30 km upstream and 30 km downstream along both banks of Hunza River have been traversed to gather the recent tectonic/deformational feature. Features found in recent deposits include folds, micro faults, jointing, horst and graben etc.

Both Probalistic Seismic Hazard Analysis (PSHA) and Deterministic Seismic Hazard Analysis (DSHA) approaches have been used to analyze the Seismic Hazard Analysis, keeping in view the on-site and regional tectonic scenario to recommend a suitable earthquake resistant design. This study has focused on the earthquake potential hazard and related ground motions and estimate the value of “g”. Peak Ground Acceleration (PGA) values for

Operating Basis Earthquake (OBE) at return period of 145 years are recomended as horizontal = 0.24 g & vertical = 0.17 g

while Safety Evaluation Eartquake (SEE) at return period of 10,000 years are recommended as horizontal = 0.44g and Vertical = 0.29 g.

Ample quantity construction materials are available in the economic haulage of the Project Area. Sand from Shishkat village area and marble from Passu and RBGM from power house area may be crushed down for coarse aggregate. The boulders in slided mass, may be use as rip rap material while silt/clay is also available for impervious blanket.

S.9 ALTERNATIVE PROJECT LAYOUT

The Project layout has been considered on either bank with powerhouse near Attabad. Options for structures location are limited due to land slided area, steep slope in reservoir area, and weak geological formation in the Project Area. Considering the aforementioned limitations Alternative Project Layout on the Left and the Right Bank have been studied.

Alternative-I: Project Layout on the Left Bank

Alternative-II: Project Layout on the Right Bank

After detail study Alternative-I Project Layout on the left bank came out to be a favourable option and further 2 options have been studied

a. Alternative -I A Headrace Tunnel Option

b. Alternative -I B Headrace with Embedded Pressure Pipe

Finally, Alternative -I A Headrace Tunnel Option has been selected for further studies. (Selected Project Layout is shown in Dwg.No.AFS-LAY-404 & Project Longitudinal X-Section in Dwg.No.AFS-LAY-407).

S.10 PROJECT LAYOUT

An overflow weir/ungated spillway along sediment flushing channel has been proposed at existing site used as spillway of Attabad Lake. Water will be diverted to power house through power intake, low pressure headrace tunnel, surge tank and penstock on the left bank. The coordinates of weir & powerhouse sites are listed below:

Site	Easting (m)	Northing (m)
Overflow Weir	484036.834	4018143.837
Powerhouse	481645.920	4017963.719

The proposed overflow weir/ ungated spillway is 60 m wide and a sediment flushing channel 19 m wide on its left side shown in Dwg.No: AFS-WR-409 & 410. The powerhouse site is about 2.5 km downstream of the proposed overflow weir along the left bank of Hunza River.

A design discharge of 60 m^3/s will be diverted towards the powerhouse through intake left bank waterway located upstream side of overflow weir / ungated spillway. A 2.32 km long low pressure headrace tunnel having a diameter of 5.5 m would run along the left bank leading to a 10 m diameter and 49 m high surge tank. From there, a 470 m long embedded steel penstock with 3.5 m diameter shown in Dwg.No: AFS-ST-430 would be laid over the left bank slopes leading down to the surface power house to generate 54 MW with 03 Francis Turbines. From powerhouse, a 18 m long tailrace channel leading from each generating unit would discharge water back into the Hunza River.

S.11 CIVIL AND HYDRAULIC STRUCTURE DESIGN

ALHPP is a Runoff River peaking scheme on Hunza River in Hunza Region. The Project is planned to develop the reach of river 2.5 km downstream of Attabad Lake to generate 54 MW power by proposing and Feasibility Level Design of the following Civil Engineering Structures has been carried out:

- Natural dam of 45 m height from river bed to act as diversion structure with low level outlet and an overflow ungated spillway.
- Power Intake structure is proposed on the left bank of river to take the design discharge of 60 m^3/s.
- Low pressure headrace tunnel having diameter of 5.5 m with total length of 2320 m.
- Vertical surge shaft of 10 m diameter with height of 49 m.
- Concrete lined pressure shaft of 3.6 m diameter having a length of 80 m.
- Steel penstock having a length of 470 m length and diameter of 3.5 m.
- Surface powerhouse with three (03) Francis units with an installed capacity of 54 MW and open switchyard.
- Tailrace channel of 18 m length.

S.12 MECHANICAL WORKS

The powerhouse will be equipped with Three Vertical Shaft Francis turbines (18.0 MW each) X-Section of powerhouse shown in Dwg. No: AFS-PH-435. The total plant out capacity of ALHPP is 54.0 MW. The turbine shall be capable to operate within a wide range of head and discharges at maximum attributable efficiency.

No. of Units	03 (Vertical Francis)
Plant Discharge, Q_{Total} (m^3/sec)	60
Rated Net Head, H_n (m)	106
Plant Capacity, P_{Total} (MW)	54

The turbine rated output is expressed by the following equation:

$P_t = 9.81 \times Q \times H_n \times \eta_t$

Where P_t	Turbine out Power (KW)	
Q	Discharge (m^3/sec)	20
H_n	Rated Net Head (m)	106
η_t	Efficiency of turbine	91.50 %
	9.81*20*106*0.915	19000 KW

Rated Turbine Output at shaft, P 19.0 MW with rated speed of 375 rpm

S.13 POWER HOUSE ELECTRICAL WORKS

The design of the generator is determined by the construction, layout and speed of the turbine. The choice of a vertical shaft Francis turbines defines a vertical generator and appropriate guide bearings. Main parameters of the generators for power house are tabulated below:

Generator Shaft Orientation	Vertically Coupled
No. of Units	3
Nominal Capacity	21.2 MVA (18 MW)
Rated Speed	375 RPM
No. of Poles	16
Efficiency	98 %
Unit Output Voltage	11 kV
Frequency	50 Hz
Power Factor	0.85
Insulation Class	F
Limit of Thermal Utilization	B
Excitation	Static
Excitation Voltage	220 V DC
Runway speed	648 rpm
Connection	Y, Neutral Grounded through transformer resistance
Cooling System	Closed circuit Air-cooling system with surface type Air/Water Coolers

S.14 POWER EVACUATION / TRANSMISSION LINE

The power generated by the ALHPP shall be mainly supplied to the load centres in the central Hunza, Aliabad and the upper Hunza (Sost) through132 kV transmission lines. A double circuit 132 kV transmission line of 27 km will be connected to the proposed Aliabad Grid station to further disperse the power in the Regional Grid Network (RGN). Along with double circuit 132 kV transmission line to Aliabad, a 132 kV single circuit of 70 km transmission line is also proposed upto the existing 33 kV grid station which will be upgraded to 132/33/11 kV grid station. Rail conductor proposed for double circuit transmission line will be in accordance with WAPDA/NTDC Specification No.P-50:88.

S.15 ENVIRONMENTAL IMPACT ASSESSMENT (EIA)

As ALHPP is planned for generation capacity of 54 MW and 132 kV power transmission lines, the Project falls within the category ‘A’ which requires full scale ESIA. The primary data have been collected and assessed with reference to different project components, i.e. dam site, reservoir area, powerhouse, construction camps etc. The data regarding climate, hydrology, geology, seismology, neo-tectonics and other physical features of the Project Area has also been obtained as part of the preparation of this Feasibility Study.

The secondary data have been collected from various offices and published reports of different organizations in the Gilgit-Baltistan. These organizations included W & P Dept., Education, Forest, Agriculture, Fisheries, Sanitation, Wildlife, Environmental Protection Agency, District Administration, Tehsil Offices, Local Councils and others. The studies are carried out on the information received during field visits of Project Area, data received from some NGOs, water samples collected from Project Area at various places and tested in Environmental Protection Agency Laboratory, Gilgit, climate data received from Metrological Department, and other data taken from earlier conducted Feasibility Study and other reports of projects.

A team of experts of Hydro Planning Organization (HPO) moved to Project Area for field investigations. The team hired services of one local graduate female and one local graduate man for questioning and answering with local people in their language. Additionally, the services of a local well educated female hired for the interviews and data collection covers the subjects of gender and women empowerment. The team spent more than three weeks to visit seven villages of upstream and two villages of downstream side of the Project Area. In this exercise both genders have been covered in field visits of Project Area. The field investigators (team) with interviewing skills minimize the sampling error and wrongly asked or interpreted or recorded answers to finalize a report with the respondents.

S. 16 CONSTRUCTION PLANNING

ALHPP involves execution of considerable quantities of excavation and concreting for structures. Considering the magnitude and nature of construction activities, mechanized construction has been considered for all type of construction works to achieve specified quality at a faster rate for timely completion of the Project. The Project involves the construction of overflow weir, sediment flushing channel / under sluice, power intake, low pressure headrace tunnel, surge tank, penstock, powerhouse and tailrace channel.

Diversion works are mandatory for the commencement of the works on sediment flushing channel and overflow weir. The construction of low pressure headrace tunnel is very significant item in order to have timely completion of the Project. The construction of the access tunnels to the headrace tunnel near power intake and surge tank areas will help to make an early start on excavation of headrace tunnel which lies on the critical path.

The proposed implementation schedule takes account of the preliminary design of each structure and facilities, work quantities and site conditions. It is prepared on the basis of the construction plan, estimated construction progress, rate of each activity and work sequence. The proposed project implementation schedule spans over a period of 50 months, which includes 14 months for the pre-construction and 36 months for the construction activities construction plan is shown in Dwg.No: AFS-CP-478.

S. 17 COST ESTIMATE

The quantities of work items for ALHPP have been worked out on the basis of Layout Plan developed for the scheme on the actual topography of the area. Material quantities required have been computed using the engineering drawings consisting of plans and sections of all Project components. The unit cost is based on prevailing market rates. Considering the Exchange Rate of 1 US$ = Rs.157 (March 21, 2021). The Project Base Cost will be Rs. 20,499.565 Million (US $ 127.573 Million).

S.18 ECONOMIC AND FINANCIAL ANALYSIS

The Project will yield Internal Economic Rate of Return (IERR) of 22.36 % by applying shadow prices. The benefits cost ratio comes to 1.55:1 at 12% discount rate which also reflect the economic viability of the proposed project. The financial benefits over the project life of 30 years calculated on certain assumptions depict an Internal Financial Rate of Return (IFRR) as 19.17% which makes the project significantly viable. Unit Cost (Cost/MW) comes out to be US $ 2.506 million (Rs.393.447 million) and cost/KWh US cent 3.61 (Rs. 5.67).

The Project is technically, socially, economically and financially viable, hence recommended for implementation.

S.19 SALIENT FEATURES OF THE PROJECT

Parameters		Units	Recommendation
Power house (PH) design discharge (Q_d)		m^3/s	60
Gross Head		m	112
Rated head at design discharge of powerhouse		m	106
Total Installed capacity (3 units)		(MW)	54
Turbine Configuration, Francis vertical (MW)	Runner diameter	m	1.676
	Unit Speed	(rpm)	3 75
Average annual energy generated		(GWh)	373.69
Plant Factor		(%age)	79
Project Base Cost		Mill.US$	127.573
Project Financial Cost		Mill.US$	135.326
Installed Cost/MW		Mill. US $	2.506
Energy Cost / KWh		(US cent)	3.610
EIRR			22.36%
FIRR			19.17%
Benefit Cost ratio			1.55:1

PAKISTAN

WATER AND POWER DEVELOPMENT AUTHORITY

ATTABAD LAKE HYDROPOWER PROJECT

FEASIBILITY STUDY

VOLUME 1

MAIN REPORT

JUNE 2021

GENERAL MANAGER (HYDRO) PLANNING

WAPDA, SUNNY VIEW ESTATE, LAHORE

ATTABAD LAKE HYDROPOWER PROJECT
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LIST OF ABBREVIATION

A

ADB	Asian Development Bank
AKCSP	Aga Khan Cultural Service Pakistan
AKDN	Aga Khan Development Net Work
AKF	Aga Khan Foundation
AKHS	Aga Khan Health Service
AKRSP	Aga Khan Rural Support Programme
C	
CBM	Confidence-building measure
CBOs-	Community-based organizations
CPEC	China Pakistan Economic Corridor
D	
DLP	Defect Liability Period
E	
EIA	Environmental Impact Assessment
EL	Elevation Level
EMMP	Environment Monitoring Management Plan
EOT	Electric Overhead Bridge Type Traveling
EPA	Environment Protection Agency
ESIA	Environmental Impact Assessment
G	
G.B	Gilgit-Baltistan
GEF	Global Environment Facility
GHG	Green House Gases
GLOF	Glacial Lake Outburst Floods
GSP	Geological Survey of Pakistan
H	
ha	Hectare
HPO	Hydro Planning Organization
HPP	Hydropower Project
I	
ICT-	Information and Communication Technologies
IEE	Initial Environmental Examination
IRS	Indus River System
IUCN	International Union for Conservation of Nature
K	
KKH	Karakoram Highway
KNP-	Khunjerab National Park
KPK-	Khyber Pakhtunkhwa
L	
LAA	Land Acquisition Act
LGO	Local Government Ordinance

LIST OF ABBREVIATION

M

M.A.S.L	Meters Above Sea Level
MBT	Main Boundary Thrust
MKT	Main Karakoram Thrust
MMM	Mitigation Management Matrix
MMT	Main Mantle Thrust
MW	Mega Watt
N	
NA	Northern Areas
NCS	National Conservation Strategy
NEQS	National Environment Quality Standards
NGO	Non- Governmental Organizations
NOC	No Objection Certificate
P	
PAP	Project Implementation and Resettlement of the Affected Persons
PEPA	Pakistan Environmental Protection Act
PEPC	Pakistan Environmental Protection Council
PMAC	Program for Mountain Areas Conservation
PPC	Pakistan Penal Code
R	
RAP	Resettlement Action Plan
RNR	Renewable Natural Resources
S	
SC	Supervisory Consultants
SWHP	Surface Water Hydrology Project
T	
TOR	Terms of Reference
U	
UNDP	United Nations Development Program
V	
VO	Village Organizations
W	
WAPDA	Water and Power Development Authority
WCSDO	Wildlife Conservation and Social Development Organizations
WCS	Wildlife Conservation Society
WHO	World Health Organization
WUO	Water Users' Organizations
WWF	World Wildlife Fund

UNITS: CONVERSION FACTORS: SI TO FPS

Length	To convert from	to	Multiply by
	m	ft	3.281
	cm	ft	0.0328
	km	ft	3,280.84
	m	mi	0.0006214
	km	mi	0.6214
Area	m^2	ft^2	10.764
	km^2	mi^2	0.3861
	m^2	acre	0.0002471
	km^2	acre	247.105
	hectare	acre	2.471
Volume	m^3	ft^3	35.315
	m^3	US gal	264.172
	m^3	UK gal	219.969
	L	ft^3	0.035315
	m^3	Acre Feet	0.000810714
Velocity	m/s	ft/s	3.281
	cm/s	ft/s	0.03281
	m/s	mi/h	2.237
	km/h	mi/h	0.622
Acceleration	m/s^2	ft/s^2	3.281
Mass	kg	lb_m	2.205
	kg	ton	0.00110
Pressure and Stress	Pa or N/m^2	psi	0.000145
Discharge	m^3/s	ft^3/s	35.315
	L/s	ft^3/s	0.035315
	m^3/s	US gal/min	15850.3
	m^3/s	UK gal/min	13198.2
	L/s	US gal/min	15.850
	L/s	UK gal/min	13.198

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1 INTRODUCTION

1.1 GENERAL

Gilgit-Baltistan of Pakistan is blessed with abundant renewable hydropower resources. More than 95% of Pakistan hydel potential is located in mountainous areas of Gilgit-Baltistan (Gilgit-Baltistan), Khyber Pakhtunkhwa (KPK) and Azad Jammu and Kashmir (AJK). The reconnaissance study of hydel potential for whole Gilgit-Baltistan is almost complete, and identified potential sites are still to be optimized in terms of capacity, cost and need of power for growing load centres. A study for identification and ranking of potential sites on tributaries of Indus river was carried out during 1992 to 1997. Out of 122 identified sites, 17 promising sites were selected to meet local/regional power demand of Gilgit-Baltistan.

On Nov, 2015 Prime Minister announced the construction of Attabad Lake Hydropower Project (ALHPP), Accordingly Govt. of Gilgit-Baltistan undertook its Feasibility Study through Annual Development Programme (ADP) for Financial Year 2016-17. In the beginning Feasibility Study of ALHPP of 32.5 MW was carried out by local consultant of Gilgit-Baltistan, Design man Consulting Engineers (Pvt.) Ltd, Islamabad in association with Mountain Infrastructure & Engineering Services Gilgit, in March 2017. On Aug 2017, Ministry of Water and Power had written letter to the Chairman WAPDA to give expert opinion on construction of ALHPP. On July 2019, a meeting was held between Chairman WAPDA and Chief Secretary Gilgit-Baltistan. It was agreed that Feasibility Study would be again carried out by Hydro Planning Organization (HPO), WAPDA because of its expertise in the field of Hydro Power Planning. Water and Power Development Department, Gilgit-Baltistan shared the already carried out Feasibility Study with HPO, WAPDA in Jan 2020. Feasibility Study was examined by HPO, WAPDA and found the proposed layout is designed without diversion works which is essential part for project execution. Therefore, Feasibility Study was again undertaken by HPO, WAPDA for comprehensive Study with additional investigation.

The Central Hunza is located on the right bank of Hunza River, extending from Murtazabad up to Attabad Village (Figure-1). Central Hunza is the hub of tourism in Gilgit-Baltistan. National and international tourists flow remain at peak during summer season. As a result, hotel industry is booming, whereby, other small-scale businesses i.e. transport sector, cottage industry, local markets and automobile workshops are most likely to flourish in the near future. The increase in tourism industry has significantly enhanced the energy demand of the area. The current demand is expected to increase exponentially in the years to come. Furthermore, the area is having multiple business opportunities due to its location on the China Pakistan Economic Corridor (CPEC), which will result in fast growth of economic activities, thus increase in the energy demand being interlinked with each other.

Figure 1-1 Map of Central Hunza (Source: Google Map)

The Gilgit-Baltistan Govt. has developed three hydropower projects on Hassanabad Nullah in Hunza with an installed capacity of 1.9 MW. The electricity from these hydropower projects is supplied to the Central and Lower Hunza through a 11-kV local distribution network. The supply from these hydropower projects is currently not sufficient to meet the existing demand, therefore it is supplemented through standby diesel generators of 3.2 MW installed capacity during peak hours, mostly in winter season. Due to abrupt surge of Shishper Glacier situated in the catchment of Hasanabad Nullah, the powerhouses on Hassanabad Nullah are under the threat of glacier lakes outburst flood (GLOF). Therefore, it is necessary to develop projects on other water resources to facilitate central Hunza.

In addition to this, there exists a community-owned hydropower project of 0.450 MW capacity on Ahmadabad stream, which is managed and operated by a Community based Public Utility Company in Ahmadabad village. This community owned and operated hydropower project is currently supplying electricity to village Ahmedabad, Altit, Mominabad, Faizabad, and Salmanabad in Central Hunza. The Ahmadabad community-owned Public Utility Company is currently refurbishing and upgrading another hydropower project with 0.370 MW capacity, which is in cascade with the existing hydropower project.

Meanwhile, the Water & Power Department (W&PD), Hunza has completed another 0.5 MW hydropower Project at village Mayans in Lower Hunza. This Project will feed into the existing 11-kV distribution network of Hunza. Furthermore, Gilgit-Baltistan Govt. has conducted a Feasibility Study of a 32.5 MW hydropower project at Attabad Lake requested WAPDA for its updation. Presently, there is high supply and demand gap; therefore, load shedding is common in summer, while it becomes very acute in winter. The commercial and industrial demand is partly fulfilled from privately owned diesel generators. The diesel generators are mainly used by the hotels, small businesses, banks and other consumers which can afford the high running cost. Apart from the cost the use of these diesel generators is creating environmental pollution (i.e. noise and air), which is also affecting the tourism in the area.

The expected fast growth in tourism industry will immensely increase the electricity demand in future, if not planned properly and addressed timely, it will most likely create a crisis like situation in the near future. The shortage of electricity in Central Hunza and vulnerability of Hasanabad Hydropower Projects from any untoward situation of GLOF and normal floods is further increasing the risk of energy crisis in this area.

The Govt. has limited resources to address the issue of sustainable electricity supply in the area. The private sector is reluctant to invest in Gilgit-Baltistan's energy sector, which is due to absence of a Power Policy and non-connectivity of the area with the National Grid. The Power Policy of Gilgit-Baltistan Govt. is currently under appraisal and approval. Aga Khan Development Network (AKDN) institutions are supplementing and complimenting the efforts of the Govt. in Gilgit-Baltistan. Small scale micro hydels have been established in remote off-grid rural areas from donor funding, while urban centres like central Hunza are beyond their scope.

The Industrial Promotion Services (IPS)/NPAK Energy is collaborating with the Govt. of Gilgit-Baltistan to improve the distribution system of Central Hunza by replacing bare AAC/ACSR conductors by ABC Cable. Considering the energy shortage in central Hunza, they intend to develop hydropower project(s) in the area to address the energy crisis. The Govt. of Gilgit-Baltistan has already indicated a concession area (from Ganish Bridge to Salmanabad village) on Hunza River to IPS/NPAK Energy to study the prospects for development of hydropower projects.

Govt. of Gilgit-Baltistan has engaged WAPDA (HPO) to update the Feasibility Study of 32.5 MW ALHPP. WAPDA is using its in-house capacity to review Feasibility Study. After thorough field investigations WAPDA has updated the proposed installed capacity to 54 MW with a 2320 m long headrace low pressure tunnel on the left side of Hunza River. The tunnel will off take from the left bank upstream of existing outlet of Attabad Lake. For this fields investigations have been carried out.

Attabad Lake was formed on January 4, 2010, when a huge mass from the right bank of Hunza River slided down near Attabad Village and blocked Hunza River for about 2 km . The inflow filled upstream valley created a reservoir 22 km long till the end of May 2010. The estimated lake initial storage was about 310 million m^3 and presently its capacity reduced to 125 million m^3.

For drainage of impounded flows of Hunza River through slided area, the excavation of material was carried out (24 m deep and 45 m wide) to form as spillway. The excavation works for the spillway was completed in the mid of May and the overflow of River flow began on May 29, 2010. The pattern of outflows was observed at downstream Ganish Bridge. The flows in summer 2010 were as a result of snow melt, no abrupt change in flows observed till to date.

Extensive field reconnaissance, topographical survey, hydrological and geo-technical investigations and engineering studies have been carried out for updating the Feasibility Study, in order to establish a Project that could provide power supply from Hunza Valley to Gilgit and Sost.

ALHPP (54 MW) has been planned to meet the winter power demand of Hunza Valley by utilizing the peaking storage facility at existing Attabad Lake. The installed power would remain available throughout the year during peak hours. As a result of the assessment of field investigations and engineering studies, it is concluded that the Project of 54 MW is technically, economically feasible and environmentally safe. The Project can further enhance due to available potential at the location of Hunza River once the Regional and National Grids established.

The most promising project layout as assessed is located at the Attabad Lake on the left bank of Hunza River at a distance of about 20 km from Karimabad, 120 km from Gilgit and 735 km from Islamabad.

The deep diversion and flushing structures are proposed to be located at the existing outlet/spillway of the Attabad Lake. The weir site is available having narrow span and firm rock strata on right side of River Hunza. The headrace tunnel is proposed along the left bank of the River along existing link road from intake to powerhouse. The powerhouse is located well above the highest flood level. The coordinates of the weir and powerhouse site are as follows:

Overflow Weir/Ungated Spilway:	484036.834 m E	4018143.837 m N	2414 m.a.s.l
Powerhouse:	481645.920 m E	4017963.719 m N	2300 m.a.s.l

The Project area is to be constructed on marginal lands owned by the community of Ahmadabad village where minimum environmental and social issues have been anticipated. The Project google site plan and location map are shown in the Figure 1.2 and Figure 1.3.

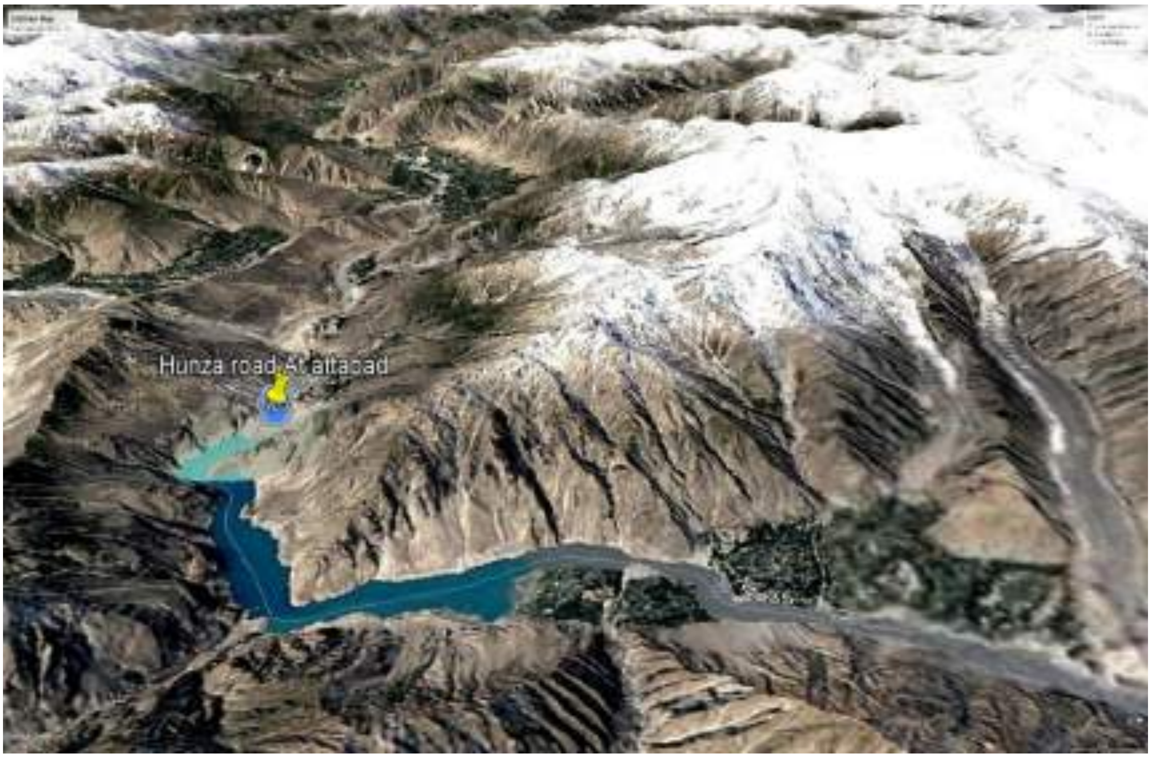


Figure 1-2 Site Plan (Source: Own Compilation from Google)

Figure 1-3 Location Map (Source: NHA Pakistan)

1.2 SALIENT FEATURES

ALHPP, a run off river Project, was initially planned to generate about 32.5 MW power in two phases, by diverting the flow of Hunza River, a major tributary of Gilgit River, into a power tunnel and ultimately releasing into Hunza River. This was designed to take care of power and energy needs of the Hunza-Nagar districts for next two decades as an isolated scheme. However, the connection of the Hunza Nagar districts to the Regional Grid makes the Project to be studied for its enhanced potential. A number of alternatives are studied and based upon the conclusions of these studies; it is finally decided to design the scheme for the generation of 54 MW (installed capacity) consisting of three units with an average annual energy of about 374 GWh.

An overflow weir will be constructed to divert the flow of Attabad Lake at Hunza River into power intake. Before construction of weir, a deep sediment flushing channel/ under sluice will be constructed this will act as a diversion channel during construction of weir. After the construction of the Project at operational stage under sluice will act as sediment flushing channel. The diverted water enters into the head race tunnel about 2320 m long. The tunnel is followed by surge shaft. Water will enter into 470 m long penstock pipe branching into three units at the end through manifold. These high-pressure penstock pipes and feed three turbines, 18 MW each.

The Project is proposed to be developed on Hunza River at Attabad Lake with design discharge 60 m^3/s to generate the rated power round the year. This Project will enhance the generation capacity and augment the power supply network of entire Hunza-Nagar Valleys and Gilgit Town.

Once completed and operational this Project will help to improve the power supply situation in the Region.

The Salient features of the envisaged power supply Project are given as follows:

Type of Development:	High Head Run of River with Peaking
Gross Head:	112.0 m
Net Head:	106.0 m
Installed Capacity:	54 MW
Type of Turbine:	Francis (Vertical)
No. of Units:	03
Design Discharge (Qd):	60.00 m^3/s (20 m^3/s to each unit)
Length of Weir:	55 m
Length of Power tunnel:	2320 m
Type of Powerhouse	External
Annual Energy:	374 GWh
Plant Factor:	79 %

1.3 CLIMATE

The climate of the district is nearly dry. The summer season is cool while winter is chilly. Wide spread snow fall occurs in winter. During winter the northern winds blow constantly bringing the temperature down considerably.

At Hunza, the mean temperature is 30.20°C in July, the hottest month and the coldest month is January with an average temperature of -3.5 °C. The mean minimum temperatures are 21.9°C in July and -7.3°C in January respectively. Hunza like other areas in extreme north-west of Pakistan receives only 136 mm precipitation of which 40% occurs in Winter and Spring.

Climate of the Hunza District is moderate with average minimum and maximum temperatures of 16 and 35.9 °C, respectively. The annual average rainfall in the study area is 136.2 mm with minimum 2.1 mm in November and maximum 28.3 mm in April.

1.4 TRANSPORT AND COMMUNICATION

The means of transportation and communication are the necessary infra-structures for movement of goods and people and play a vital role in the economic development of any region.

All the Union Council centers except few are connected with each other by metalled roads, nevertheless, there are certain parts of these roads which must be improved and for transportation during winter, the district remains connected throughout the year with the rest of country through Karakoram Highway (KKH).

There is transportation through KKH between Gilgit, Hunza upto Sost and Khunjrab Pass towards China by buses and trucks. The road is in excellenet condition and asphalted, although the traffic remains suspended due to heavy snowfall during December to March at Khunjerab Pass, which lies at an altitude of about 4693 m.a.s.l. The road is characterized by bends and steep slopes while descending from top to Hunza Valley.

1.5 ACCESS TO THE PROJECT AREA

The present available access to the Project area by Motorway from Islamabad to Thakot and afterwards by KKH from Thakot to Project Area is very good. Power house site is located on the left bank of Hunza River near Salmanabad Village. Access to the Project Site, along the Attabad Lake is very easy with steep slopes and moderate bends. It will not create problem with the transportation of heavy construction and permanent equipment for the Project as well as the heavy construction materials. These difficulties may significantly affect the overall construction schedule. However, the road towards Power House Site needs improvement involving rock blasting and widening of the track to cater for the transportation of the heavy construction material and machinery.

1.6 EXISTING POWER SUPPLY

The present installed capacity of hydropower and thermal power stations is 5.6 MW for peak hours. Although the consolidated installed capacity of Hassanabad hydropower projects is 1.9 MW, but over the time, the efficiency of these projects have reduced due to high amount of silt in the Hassanabad Nullah, resulting in regular need for overhauling of the turbines at least twice a year. The diesel generators with a consolidated installed capacity of 3.2 MW are used as standby. These diesel generators are operated during peak hours only, and are subject to the availability of funds for purchase of fuel & oil for their operation. The list of projects in district Hunza which are under operations, under construction and proposed are given in the Table-1.2

The available output from the existing hydropower stations and diesel generators is evacuated through 11-kV lines to the load centers. Further distribution is made after stepdown through 11/400-kV transformers and 400/230 V, LV distribution lines. The existing 11-kV distribution system is overloaded resulting in high voltage drops, especially at the end users' premises. The technical losses are very high and accounted for more than 30%. Hence, the net supply available for the consumers is well below the installed capacity.

At present the conservative demand of Central Hunza is estimated at being 7.0 MW during summer and 10 MW in winters. However, the optimistic demand of consumers is estimated as 12 MW during summer and 18 MW in winter season, details of which has been given in the Chapter No-3 "Power Market & Demand Forecast".

In Gilgit-Baltistan, most of the power generation, transmission and distribution system is being maintained and operated by Water & Power Deptt. Gilgit-Baltistan.

1.7 ADMINISTRATIVE ORGANIZATION

Hunza is one of the fourteen districts constituting the Gilgit-Baltistan of Pakistan. The highest administrative authority is the Deputy Commissioner, who is assisted by Assistant Commissioners of two sub-divisions. Administratively, the Hunza District comprises two tehsils, the Aliabad Tehsil and the Gojal Tehsil. The villages of lower Hunza and central Hunza are located in the Aliabad Tehsil, whereas the villages from the Attabad Lake up to the Khunjerab Passare located in the Gojal Tehsil. In lower Hunza, Shinais the main language, whereas in central Hunza, the dominant language is Burushashki, and in upper Hunza, Wakhiis the main language. District administration is exercised by the Deputy Commissioner (DC), with the assistance of an assistant commissioner. The Hunza police force is commanded by the Superintendent of Police (SP).

These institutions have technical support of various departments of Govt. of Gilgit-Baltistan in Hunza town such as Communication, Roads, Agriculture, Irrigation, Fishing, Education, Health, Revenue, Food, Social Welfare Office and Forest Division. All are located in Hunza town.

Table 1-1 Salient Features of Attabad Lake Hydropower Project

Location	Attabad village, Hunza District, Gilgit-Baltistan of Pakistan, 120 km west of Gilgit & 735 km north- of Islamabad	Design Discharge Gross head Net head Installed Capacity Mean Annual Energy Plant Factor	60 m^3/s 112.0 m 106.0 m 54 MW 373.69 GWh 79 %
River Catchment Area Mean Annual Flow Mean Annual Vol.	Hunza 8901 km^2 209 m^3/s 6591 M m^3	Penstock Length Diameter Thickness	1No. 470 m 5.5 m 15 mm
Weir Crest elevation Crest length Weir height Design Flood Max. Flood level Sediment Flushing Channel Sill level Nos. and Gate size	Overflow Weir/ Ungated Spilway 2414 m.a.s.l 60 m 30 m 3250 m^3/s (1:10,000 returned period) 2421 m.a.s.l UnderSluice/Diversion Channel 2402 m.a.s.l 3 & 5m x 5m	Powerhouse Size Height Type of units No. of units Speed No. of Generator No. of Transformer	External Slope type 45 m x 18 m 22 m Francis 3 375 rpm 3, 21.2 MVA 3, 222 MVA
Attaabad Lake length Lake width Lake depth	14000 m 400 to 600 m 50 to 60 m	Tailrace Turbine level Max. Flood level	18 m, concrete lined 2300.0 m.a.s.l 2307.0 m.a.s.l
Tunnel length Diameter of Tunnel Typel	2320 m 5.5 m Horse shoe	Firm Power Off peak winter Peak Summer	26 MW 18 MW 54 MW
Peaking storage Full supply level Minimum supply level Gross Storage	5 M m^3 2414 m.a.s.l 2412 m.a.s.l 125 M m^3	Distance up to Gilgit Voltage Level Transmission Line Areas to be served	120 km 132 KV 70 km single circuit upto Sost & 27 km double circuit upto Aliabad. Hunza, Gilgit & Ghizar Region

Table 1-2 Hydropower/Thermal Stations Operational, under Construction and Proposed

S#	Name	Installed Capacity (MW)	AvailableCapacity (MW)	
			Summer	Winter
Hydropower Stations under Operation				
1	SHP Hassanabad Ph-I	1.20	1.00	1.00
2	SHP Hassanabad Ph-II	0.20	0.16	0.11
3	SHP Hassanabad Ph-III	0.50	0.35	0.30
4	SHP Ahmadabad	0.45	0.45	0.25
	Sub Total	**2.35**	**1.96**	**1.66**
Thermal Stations under Operation (Operational during peak hours subject to availability of funds)				
1	Hassanabad I	1.00	1.00	1.00
2	Hassanabad II	1.00	1.00	1.00
3	Ganish	1.00	1.00	1.00
4	Khizerabad Shinaki	0.20	0.20	0.20
	Sub Total	**3.20**	**3.20**	**3.20**
Under Construction Hydropower Projects			**Remarks**	
1	SHP SHP Mayun	0.50	Recently construction completed	
2	SHP Hassanabad Nullah	2.00	Abandoned due to Shishper Glacier	
3	SHP Ahmadabad	0.37	Under Construction community project	
	Sub Total	2.87		

2 POWER MARKET AND DEMAND FORECAST

2.1 INTRODUCTION

An optimized planning for energy load forecasting is always the crucial part to determine future power demand for any developing region. In the power sector, reliable planning/load forecasting is the threshold to cater the future electricity demand. Power Infrastructure design including generation, transmission and distribution can be proposed on a power plan with improvising scenarios. Poor forecasting and planning could be rankled to manage the load demand while precise forecasting could be savvy to overcome the underestimations & overestimations of load management, which avoid financial and social-economic impact.

Thus, power market survey (short, medium and long period Load Forecast) contributes to overcome the energy shortage and facilitate all type of patrons including Residential, Commercials & Industrial.

This chapter describes and evaluates the future power demand in Gilgit-Baltistan, based on figures of the GDP and an expected increase in per capita consumption. For the design of the transmission & interconnection system, this information is advantageous as one of the chief matters for the layout of the Attabad Hydropower Project is to determine the future power demand in the Hunza district and the whole Gilgit-Baltistan.

The Gilgit-Baltistan being far off from National Grid has been facing severe shortages of power supply. Because electricity from fossil fuel is not only expensive moreover it causes pressure on foreign exchange reserves of Pakistan, hydropower being renewable resource constitutes is the best option which needs to be exploited in a rational manner. The tributaries and rivers of Gilgit-Baltistan have been considered for the development of hydropower resources to meet the local energy requirements and eventually to transfer the power to national grid.

2.2 GILGIT-BALTISTAN POWER SECTOR OVERVIEW

Gilgit-Baltistan had ten districts (Gilgit, Ghizer, Nagar, Hunza, Diamer, Astore, Skardu, Ghanche, Shigar and Kharmang).

Figure 2-1 Map of Gilgit-Baltistan

Power Network System in Gilgit-Baltistan is based on foresaid ten districts. This chapter presents the district wise current Demand, Generation, Energy Deficit & Load Forecast studies of electricity demand from the year 2021 to 2050, a planning horizon of 30 years.

In order to provide electricity to the isolated network of the Gilgit-Baltistan areas, the Northern Areas Public Works Department (NAPWD) was established, which is responsible for the generation and distribution of electricity. The NAPWD is divided into two departments. The Water and Power Department responsible for Hydropower Projects and Public Works Department responsible for roads and infrastructure of the Gilgit-Baltistan area. Water and Power Department has constructed various mini hydropower stations in the region and the lines for the transmission of power to consumers.

2.2.1 Establishment of Regional Grids in Gilgit-Baltistan (Phase-1 & 2)

Water and Power Department of Gilgit-Baltistan has prepared PC-I regarding “Establishment of Regional Grids in Gilgit-Baltistan Phase-1 & 2” wherein the future expansion plan and establishment of regional grids are consisted on 10 valleys of Gilgit-Baltistan based on population and its growth, industrialization and consumption patterns. The model forecasts demand for electricity as the consolidated sum of demands from households of each domestic consumption (divided into three income groups), commercial centers, and public service units and from small industries.

The plan of Establishment of Regional Grids in Gilgit-Baltistan “Phase-I & II” relate to transmission planning, Grid stations & up-gradation of the existing power network of Gilgit-Baltistan. Its objective is to interconnect the following hydropower projects to efficiently utilize the generated electrical energy.

- 18 MW Hydro Power Project Nalter IV.
- 16 MW Hydro Power Project Nalter III.
- 14 MW Hydro Power Project Nalter V.
- 20 MW Hydro Power Project Hanzel Gilgit.
- 34.5 Mw Hydro Power Project Harpo Skardu.
- 80 MW Hydro Power Project Phander Ghizer.
- 100MW Hydro Power Project KIU Gilgit.
- 32.5 MW Hydro Power Project Attabad Hunza (power enhanced upto 54MW)
- 26 MW Hydro Power Project Shagharthang Skardu.

Another purpose of the above plan is to attract private investors to take interest in the development of Hydropower projects to harvest maximum hydro potential. The proposed project of phase1 caters to the power demand in these districts (Gilgit, Hunza/Nagar and Skardu & Astore).

Existing Regional Grid of Gilgit-Baltistan is not connected with National Grid of Pakistan, mostly small hydro and thermal unit installed by the local Govt. are having the energy contribution to a local level. Large Hydropower projects are in the studies & construction stage which will be committed to meet the national and regional energy crisis.

Different interconnection schemes are under consideration by the NTDCL planning department to interconnect the regional Gilgit-Baltistan grid to National Grid, and to evacuate from the upcoming mega hydropower projects. In future bulk supply will be fed from Mega Hydropower Project i.e. Diamer Basha and Bunji while medium and small hydropower projects i.e. Phandar, Attabad & Harpo to overcome the demand in Gilgit-Baltistan and surplus power after then could be drawn to the national grid.

Hydel is the major contributor in Gilgit-Baltistan to produce electricity. WAPDA and Water and Power Department, Gilgit-Baltistan intend to commission mega to small scale hydropower projects to supply clean and cheap electricity at the regional and national level. Many small and medium hydropower projects have been installed and some are in construction stage while others are in the feasibility & design stage.

32.5 MW Attabad Hydropower Project was also part of the aforesaid plan, but after the revised study being conducted by WAPDA, the project is upgraded upto 54 MW and needs to redefine the Interconnection and power evacuation plan after 1.67 times enhanced power.

2.2.2 Power Generation in Gilgit-Baltistan

The power demand in Gilgit-Baltistan is mostly covered by small hydropower plants (<20 MW). Electrical energy is transmitted over short distances through 66 kV, 33 kV and 11 kV gridlines and is further distributed to the consumers through 400 V LT systems. Due to the geographical boundaries, the existing grid is a regional one with no link to the national grid. Indeed, in the future, it is planned to link the existing regional grid to the national grid. However, this requires the completion of both planned Mega-Projects “Diamer Basha” (in construction stage) and “Bunji” (investors for funding are required to construct the project). In Gilgit-Baltistan, Total 118 nos. power stations have been commissioned with total 194.55 MW installed capacity. Table 2-1 shows the district wise installed power & Figure 2-2 shows the no. of installed power plants in different regions of Gilgit-Baltistan.

Table 2-1 District Wise Installed Power Potential in GILGIT-BALTISTAN

District	Hydel Stations	Thermal Stations	Hydro Power	Thermal Power	Total Installed Capacity
	Nos.	Nos.	MW	MW	MW
Gilgit	19	13	58.37	9.41	67.78
Diamer	10	5	15.48	2.90	18.38
Skardu	19	7	36.90	6.00	42.9
Ghizer	14	3	15.37	0.90	16.27
Ghanche	12	2	11.94	0.40	12.34
Astore	9	2	5.62	0.70	6.32
Nagar	9	2	6.00	0.75	6.75
Hunza	8	4	6.08	3.51	9.59
Shiger	7	0	4.70	0.00	4.70
Kharmang	11	0	10.50	0.00	10.50

Total	**118**	**38**	**169.98**	**24.57**	**194.55**

Figure 2-2 Installed Power in Gilgit-Baltistan

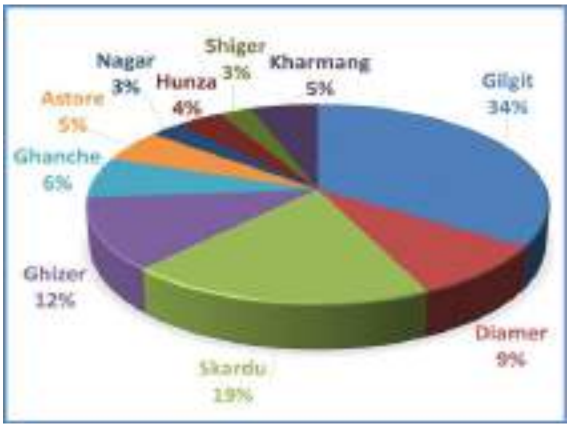


Figure 2-3 Percentage of District wise Hydel Power Generation in Gilgit-Baltistan

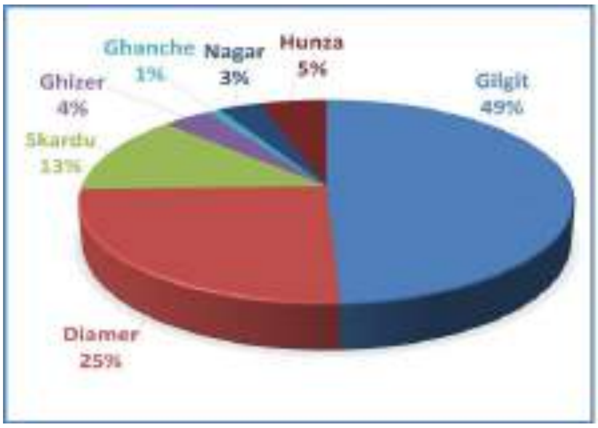


Figure 2-4 Percentage of District wise Thermal Power Generation in Gilgit-Baltistan

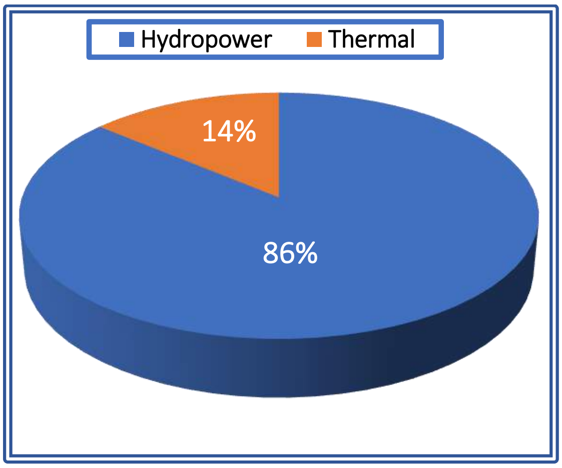


Figure 2-5 Percentage Wise Power Sharing in Gilgit

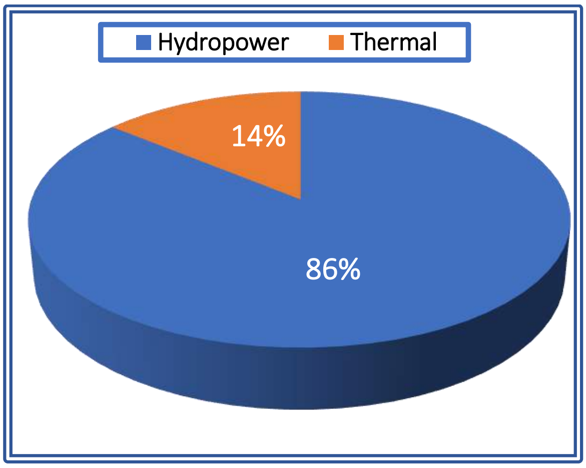


Figure 2-6 Percentage Wise Power Sharing in Gilgit

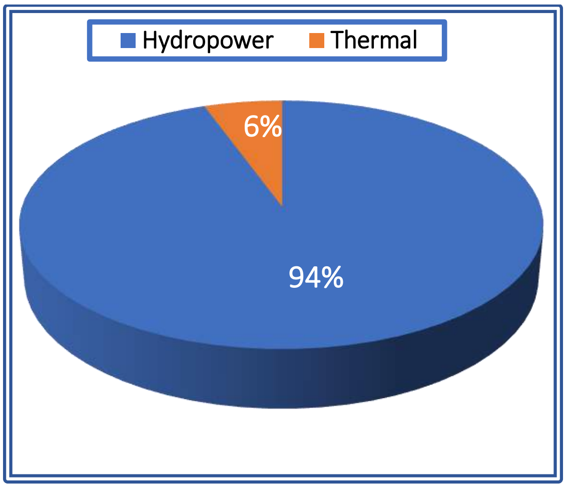


Figure 2-7 Percentage Wise Power Sharing in Ghizer

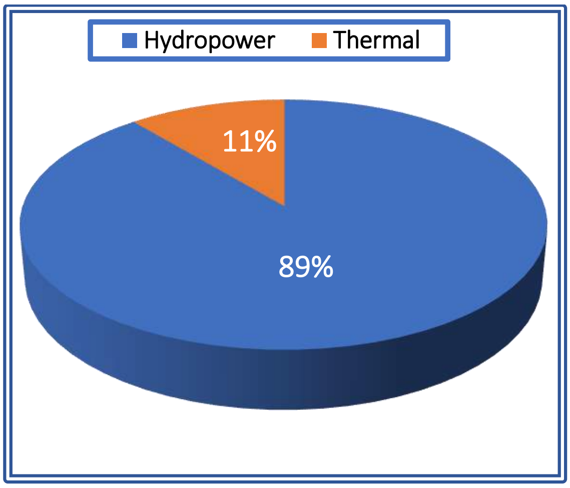


Figure 2-8 Percentage Wise Power Sharing in Astore

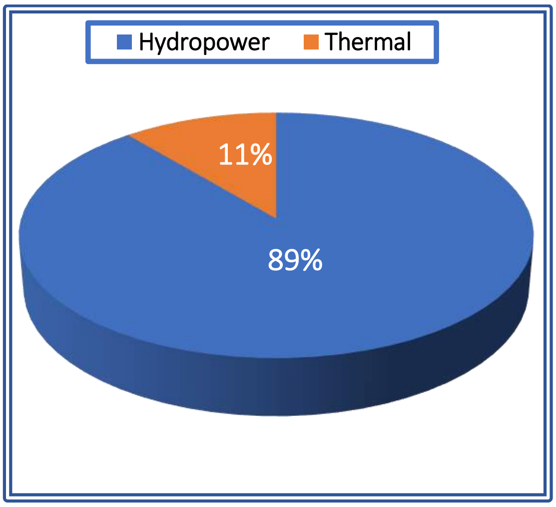


Figure 2-9 Percentage Wise Power Sharing in Nagar

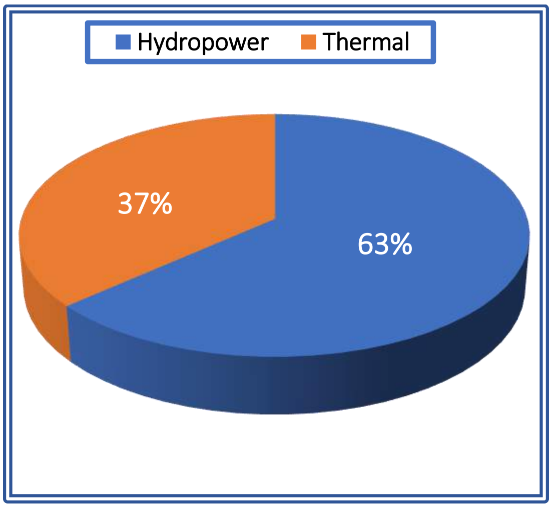


Figure 2-10 Percentage Wise Power Sharing in Hunza

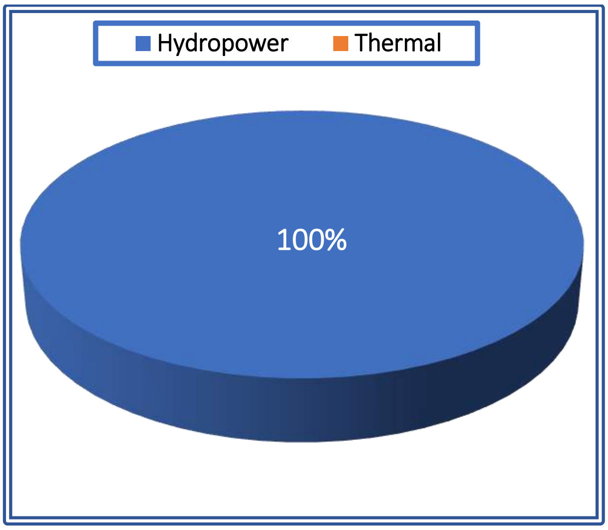


Figure 2-11 Percentage Wise Power Sharing in Shiger

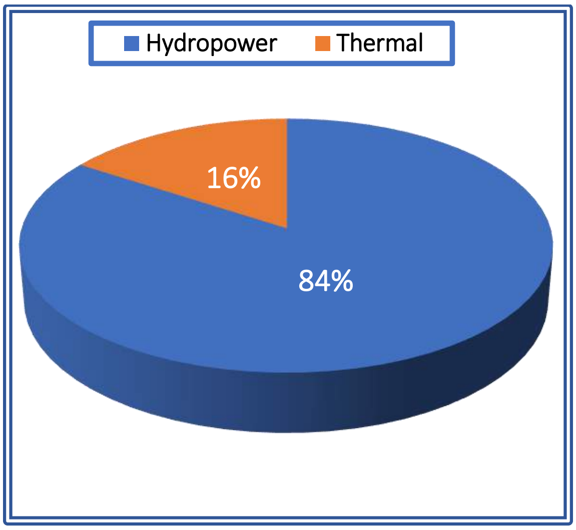


Figure 2-12 Percentage Wise Power Sharing in Diamer

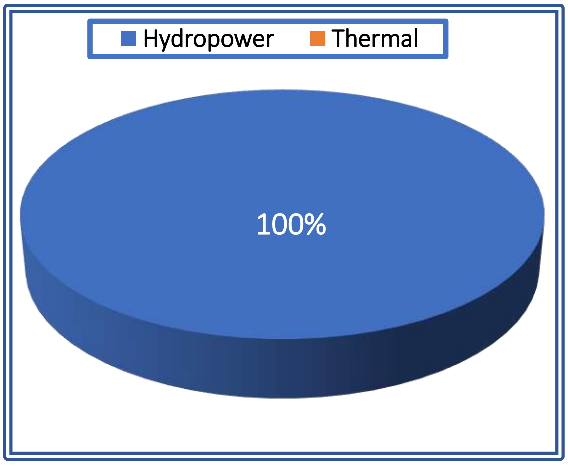


Figure 2-13 Percentage Wise Power Sharing in Kharmang

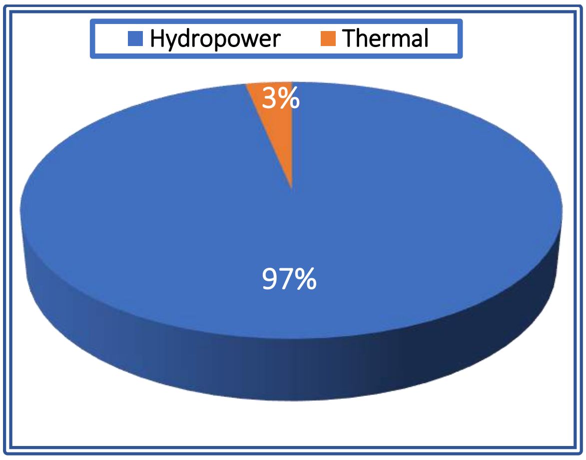


Figure 2-14 Percentage Wise Power Sharing in Ghance

2.2.3 Hydropower Potential in Gilgit-Baltistan

The entire region of Gilgit-Baltistan is enriched with natural resources. Nature has blessed Gilgit-Baltistan with minerals, attractive weathers, world high peaks, glaciers, water torrents, rivers & tributaries, sunlight and other natural resources.

Although, Gilgit-Baltistan is producing electricity by two means (Hydel & Thermal) but it has potential to produce electricity from other renewable resources. The Govt. of (GILGIT-BALTISTAN) is also willing to get untainted energy from renewable resources. The inception studies to get power from renewable resources are under progress by Water & Power Dept. Gilgit-Baltistan and will be made part of Power Plan in future.

The main rivers and tributaries in the Gilgit-Baltistan Area have been divided into three regions, i.e. the Eastern, Northern and Southern Regions.

Eastern Region: The Eastern Region comprises on Kharmang (River Kharmang and its tributaries), Shyok (River Shyok and its tributaries), Skardu (River Braldu, River Bashu, River Shigar and River Indus) and Rondu/ Haramosh (River Indus and its regional tributaries).

The Northern Region: Comprises of Gilgit (River Gilgit, River Naltar and its tributaries), Hunza (River Boladas, River Hunza and other tributaries), Ishkuma (River Ishkuman and Ghizar and their tributaries), Khunjerab (River Khunjarab, River Kilik and its tributaries) and Yasin (River Yasin, River Gilgit and their tributaries).

Southern Region: The Southern Region comprises the Chilas (River Indus and its tributaries) and Astore (River Astore and its tributaries) Total 118 Hydel Power Stations are in operation in Gilgit-Baltistan, mostly of projects have been listed in Table 2-2:

Table 2-2 Installed Hydel Power Potential in Gilgit-Baltistan

Sr.	Hydel Station	Location	Power (MW)
1	Naltar	Gilgit	18
2	Satpara	Skardu	16
3	Gilgit	Gilgit	10.63
4	Skardu-I	Skardu	6.96
5	Chilas-I	Chilas	5.62
6	Hunza	Hunza	5.13
7	Shyok	Shyok	4.85
8	Kar Gah Phase VI	Gilgit	4
9	Astore	Astore	3.11
10	Kachura Phase II	Skardu	3
11	Ghizar	Ghizar	2
12	Thak	Chilas	2
13	Phandar	Distt. Ghizar	2
14	Bordas	Ghanche	2
15	Kharmang	Kharmang	1.89
16	Yasin	Distt Ghizar	1.61
17	Rondu	Rondu	1.52
18	Bunnar Chilas	Chilas, Distt. Diamer	1.5
19	Dumsum	Gha, Distt. Ghanche	1.5
20	Balagond	Gha, Dstt. Ghanche	1.5
21	Ishkuman-I	Ishkuman	1.38
22	Kar Gah Phase V	Gilgit	1.2
23	Singul	Gilgit	1.2
24	Sher Qila	Gilgit	1.11
25	Parishing/ Lous	Astore	1
26	Darel Phase II	Chilas	1
27	Bunner	Chila	1
28	Tangir	Chilas	1
29	Kar Gah Phase VII	Gilgit	1
30	Jalalabad	Gilgit	1
31	Hassanabad Phase V	Hunza	1
32	Hisper Phase I	Hunza	1

Sr.	Hydel Station	Location	Power (MW)
33	Ishkuman-II	Ishkuman	1
34	Naz Bar	Yasin	1
35	Jaglot Phase-II	Gaglot/Gilgit	1
36	Chalt	Nagar Valley/Gilgit	1
37	Khyber-II	Hunza/Gilgit	1
38	Shigar	Skardu	1
39	Shirting	Skardu	1
40	Skardu Phase III	Skardu	1
41	Pion	Distt. Ghanche/Gha	1
42	Haramosh	Gilgit	1
43	Sermik	Skardu	1
44	Basho Phase I	Skardu	0.8
45	Tormic Phase I	Rondu	0.8
46	Skardu Phase II	Skardu	0.64
47	Bubind	Astore	0.64
48	Kar Gah Phase III	Gilgit	0.6
49	Kar Gah Phase IV	Gilgit	0.6
50	Boladas Phase I	Hunza	0.6
51	Khunjerab	Gujrab river	0.59
52	Gol	Skardu	0.4
53	Harpo Phase I	Rondu	0.4
54	Harchu	Astore	0.4
55	Hassanabad Phase II	Hunza	0.4
56	Hassanabad Phase IV	Hunza	0.4
57	Kar Gah Phase I	Gilgit	0.32
58	Danyor	Gilgit	0.32
59	Gurikot	Astore	0.25
60	Kayo	Skardu	0.24
61	Dango Das	Astore	0.22
62	Manthoka	Khamang	0.2
63	Astore	Astore	0.22
64	Gulmit	Ishkuman	0.22
65	Tolti Phase I	Kharmang	0.2
66	Khaplu Phase II	Shyok	0.2
67	Kachura Phase I	Skardu	0.2
68	Darel Phase I	Chilas	0.2
69	Hassanabad Phase III	Hunza	0.2
70	Khaibar Phase-I	Khunjerab	0.2
71	Khaibar Phase-II	Khunjerab	0.2
72	Parishing/Mushke	Astore	0.19
73	Rattu	Astore	0.19
74	Misgar	Khunjerab	0.19
75	Ghandus	Kharmang	0.16
76	Kiris Phase I	Shyok	0.16
77	Thally Phase I	Shyok	0.16

Sr.	Hydel Station	Location	Power (MW)
78	Mendi	Rondu	0.16
79	Stak	Rondu	0.16
80	Tangir Phase I	Chilas	0.16
81	Chilas-II	Chilas	0.16
82	Hassanabad Phase-I	Hunza	0.16
83	Hayul	Ishkuman	0.16
84	Khaplu Phase-I	Shyok	0.13
85	Sumayar Phase I	Hunza	0.13
86	Mehdabad	Kharmang	0.11
87	Nomal	Gilgit	0.11
88	Pari	Gilgit	0.11
89	Jaglot Sai	Gilgit	0.11
90	Sermik Phase-I	Kharmang	0.1
91	Olding Phase I	Kharmang	0.1
92	Thore	Chilas	0.1
93	Minapin Phase-I	Hunza	0.1
94	Naltar	Gilgit	0.08
95	Ahmadabad Phase I	Hunza	0.05
96	Ahmadabad Phase II	Hunza	0.05
97	Chalt Phase-I	Hunza	0.04
98	Sost	Yasin	0.01

About planned 26,000 MW is shown in table 2-3 with current status.

Table 2-3 Planned Hydropower Projects in Gilgit-Baltistan

PROJECT NAME	POWER CAPACITY (MW)	GROSS/LIVE STORAGE (MAF)	TRIBUTARY/ RIVER	STATUS
MEGA & LARGE HYDROPOWER PROJECTS				
Diamer Basha	4500	8.1/6.4	Indus	Under Const.
Bunji	7,100	RoR	Indus	DED completed
Yulbo	2,800	RoR	Indus	DS completed
Tungas	2,200	RoR	Indus	DS completed
Skardu	1500	3.2/2.2	Indus	DS completed
Thorgonar	600	RoR	Indus	Identified
Sermik	600	RoR	Indus	Identified
Kharmang	1,100	RoR	Indus	Identified
Shyok	640	1.2	Shyok	FS completed
Lower Astore	300	RoR	Astore	Identified
Middle Astore	400	RoR	Astore	Identified
Upper Astore	600	RoR	Astore	Identified

Altit	250	RoR	Hunza	Identified
Kanch	188	RoR	Kunhar	Identified
Doyian	490	RoR	Astore River	FS completed
Gilgit River (7 Schemes)	2,500	RoR	Gilgit	Identified
Subtotal	**25,768**			
MEDIUM & SMALL HYDROPOWER PROJECTS				
Satpara	**17.3**	**0.093/ 0.053**	**Satpara**	**In Operation**
Basho	40	RoR	Basho Nala	FS completed
Harpo	34.5	RoR	Harpo Nala	FS completed
Phandar	80	RoR	Ghizar	DED completed
Nasirabad	96	RoR	Hunza	Identified
Tangir	52	RoR	Tangir	Identified
Sher Qila	88	RoR	Gilgit River	Identified
Attabad lake	54	RoR	Hunza	FS in progress
Tormik	40	RoR	Tormik Gah	Identified
Tallu	25	RoR	Talu Lugma	Identified
Kachura	20	RoR	Kachura Lake	Identified
Shaghartung	25	RoR	Shagartung	Identified
Subtotal	**569.8**			
Total	**26,337.8**			

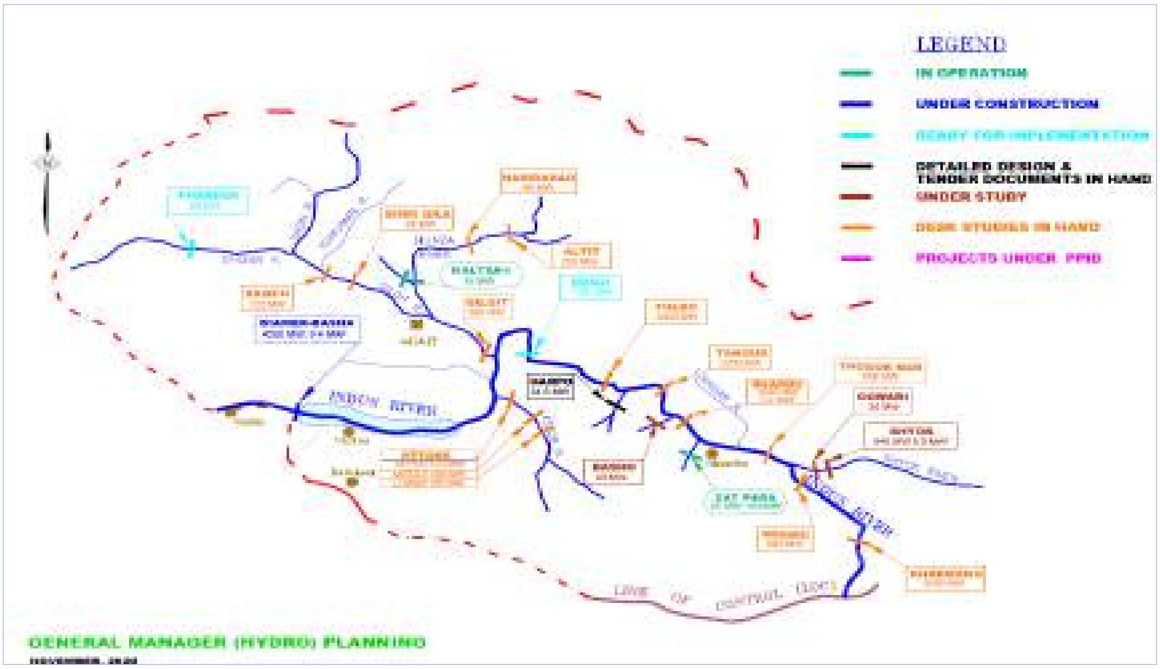


Figure 2-15 Location Map of Hydropower Power Projects in Gilgit-Baltistan

Many small Hydropower projects (Table 2-4) have been commission by Govt. of GILGIT-BALTISTAN with time. Some hydropower projects are in the construction stage while some are in the study stage and to be commissioned in the future.

Table 2-4 Small Hydropower Projects in Gilgit-Baltistan by W&P Dept.

Sr. No	Project Name	Power Capacity (MW)	Location
PROPOSED HYDROPOWER STATION			
District Skardu			
1	Hydro Power Project Cane	3.20	Cane Kargah Gilgit
2	Hydro Power Project Sai	3.00	Sai Juglote Gilgit
3	Hydro Power Project Bagarote	2.00	Bagarote Gilgit
4	Hargosil	1.00	Kharmang skardu
5	Shigar Phase-III	2.00	Shigar Skardu
6	Mehdi Abad Ph-II	1.30	Kharmang Skardu
7	Nar and Ghoro	1.00	Skardu
SUB TOTAL		**13.5**	
Ghanche Valley			
1	Power Project (Phase-II)	2.00	Thalay Ghanche
2	Hydro Power Project	0.70	Hassanabad
3	Hydro Power Project	2.00	Kondus Ghanche
4	Hydropower project Kundus	2.00	Kundus Ghanche
SUB TOTAL		**6.70**	
TOTAL		**20.2**	
Projects under FPSDP expected to be completed			
1	Hydro Power Project Nalter-Ill	16.00	Nalter Gilgit
2	Hydro Power Project Nalter-V	14.00	Nalter Gilgit
3	Hydro Power Project Skardu Shagharthang	26.00	Skardu
4	Hydro Power Project Thak	4.00	Thak Chilas
TOTAL		**60.00**	
New Hydropower Projects completed			
1	District Gilgit (03 Nos)	6.70	
2	District Skardu (05 Nos)	4.60	
3	District Diamer (04 Nos)	5.00	
4	District Ghizer (03 Nos)	3.50	
5	District Ghanche (04 Nos)	5.50	
6	District Hunza-Nagar (04 Nos)	2.50	
7	District Astore (03 Nos)	3.40	
	TOTAL	**31.20**	
Solicited Hydro Power Projects			
1	Hydro Power Project Hanzel	20.00	Hanzel Gilgit
2	Hydro Power Project Hassanabad	5.00	Hassanabad Hunza
3	Hydro Power Project Tormic	10.00	Tormic Skardu
4	Hydro Power Project Ghowari	30.00	Ghowari Skardu
5	Hydro Power Project Darmadar	2.60	Darmadar Ghizer
TOTAL		**67.60**	
Un-solicited Hydro Power Projects			
Skardu Valley			

1	Ganji	3.00	Ganji Skardu
2	Doro/Shilla	3.00	Kharmang Skardu
3	Basha (Dogro)	5.00	Shigar Skardu
4	Turghun Kharmong	2.00	Kharmang Skardu
5	Mehdiabad	2.00	Kharmang Skardu
6	Manthoka Kharmong	2.00	Kharmang Skardu
7	Stak Rundu	10.00	Rundu Skardu
8	Mendi Phase-II	2.00	Rundu Skardu
9	Gultri	1.00	Skardu
10	Talu Phase-II	2.00	Rundu Skardu
11	Harpo Phase-III	2.00	Rundu Skardu
SUB TOTAL		**34.00**	
Ghanche Valley			
1	Thallay Phase-III	3.00	Thalay Ghanche
2	Hushay (River)	3.00	Hushay Ghanche
SUB TOTAL		**6.00**	
TOTAL		**40.00**	

2.3 POWER MARKET STUDY CONDUCTED BY WAPDA WITH GTZ

Comprehensive planning of hydropower resources on tributaries of Indus River in Northern Areas was started in July 1992, by Hydro Planning Organization (HPO) before known as Hydro Electric Planning Organization (HEPO) WAPDA, in collaboration with the German Agency for Technical Corporation (GTZ) from the Public Federal Republic of Germany. In the study, project areas were divided into 12 regions which are listed below.

Table 2-5 Surveyed Region

Sr. No	Region	Area
1	Region-3	Gilgit
2	Region-4	Hunza
3	Region-5	Ishkuman
4	Region-6	Yasin
5	Region-12	Ghizer
6	Region-7	Skardu
7	Region-11	Khunjerab
8	Region-8	Shyok
9	Region-9	Harmosh
10	Region- 1	Chilas
11	Region-2	Astore
12	Region-10	Kharmang

2.3.1 Methodology

Studies were followed the DIPO system, a methodology for technically and economically optimum development of proximal hydropower potentials for regional power development mainly in isolated rural areas, by

- Definition of requirements and Objectives
- Identification of Power Demand and matching Hydro Potential
- Planning of Regional Power Supply Systems
- Execution of the planned installations
- Operation of the systems

The system was developed within different projects of German Technical Cooperation over a period of 17 years; Burundi, Peru and then in Pakistan prepared for Current and Future Development as a permanent dynamic planning instrument.

The study presented the available sources of energy, demand forecast upto the year 2014 for identified potential. Demand Forecast was carried out analytically.

2.3.2 Load Separation

Possible Load (electricity demand) was categorized in two main types;

I. Autonomous Load: The load normally in such areas for domestic, commercial, crafts and public services (DCCP).

II. Promoted Load: Resulting from special incentives etc. given to utilize electricity e.g. for heating, baking and cooking (HBC-Load) to protect forest and /or for prospective development Projects.

2.3.3 Autonomous Load

It is the normal demand of the people which increases with the growth of population, with more people in a locality more power would be consumed. The demand automatically increases due to development in agricultural, industry health facilities educational opportunities communication system. These development activities lead to change in income level and people start using new products and appliances.

The population growth rate was the main determining factor for future load development. As autonomous load is essentially the demand of power of the people in the locality, it is essential to give the basis of growth rate for the years 1994-2004. Taking into consideration the Govt. policies, it is likely that in medium and long (10-20 years) the growth rate was declined. But future rates of growth cannot be defined exactly, and assumptions were made. To make a sensitivity analysis, three alternatives were made.

For estimating the power demand, the autonomous load for power and energy was considered. This load generally develops if electricity is provided to any region. It had three basic characteristics.

Optimistic (High): The increase in population during 1994-2004 was assumed at the same rate as experienced during 1981-94.

Intermediate (Medium): The same growth rate during 1994-2004, but the decrease of 0.5 percent was expected for the next year 10 years from 2004 to 2014.

Conservative (Low): The growth rate is assumed to be decreased by 0.5 per annum during 1994-2004 and it is further declined by 0.5 percent per annum on average from 2004-2014.

Table 2-6 shows the projected load demand from 1994 to 2014, forecasted for all regions.

Table 2-6 Load Forecast Projected by WAPDA & GTZ

SECTORS		OPTIMISTIC LOAD (kW)			INTERMEDIATE LOAD (kW)			CONSERVATIVE LOAD (kW)		
		1994	**2004**	**2014**	**1994**	**2004**	**2014**	**1994**	**2004**	**2014**
Region 1	**Chilas**	-	-	-	3158	11304	18520	5581	9817	15426
Region 2	**Astore**	4353	8570	1641	3875	7628	13959	3488	6553	11428
Region 3	**Gilgit**	13841	26799	48710	12441	24127	42329	11343	21227	36105
Region 4	**Hunza**	5115	9937	17609	4478	8705	14760	3981	7379	11922
Region 5	**Ishkuman**	1772	3394	6180	1570	3011	5223	1418	2579	4263
Region 6	**Yasin**	2025	4018	7218	1827	3618	6193	1665	3140	5122
Region 7	**Skardu**	10007	18604	34655	9193	17124	30822	8533	15379	27024
Region 8	**Shyok**	11164	15952	23817	9934	14180	20202	8943	12191	16592
Region 9	**Rondu/ Harmosh**	1757	3160	5794	1555	2801	4897	1398	2398	3992
Region 10	**Kharmang**	4644	8819	15848	4140	7856	13427	3731	6752	11017
Region 11	**Khunjerab**	406	777	7038	376	711	1204	350	637	1026
Region 12	**Ghizer**	595	1176	2120	542	1062	1824	491	922	1509
Total		**55679**	**101206**	**170630**	**53089**	**102127**	**173360**	**50922**	**88974**	**145426**

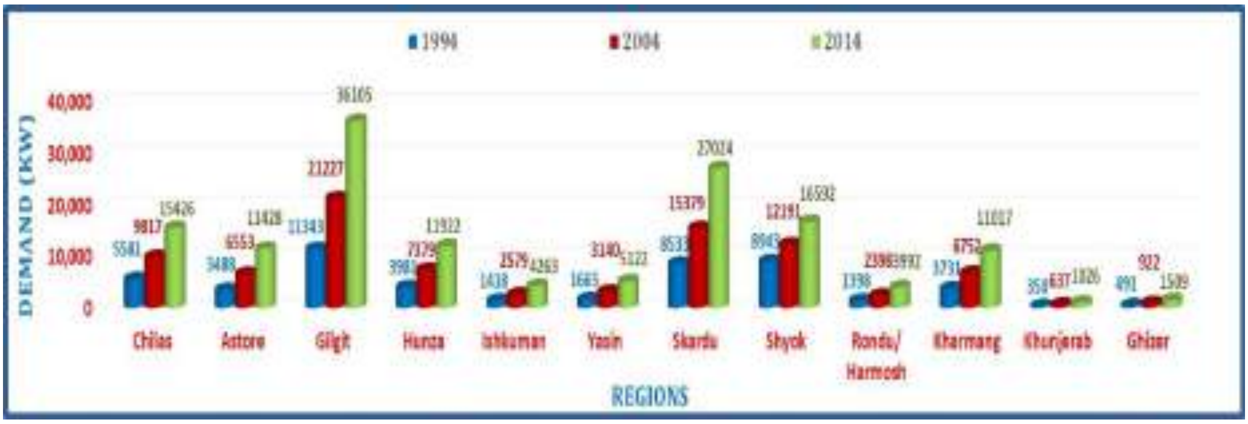


Figure 2-16 Conservative Load Forecast

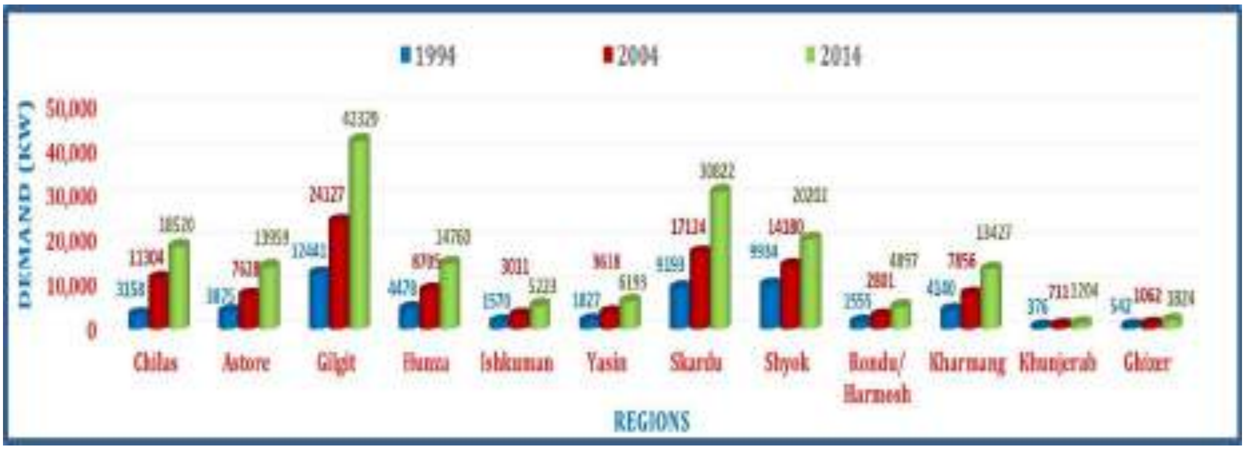


Figure 2-17 Intermediate Load Forecast

Figure 2-18 Optimistic Load Forecast

Table 2-7 Projected Load Forecast in Hunza

LOAD CENTERS	OPTIMISTIC DEAMAND (kW)			INTERMEDIATE DEAMAND (kW)			CONSERVATIVE DEAMAND (kW)		
	1993	2003	2013	1993	2003	2013	1993	2003	2013
CHALT	187	338	549	170	307	471	154	263	388
CHAPROT	141	255	415	128	230	356	117	198	295
BUDELAS	59	105	167	52	94	144	48	81	120
BAR	115	203	329	103	183	284	95	159	232
SKINDARABAD	90	175	316	80	157	267	72	136	221
NILT	213	421	755	189	375	640	171	321	522
GULMIT	121	216	351	106	189	294	94	160	237
MINAPIN	124	224	365	109	196	304	96	166	245
FAKKAR	296	615	1116	260	539	931	230	457	751
SUMAYAR	523	942	1539	450	808	1256	394	674	998
NAGAR	481	998	1817	421	874	1516	374	740	1222
HOPER	268	583	1114	230	502	912	201	417	724
NASIRABAD	93	207	408	84	188	354	77	165	296
KHANABAD	82	158	282	73	144	244	67	126	203
HUSSAINABAD	69	133	238	63	122	205	58	106	173
MURTAZABD	189	371	662	169	329	560	152	282	457
ALIABAD	368	721	1357	328	641	1152	296	551	944
HYDERABAD	224	440	787	200	391	667	180	337	546
GANISH	183	359	642	157	308	527	137	257	418
KARIMABAD	495	963	1731	425	832	1494	372	694	1190
ALTIT	211	436	821	182	374	670	159	313	533
AHMADABAD	74	151	283	63	129	230	56	108	184
ATTABAD	84	172	325	73	150	265	63	125	212
AYUNABAD	93	165	269	80	143	219	70	120	174
GULKIN	206	350	571	80	300	467	154	252	374
PASSU	69	122	197	59	105	163	52	88	129
SHIMSHAL	57	114	203	47	98	168	42	83	134
*SOST	57	115	206	52	101	174	47	88	144
TOTAL	**5,172**	**10,052**	**17,815**	**4,433**	**8,809**	**14,934**	**4,028**	**7,467**	**12,066**

2.4 POWER MARKET - PRESENT SCENARIO

Life in Gilgit-Baltistan is predominantly agrarian. Farming has continued to be a major occupation of the people. Agriculture is dependent upon vagaries of climatic conditions as winters are long and harsh. The farm sizes are small, fragmentation is taking place and the household incomes are on a subsistence level. There is the migration of workforce to cities and towns in the down country, and also as far as to Karachi in the south to sustain meager livelihood.

2.4.1 Exploitation of Natural Resources

Agriculture is a major occupation of the people in Gilgit-Baltistan which depends upon whims of climatic conditions as winters are long and harsh. The non-availability of electricity is a major constraint to undertake farm cultivation program on a large scale. There are no cold storage facilities to preserve fruits which can earn substantial income to the orchard growers. Hunza and Nagar valleys have precious mineral resources which have remained unexploited. The incomes are on a subsistence level, thus making pavement for the migration of workforce to cities and towns in the down country to sustain meager livelihood. The availability of electricity will certainly develop a set up on large scale to preserve fruits and for exploration of minerals.

2.4.2 Tourism

The Gilgit-Baltistan region and its valleys are tourist's paradises for tracking and mountaineering. There is a great potential for business and employment prospects in this sector. At present a few opportunities under Govt.'s social and infrastructure development programs are available for the educated and skilled workforce in various trades. The reliable energy sources and transmission network are key factors for the development tourism and mountaineering.

2.4.3 Trade Route to China

The opening up of Gilgit-Baltistan region to China has provided an incentive to the local entrepreneurs for self-employment and outlets for income generation. This has resulted in job creations for educated young people. Hunza is developing into a central city for economic activities for tourism. With the provision of the basic infrastructural facility of electricity, Hunza and its surrounding towns have the potential for development in the coming years. Sost is the last town of Gojal, Upper Hunza inside Pakistan on the Karakoram Highway before the Khunjerab Border. This town has importance due to the dry port. The Silk Route Dry Port is functional since 2002. Sost dry port is the first formal port at China-Pakistan border, facilitating customs clearance and other formalities for goods moving between China & Pakistan. Currently, this region is also facing the shortfall of electricity and only Misghar power station is installed nearby this town. After commissioning the Attabad Hydro Power Project, current electricity shortfall scenario will be changed and routine trade will be accelerated.

2.4.4 Change in Social Life

Many social and economic changes have taken place at the macro level in the Gilgit-Baltistan region. The people desire to get education and obtain skills in trades and vocations, and also development and improvements in transport and communication have opened new avenues of income generation. The improvement in these sectors has continued to grow with time. The requirements of electricity have increased in homes, both public and private offices, education institutions, hospitals, and health care centers in towns and habitats in the remote rural areas of valleys in Gilgit-Baltistan region.

2.4.5 Investment Incentive

Electric power is a prerequisite to any other investments. Without electricity both human and physical resources will remain unutilized for increasing welfare of the masses for providing income opportunities at or near the level being available to people in the developed part of the country. The elaboration of social, cultural and the people's desire to be prosperous has necessitated the present update of the power demand estimation in the isolated power supply area of Gilgit-Baltistan.

2.4.6 Power Generation, Demand & Shortfall of Districts of Gilgit-Baltistan

According to the statistics provided by Water & Power Division GILGIT-BALTISTAN, the power generation & demand is grouped for two seasons like summer and winter. In the Gilgit region 49 & 33.6 MW produced in summer & winter respectively with demanded power of 49.89 & 94.51 MW. Gilgit has faced the short fall of 0.89 & 60.91 MW. Diamer has produced 10.59 & 10.75 MW while the present demand noted 36.02 & 50.34 MW with the shortfall of 25.43 &

39.59 MW. In the Skardu region 20.30 & 16.20 MW produced in summer & winter respectively with demanded power of 50.6 & 94.47 MW. Skardu has faced the short fall of 30.3 & 78.27 MW.

Ghizer has produced 12.50 & 9.38 MW while the present demand noted 38.88 & 71.34 MW with the shortfall of 26.38 & 61.96 MW. In the Ghanche 8.09 & 5.16 MW produced in summer & winter respectively with demanded power of 25.5 & 48.52 MW. Ghanche has faced the short fall of 17.41& 43.36 MW. Astore has produced 4.50 & 4.0 MW while the present demand in 2020 noted 14.83 & 24.53 MW with the shortfall of 10.33 & 20.53 MW. In the Nagar 4.56 & 2.53 MW produced in summer & winter respectively with demanded power of 9.27 & 16.97 MW. Nagar has faced the short fall of 4.71 & 14.44 MW in summer and winter respectively. Hunza has produced 4.71 & 3.58 MW while the present demand noted 12.83 & 20.61 MW with the shortfall of 8.12 & 17.03 MW. In the Shiger 3.50 & 2.0 MW produced in summer & winter respectively with demanded power of 10.35 & 18.36 MW. Shiger has faced the short fall of 6.85 & 16.36 MW in summer and winter respectively. Khermang has produced 4.61 & 4.07MW while the present demand in 2020 noted 6.65 & 12.54 MW with the shortfall of 2.04 & 8.47 MW. The district wise power values are mentioned in Table 2.8.

Table 2-8 Current Power Scenario of Gilgit-Baltistan

District	Present Generation (MW)						Present Demand (MW)		Present Shortfall (MW)	
	Summer			Winter			Summer	Winter	Summer	Winter
	Hydel	Thermal	Total	Hydel	Thermal	Total				
Gilgit	49.00	0.00	49.00	25.80	7.80	33.6	49.89	94.51	0.89	60.91
Diamer	9.79	0.80	10.59	6.75	4.00	10.75	36.02	50.34	25.43	39.59
Skardu	20.30	0.00	20.30	14.20	2.00	16.20	50.6	94.47	30.3	78.27
Ghizer	12.50	0.00	12.50	8.80	0.58	9.38	38.88	71.34	26.38	61.96
Ghanche	8.09	0.00	8.09	5.00	0.16	5.16	25.5	48.52	17.41	43.36
Astore	4.50	0.00	4.50	4.00	0.00	4.00	14.83	24.53	10.33	20.53
Nagar	4.56	0.00	4.56	2.03	0.50	2.53	9.27	16.97	4.71	14.44
Hunza	3.91	0.80	4.71	2.78	0.80	3.58	12.83	20.61	8.12	17.03
Shiger	3.50	0.00	3.50	2.00	0.00	2.00	10.35	18.36	6.85	16.36
Khermang	4.61	0.00	4.61	4.07	0.00	4.07	6.65	12.54	2.04	8.47
Total	**120.76**	**1.60**	**122.36**	**75.43**	**15.84**	**91.27**	**254.82**	**452.19**	**132.46**	**360.92**

In figure 2-19, Power scenario is sketched out for the summer 2020, which shows that due to bulk supply of water in summer deficit between demand and generation is less than from winter power scenario which has shown in figure 2-20.

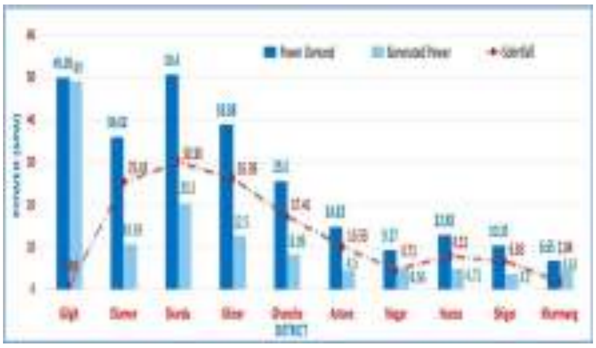


Figure 2-19 District wise Summer Power Scenario in Gilgit-Baltistan

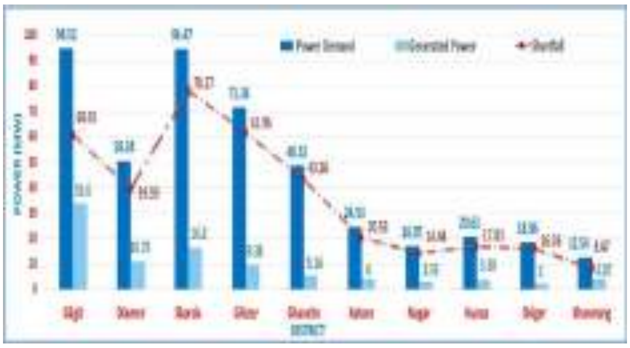


Figure 2-20 District wise Winter Power Scenario in Gilgit-Baltistan

In Figure 2-21, comparison could be easily seen for the power demand in Gilgit-Baltistan for the both season of summer and winter.

Figure 2-21 District wise Overall Power Demand in Gilgit-Baltistan

2.4.7 Current Power Market HUNZA District

Energy is a critical input for economic development and correspondingly power sector comprises an indispensable infrastructure in any economy. Providing adequate and affordable electric power is essential for economic development, human welfare and better living standards. The growth of the economy along with its global competitiveness hinges on the availability of reliable and quality power at competitive rates to all consumers throughout the country. Electricity is central to achieving economic, social and environmental objective.

Attabad Lake Hydropower Project is located in the Hunza District, it is worthy to discuss the current Power scenario of Hunza district in detail for understanding the imperial impact of project in the region and forecast the demand for the future. The power supply area of the proposed site covers mainly the Upper, Middle and Lower Hunza District. Currently following hydropower projects are operating in Hunza.

Table 2-9 Installed Power in Hunza

Sr.No.	Name of Power Station	Year of Completion	Unit Capacity (MW)
1	Hassanabad Hunza HPS Phase-I	1996	1.200
2	Hassanabad Hunza HPS Phase-II	1991	0.200
3	Hassanabad Hunza HPS Phase-III	2003	0.500
4	Khyber Gojal Hunza HPS Phase-I	1987	0.400
5	Khyber Gojal Hunza HPS Phase-II	1996	0.400
6	Misgar Gojal Hunza HPS	2017	3.00
7	Ganish Hunza Diesel Generator Set	2018	1.00
8	Hassanabad-1 Diesel Generator Set	2008	1.00
9	Hassanabad-2 Diesel Generator Set	2017	1.00
10	Khizerabad Diesel Generator Set	2018	0.20
11	MHP Shimshal	2017	0.20
		Total	**9.1**

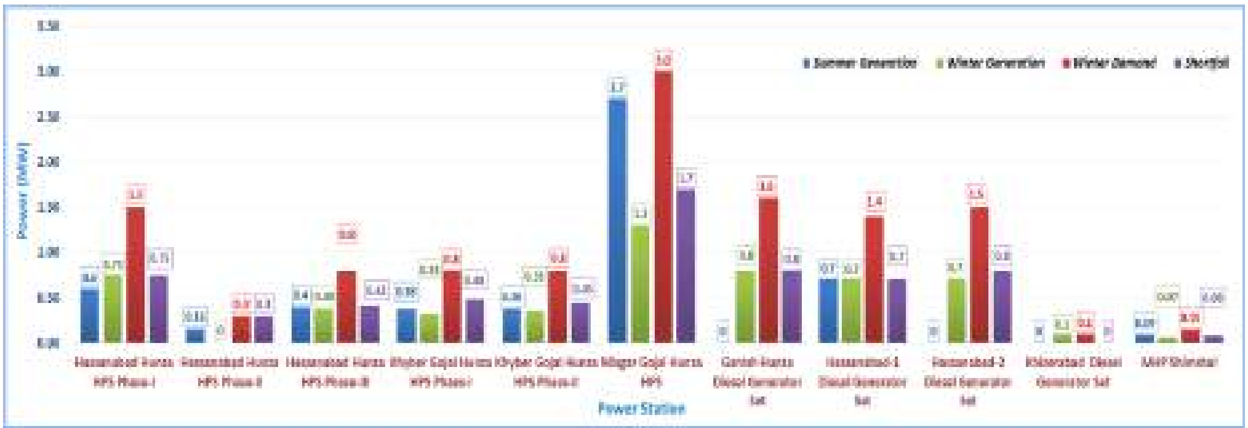


Figure 2-22 Installed Capacity in Hunza

2.4.8 Load Shedding

The per capita consumption of electrical energy depends on various factors of which the most important are:

- No. of consumers connected to the electrical grid - the more consumers are connected to the grid the higher the per capita consumption will beLoad shedding pattern - the per capita consumption will increase with lower load shedding rates No. of electrical devices per consumer - a growing economy results in a higher prosperity what increases the no. of electrical devices per consumer (fridges, air- conditioning, television etc.).

- Industrialization - a growing economy also results in a growing no. of commerce and industry. Thus the per capita consumption also includes industrialization.

The scenario of constricted supply-demand is envisaged to undergo a radical improvement with the execution of the new powerhouses. The availability of electricity for production of goods and commodities will result in higher income generation. This increase in income will raise standard of living of the people who will have an impetus to purchase household electric gadgets and appliances.

In the present situation, Gilgit-Baltistan is facing power shortage. Therefore, load shedding is being carried out as load management in entire region. Hunza is also facing worst power shortage which badly impacts its economy. During the survey in Aliabad and Karimabad which are tourist hubs and have sufficient local population it is conceded that the hoteling and local business have been disturbed badly due to long hour load shedding. The load management schedule of Hunza District is listed as under.

Table 2-10 Load Shedding Hours in Hunza

<table>
<tr><th>Project</th><th>Supply Area</th><th>Status</th><th>Current Generation (MW)</th><th>Load Management / Schedule (Hours)</th></tr>
<tr><td>Hassanabad Hunza HPS Phase-I</td><td>Hassanabad and Aliabad</td><td>Operation</td><td>0.60</td><td>14</td></tr>
<tr><td>Hassanabad Hunza HPS Phase-II</td><td>-</td><td>Un-operational</td><td>-</td><td>-</td></tr>
<tr><td>Hassanabad Hunza HPS Phase-III</td><td>Murtazabad to Khiziriabad</td><td>Operational</td><td>0.7</td><td>14</td></tr>
<tr><td>Khyber Gojal Hunza HPS Phase-I</td><td>Khyber to Nazimabad</td><td>Operational</td><td>0.380</td><td>22</td></tr>
<tr><td>Khyber Gojal Hunza HPS Phase-II</td><td>Passu to Shiskhat</td><td>Operational</td><td>0.380</td><td>18</td></tr>
<tr><td>Misgar Gojal Hunza HPS</td><td rowspan="2">Misgar, Sost, Khudabad, Chipurson, Ganish, Garelth, Karimabad, Hyderabad, Dorkan & Rahimabad</td><td>Operational</td><td>2.6</td><td rowspan="2">22</td></tr>
<tr><td>Misgar HPS (1.8 kW)</td><td>Operational in Winter Season</td><td>-</td></tr>
<tr><td>MHP Shimshal</td><td>Shimshal</td><td>Operational</td><td>0.060</td><td>No load shedding</td></tr>
</table>

2.4.9 Electricity Consumers in HUNZA District

Energy is a critical input for economic development and correspondingly power sector comprises an indispensable infrastructure in any economy. Providing adequate and affordable electric power is essential for economic development, human welfare and better livings.

In this chapter, current consumers of Hunza District have been shown in Figure 2-23. As per administrative record, total population of Hunza, Water & Power Dept. (Gilgit-Baltistan) owns 11416 consumers which are categorized into three main consumer groups shown in below table.

Consumer	Domestic	Commercial	Industrial	Total
Connection	9191	2159	66	11416

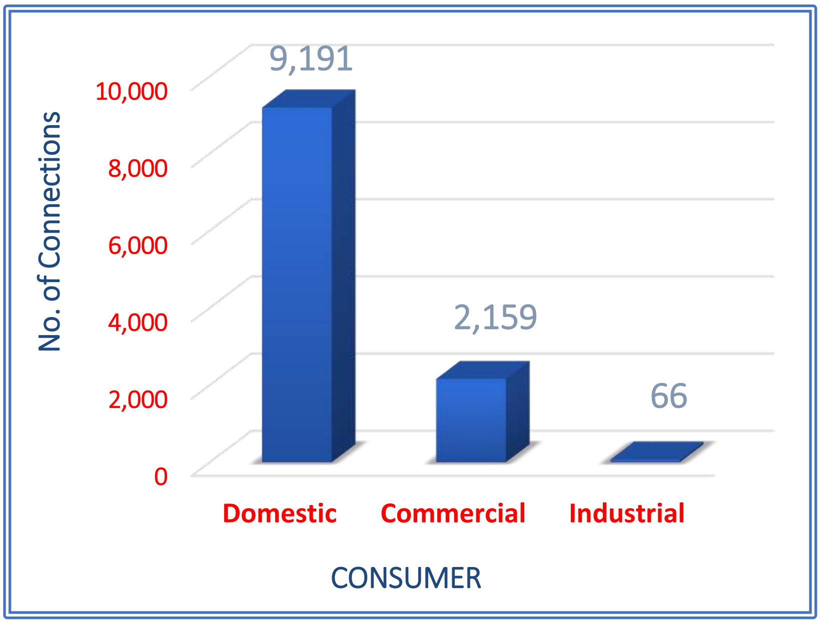


Figure 2-23 Electricity Consumers in Hunza

2.5 POWER DEMAND FORECASTING

2.5.1 Determination and Forecast Power Demand

For a reasonably reliable determination of the power demand, it is foremost mandatory to know the power supply area in which the generated power will be transmitted. Furthermore, the power demand itself and its growth mainly depend on the growth of the population, the increase of the per capita consumption itself and the growth of the economic strength in the area. The per capita consumption usually increases with an increase in the economic strength which highly depends on the available electrical energy.

2.5.2 Basis of Load Demand Forecast

Reports of PC-I “Establishment of Regional Grids in Gilgit-Baltistan Phase- I & II” have been used to carry out the Load Forecast as it is recently prepared by the Water and Power (Gilgit-Baltistan). In this report, load demand forecast has been made using WAPDA’s methodology (trend analysis) which takes into consideration the annual electricity consumption of domestic, commercial, craft and other users assessed and the historical growth rate for each is calculated on the of available data collected during the survey or the information received from census authorities.

The historical growth rate of each category is further adjusted for forecast keeping in view the prevailing conditions, load factor, increase in standard of living etc. The adjusted growth rates are then adopted for each category and accordingly load demand forecast is worked out.

During survey, the number of consumers, their connected load, their annual energy consumption, population of each area etc. is obtained for the initial years. The demand for the initial year is calculated, and further projected at the adjusted growth rates. Requirement of power energy may be carried out for a period of ten, twenty or thirty years in demand Forecast.

The period will be covered from 2021 to 2050 (30 years). The reason to extend the plan upto 2050 is to bout with the National Power IGCEP Plan 2047, prepared by the NTDCL. These demand estimates are made for domestic, commercial, crafts, agriculture, industries, public services and lights separately for various load centres identified in ten districts of Gilgit – Baltistan.

As autonomous load is essentially the demand of power of the population in a locality. Thus the rate of population growth is the main determining factor for future load development. It is therefore, essential to give the basis of population growth rate for determining annual power demand as shown In Table 2-11.

Table 2-11 Forcosted Population Growth Rate Per Annum (2.74%) in Million (2021-2050)

S#	Grid Stations	Location	No. of Load Centers	No. of Villages	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050
1	132/66/11 KV Humayun Bridge	Skardu	6	14	0.72	0.74	0.76	0.781	0.802	0.824	0.847	0.87	0.894	0.918	0.943	0.969	0.996	1.023	1.051	1.08	1.11	1.14	1.171	1.203	1.236	1.27	1.305	1.341	1.377	1.415	1.454	1.494	1.535	1.577
2	132/66/11 KV Khaplu	Khaplu City	4	12	0.232	0.238	0.245	0.252	0.258	0.266	0.273	0.28	0.288	0.296	0.304	0.312	0.321	0.33	0.339	0.348	0.358	0.367	0.377	0.388	0.398	0.409	0.42	0.432	0.444	0.456	0.469	0.481	0.495	0.508
3	132/66/11 KV Ghowari	Ghanche	2	10	0.027	0.028	0.028	0.029	0.03	0.031	0.032	0.033	0.034	0.034	0.035	0.036	0.037	0.038	0.039	0.041	0.042	0.043	0.044	0.045	0.046	0.048	0.049	0.05	0.052	0.053	0.055	0.056	0.058	0.059
4	132/66/11 KV Gahkuch	Ghizer	2	10	0.165	0.17	0.174	0.179	0.184	0.189	0.194	0.199	0.205	0.21	0.216	0.222	0.228	0.234	0.241	0.248	0.254	0.261	0.268	0.276	0.283	0.291	0.299	0.307	0.316	0.324	0.333	0.342	0.352	0.361
5	132/66/11 KV Gupis	Ghizer	2	8	0.118	0.121	0.125	0.128	0.131	0.135	0.139	0.143	0.146	0.151	0.155	0.159	0.163	0.168	0.172	0.177	0.182	0.187	0.192	0.197	0.203	0.208	0.214	0.22	0.226	0.232	0.238	0.245	0.252	0.258
6	66/11 KV Yasin	Ghizer	2	8	0.015	0.015	0.016	0.016	0.017	0.017	0.018	0.018	0.019	0.019	0.02	0.02	0.021	0.021	0.022	0.023	0.023	0.024	0.024	0.025	0.026	0.026	0.027	0.028	0.029	0.029	0.03	0.031	0.032	0.033
7	66/11 KV Chatorkhand	Ghizer	2	7	0.02	0.021	0.021	0.022	0.022	0.023	0.024	0.024	0.025	0.026	0.026	0.027	0.028	0.028	0.029	0.03	0.031	0.032	0.033	0.033	0.034	0.035	0.036	0.037	0.038	0.039	0.04	0.041	0.043	0.044
8	66/11 KV Ishkoman	Ghizer	2	8	0.027	0.028	0.028	0.029	0.03	0.031	0.032	0.033	0.034	0.034	0.035	0.036	0.037	0.038	0.039	0.041	0.042	0.043	0.044	0.045	0.046	0.048	0.049	0.05	0.052	0.053	0.055	0.056	0.058	0.059
9	66/11 KV Gulmit	Hunza	2	8	0.02	0.021	0.021	0.022	0.022	0.023	0.024	0.024	0.025	0.026	0.026	0.027	0.028	0.028	0.029	0.03	0.031	0.032	0.033	0.033	0.034	0.035	0.036	0.037	0.038	0.039	0.04	0.041	0.043	0.044
10	66/11 KV Sost	Hunza	2	7	0.026	0.027	0.027	0.028	0.029	0.03	0.031	0.031	0.032	0.033	0.034	0.035	0.036	0.037	0.038	0.039	0.04	0.041	0.042	0.043	0.045	0.046	0.047	0.048	0.05	0.051	0.053	0.054	0.055	0.057
11	66/11 KV Gudai	Astore	2	8	0.027	0.028	0.028	0.029	0.03	0.031	0.032	0.033	0.034	0.034	0.035	0.036	0.037	0.038	0.039	0.041	0.042	0.043	0.044	0.045	0.046	0.048	0.049	0.05	0.052	0.053	0.055	0.056	0.058	0.059
12	66/11 KV Rehmanpur	Astore	2	7	0.031	0.032	0.033	0.034	0.035	0.035	0.036	0.037	0.038	0.04	0.041	0.042	0.043	0.044	0.045	0.047	0.048	0.049	0.05	0.052	0.053	0.055	0.056	0.058	0.059	0.061	0.063	0.064	0.066	0.068
13	66/11 KV Shigar	Shigar	2	7	0.027	0.028	0.028	0.029	0.03	0.031	0.032	0.033	0.034	0.034	0.035	0.036	0.037	0.038	0.039	0.041	0.042	0.043	0.044	0.045	0.046	0.048	0.049	0.05	0.052	0.053	0.055	0.056	0.058	0.059
14	66/11 KV Machulu	Ghanche	2	8	0.023	0.024	0.024	0.025	0.026	0.026	0.027	0.028	0.029	0.029	0.03	0.031	0.032	0.033	0.034	0.035	0.035	0.036	0.037	0.038	0.039	0.041	0.042	0.043	0.044	0.045	0.046	0.048	0.049	0.05
15	66/11 KV Dumsum	Ghanche	2	7	0.028	0.029	0.03	0.03	0.031	0.032	0.033	0.034	0.035	0.036	0.037	0.038	0.039	0.04	0.041	0.042	0.043	0.044	0.046	0.047	0.048	0.049	0.051	0.052	0.054	0.055	0.057	0.058	0.06	0.061
16	66/11 KV Pion	Ghanche	2	7	0.026	0.027	0.027	0.028	0.029	0.03	0.031	0.031	0.032	0.033	0.034	0.035	0.036	0.037	0.038	0.039	0.04	0.041	0.042	0.043	0.045	0.046	0.047	0.048	0.05	0.051	0.053	0.054	0.055	0.057
17	66/11 KV Tolti	Skardu	3	8	0.031	0.032	0.033	0.034	0.035	0.035	0.036	0.037	0.038	0.04	0.041	0.042	0.043	0.044	0.045	0.047	0.048	0.049	0.05	0.052	0.053	0.055	0.056	0.058	0.059	0.061	0.063	0.064	0.066	0.068
18	66/11 KV Tangir	Diamer	3	6	0.038	0.039	0.04	0.041	0.042	0.043	0.045	0.046	0.047	0.048	0.05	0.051	0.053	0.054	0.055	0.057	0.059	0.06	0.062	0.064	0.065	0.067	0.069	0.071	0.073	0.075	0.077	0.079	0.081	0.083
19	66/11 KV Darel	Diamer	3	7	0.04	0.041	0.042	0.043	0.045	0.046	0.047	0.048	0.05	0.051	0.052	0.054	0.055	0.057	0.058	0.06	0.062	0.063	0.065	0.067	0.069	0.071	0.072	0.074	0.077	0.079	0.081	0.083	0.085	0.088
	Total		47	157	1.641	1.69	1.73	1.78	1.83	1.88	1.93	1.98	2.04	2.09	2.15	2.21	2.27	2.33	2.4	2.46	2.53	2.6	2.67	2.74	2.82	2.89	2.97	3.06	3.14	3.23	3.31	3.4	3.5	3.59

2.5.3 Parameters of Load Demand Forecast

To develop parameters for prospective power consumption by different types of consumers of different locations/villages of Gilgit-Baltistan, the related results of similar area of other provinces of Pakistan have been studied and used as basic reference for the development of parameters etc. However, the effects of local climate, terrain and financial states of the public have also been considered while designing basic parameters etc.

Based on load demand and energy consumption survey carried out in the sample urban and rural localities, Load demand parameters have been developed for rural and urban localities. Considerable accuracies in proportionate to increase/decrease with the population census have been recorded.

2.5.4 Parameters Categorization

The load demand forecast parameters adopted for rural and urban localities of different districts of Gilgit-Baltistan are given in the following table.

Table 2-12 Load demand parameters Rural Consumers

Sr. No	Type of consumers	Load (KW)
1	Domestic	2
2	Commercial	3
3	Community	5
4	Small industry	12
5	Pump water supply	15
6	Pump irrigation	7.50
7	Street lights	3

Table 2-13 Load Demand parameters Urban Consumers

Sr. No	Type of Consumers	Load (KW)			
		3-5 Marla	7-10 Marla	1-Kanal	2-Kanal
1	Domestic	3	8	12	20
2	Commercial	10	15	20	25
3	Community	10	15	26	30
4	Small Industry	10	15	30	60
5	Pump water supply	-	-	-	40
6	Pump irrigation	-	-	-	25
7	Street lights	-	-	-	0.2

2.5.5 Load Forecasting Results

Based on above various power demand/ load forecast has been estimated in terms of maximum power which generally occurs in January, required for the present connected consumers and the deprived villages. According to the assessment of the existing load position in the area optimistic scenario is not far from realistic demand assessment and could be considered as the likely power demand/ load forecast of the regions in Gilgit-Baltistan. The load forecast up to 2050 is tabulated as under:

Table 2-14 Load Demand Forecast (MW) Gilgit-Baltistan upto 2050

YEAR	DISTRICTS									
	Gilgit	Ghizer	Nagar	Hunza	Diamer	Astore	Skardu	Ghance	Shiger	Khar mang	Total
2021	115.97	71.22	28.1	28.2	106.48	45.26	94	47.27	27.5	25.5	589.5
2022	117.96	72.44	28.58	28.69	108.31	46.04	95.62	48.08	27.97	25.94	599.63
2023	119.99	73.69	29.07	29.18	110.17	46.83	97.26	48.91	28.45	26.38	609.93
2024	122.06	74.96	29.58	29.68	112.07	47.64	98.93	49.75	28.94	26.84	620.45
2025	124.16	76.25	30.08	30.19	114	48.46	100.64	50.61	29.44	27.3	631.13
2026	126.29	77.56	30.6	30.71	115.96	49.29	102.37	51.48	29.95	27.77	641.98
2027	128.46	78.89	31.13	31.24	117.95	50.14	104.13	52.36	30.46	28.25	653.01
2028	130.67	80.25	31.66	31.78	119.98	51	105.92	53.26	30.99	28.73	664.24
2029	132.92	81.63	32.21	32.32	122.04	51.88	107.74	54.18	31.52	29.23	675.67
2030	135.21	83.03	32.76	32.88	124.14	52.77	109.59	55.11	32.06	29.73	687.28
2031	137.53	84.46	33.32	33.44	126.28	53.68	111.48	56.06	32.61	30.24	699.1
2032	139.9	85.92	33.9	34.02	128.45	54.6	113.4	57.02	33.17	30.76	711.14
2033	142.31	87.39	34.48	34.6	130.66	55.54	115.35	58	33.74	31.29	723.36
2034	144.75	88.9	35.07	35.2	132.91	56.49	117.33	59	34.33	31.83	735.81
2035	147.24	90.43	35.68	35.8	135.19	57.47	119.35	60.02	34.92	32.38	748.48
2036	149.78	91.98	36.29	36.42	137.52	58.45	121.4	61.05	35.52	32.93	761.34
2037	152.35	93.56	36.92	37.05	139.88	59.46	123.49	62.1	36.13	33.5	774.44
2038	154.97	95.17	37.55	37.68	142.29	60.48	125.61	63.17	36.75	34.08	787.75
2039	157.64	96.81	38.2	38.33	144.74	61.52	127.77	64.25	37.38	34.66	801.3
2040	160.35	98.47	38.85	38.99	147.23	62.58	129.97	65.36	38.02	35.26	815.08
2041	163.11	100.17	39.52	39.66	149.76	63.66	132.21	66.48	38.68	35.86	829.11
2042	165.91	101.89	40.2	40.34	152.34	64.75	134.48	67.63	39.34	36.48	843.36
2043	168.77	103.64	40.89	41.04	154.96	65.86	136.79	68.79	40.02	37.11	857.87
2044	171.67	105.43	41.6	41.74	157.62	67	139.15	69.97	40.71	37.75	872.64
2045	174.62	107.24	42.31	42.46	160.33	68.15	141.54	71.18	41.41	38.4	887.64
2046	177.63	109.08	43.04	43.19	163.09	69.32	143.97	72.4	42.12	39.06	902.9
2047	180.68	110.96	43.78	43.94	165.89	70.51	146.45	73.65	42.84	39.73	918.43
2048	183.79	112.87	44.53	44.69	168.75	71.73	148.97	74.91	43.58	40.41	934.23
2049	186.95	114.81	45.3	45.46	171.65	72.96	151.53	76.2	44.33	41.11	950.3
2050	190.16	116.78	46.08	46.24	174.6	74.22	154.14	77.51	45.09	41.81	966.63

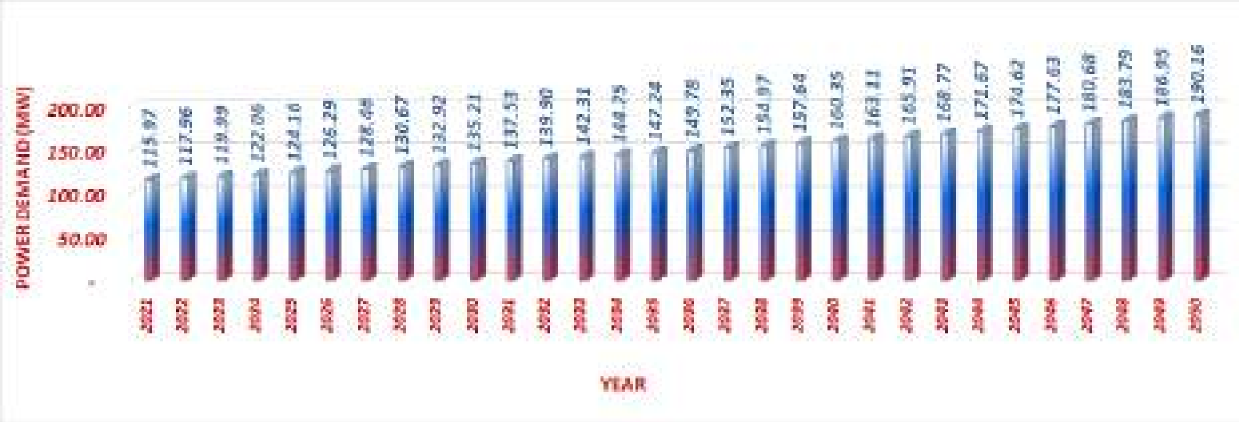


Figure 2-24 Power Demand Forecast Gilgit (2021-50)

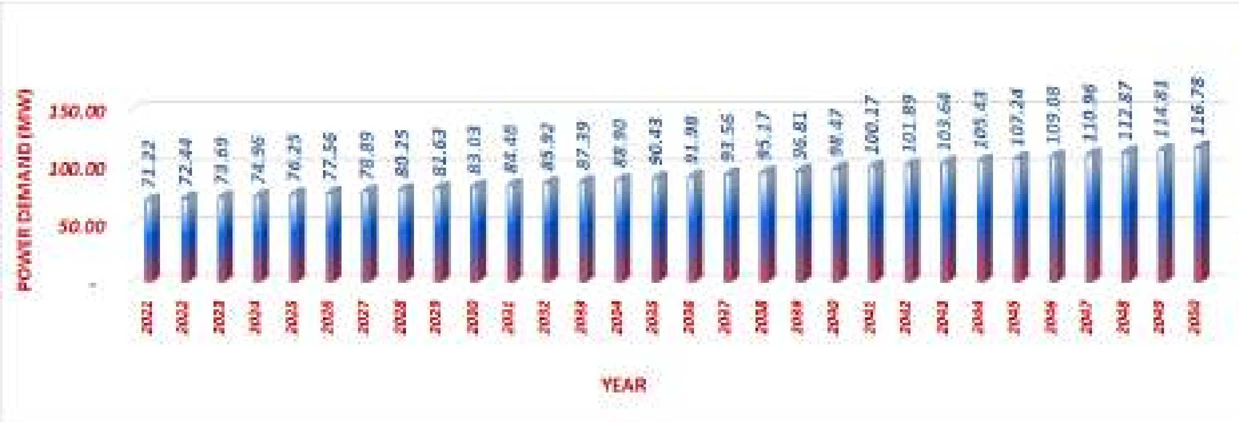


Figure 2-25 Power Demand Forecast Ghizer (2021-50)

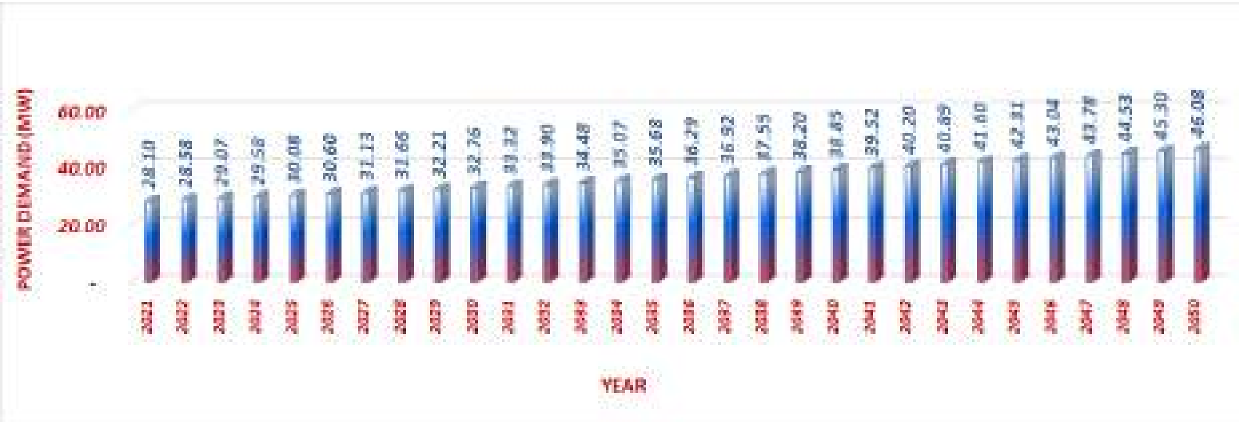


Figure 2-26 Power Demand Forecast Nagar (2021-50)

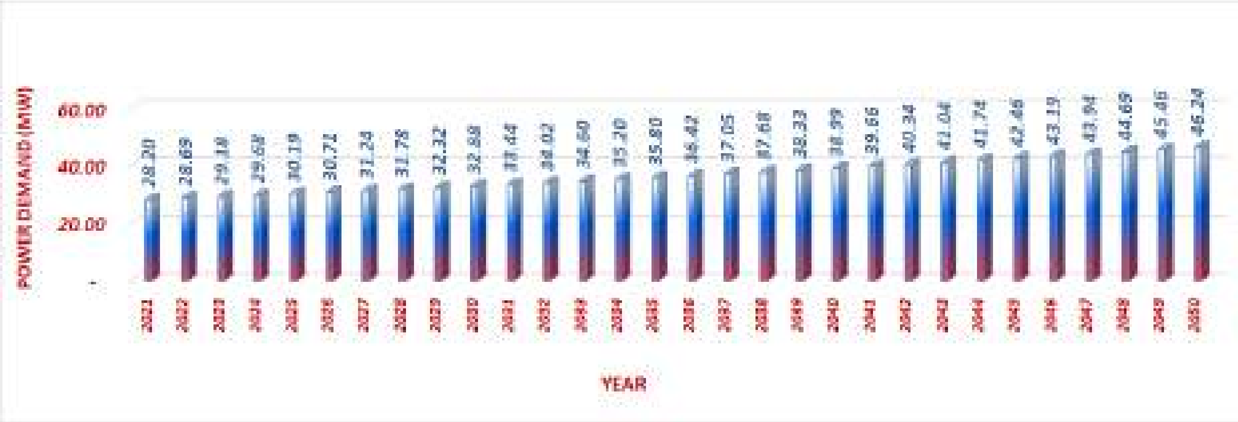


Figure 2-27 Power Demand Forecast Hunza (2021-50)

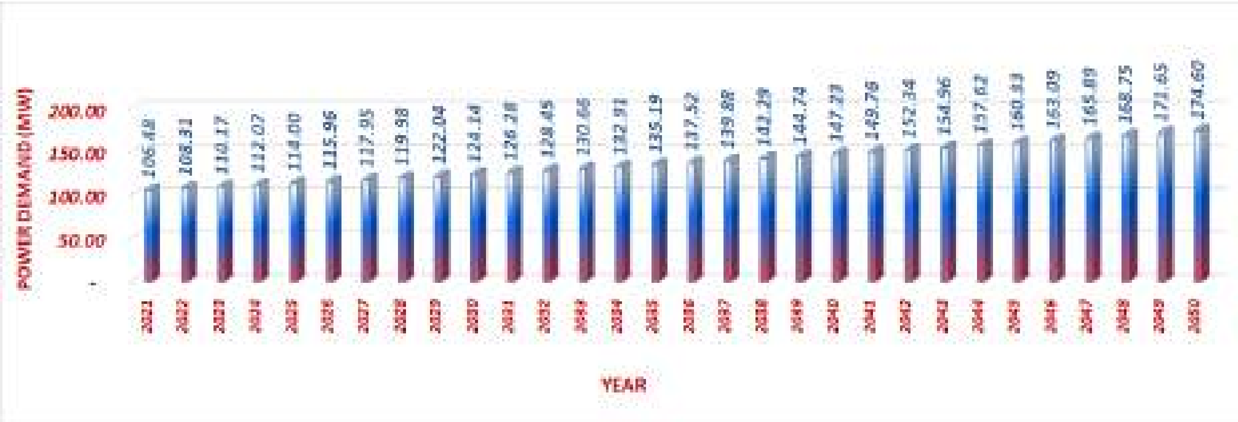


Figure 2-28 Power Demand Forecast Diamer (2021-50)

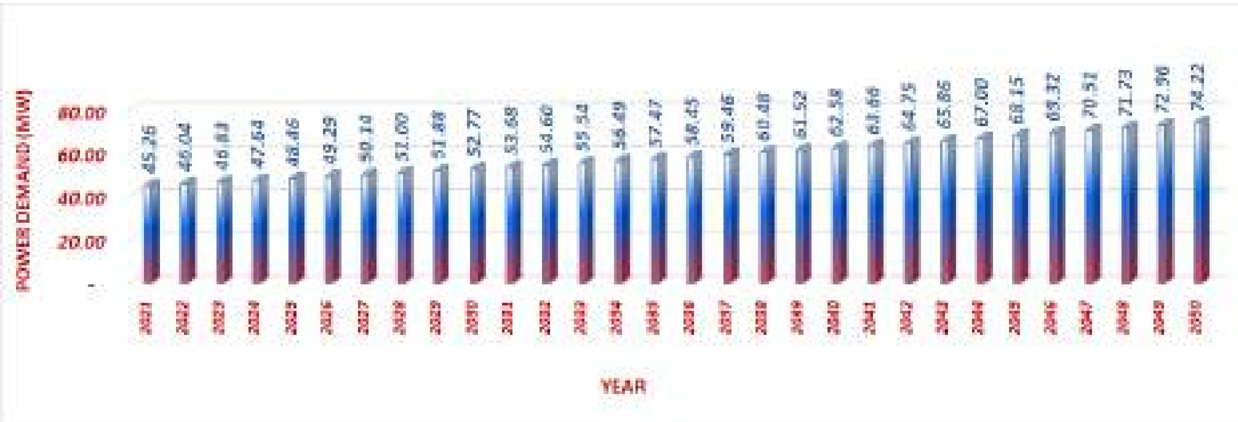


Figure 2-29 Power Demand Forecast Astore (2021-50)

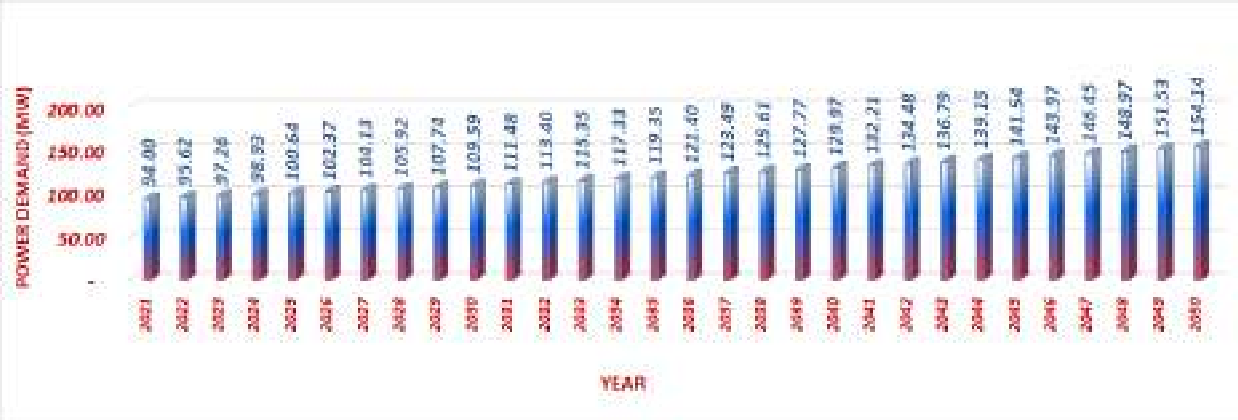


Figure 2-30 Power Demand Forecast Skardu(2021-50)

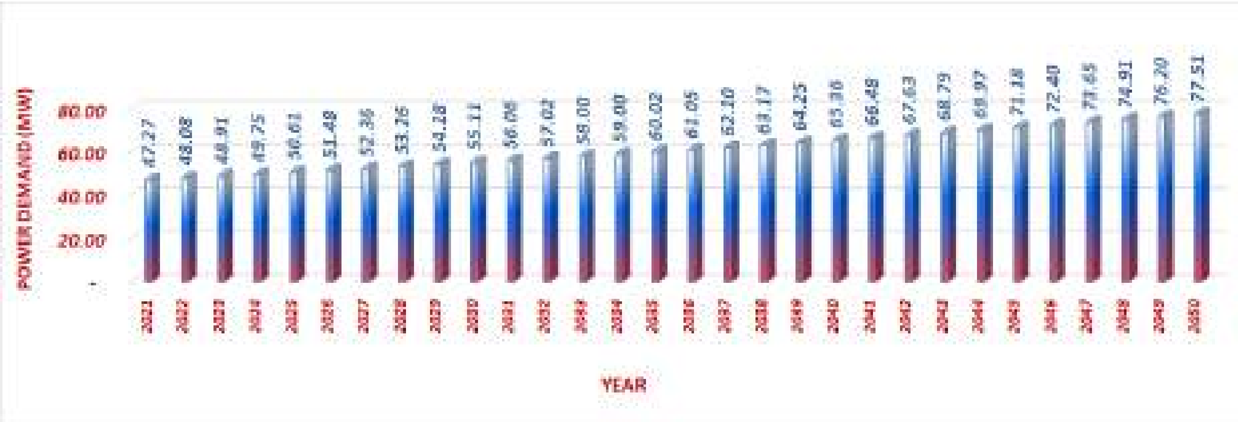


Figure 2-31 Power Demand Forecast Ghance (2021-50)

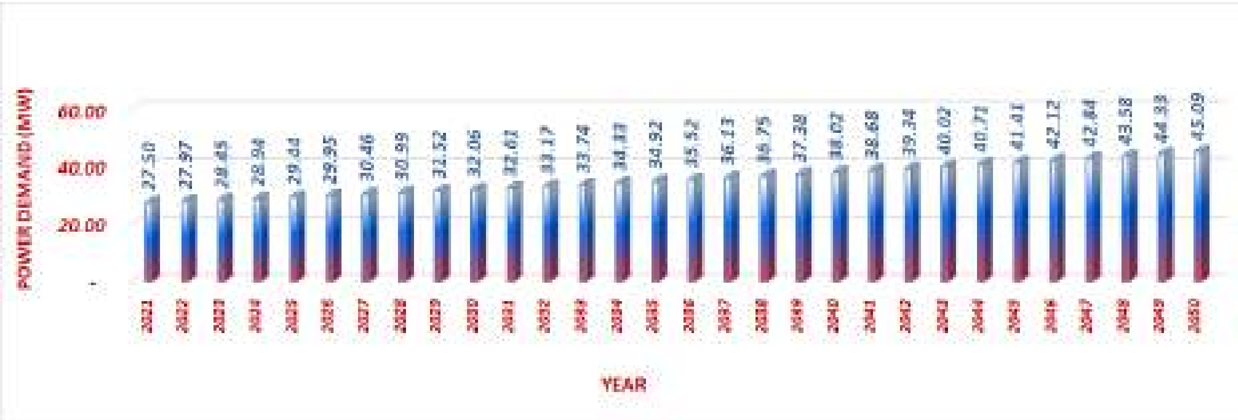


Figure 2-32 Power Demand Forecast Shiger (2021-50)

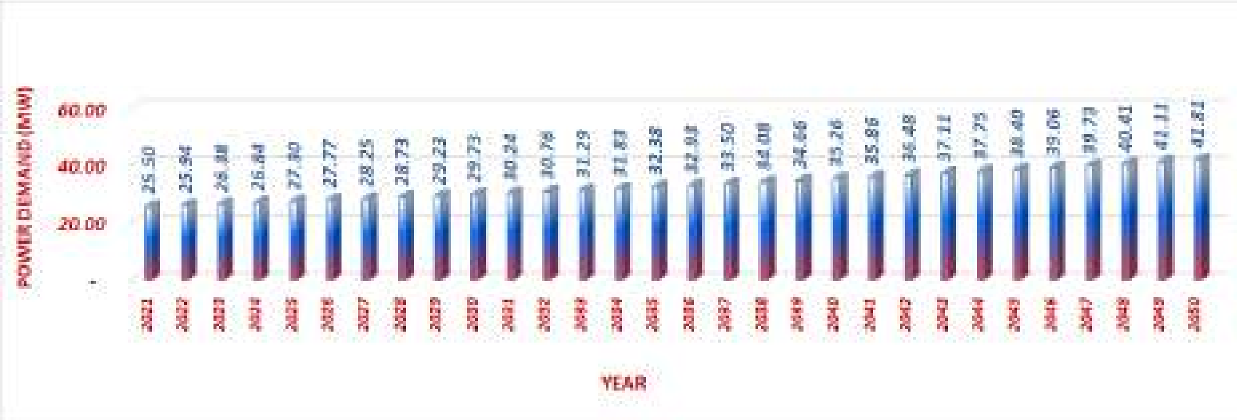


Figure 2-33 Power Demand Forecast Kharmang (2021-50)

2.5.6 Estimated Power and Energy of Attabad Lake Hydropower Project

Attabad Hydropower Project will be constructed on Hunza River and KKH is the only way to approach the project. This route has prominence due to China-Pak Economic Corridor (CPEC), which started in Pakistan from the Khunjerab Pass. The main focus in Market survey/ load forecast is being kept on the Hunza region as power will be transmitted to Sost (Upper Hunza) and Aliabad (Central Hunza), further interconnected to the regional grid of Gilgit-Baltistan from the proposed switchyard of Aliabad and also available to supply the power to Lower Hunza and Nagar Valley as 132/66/11 Grid proposed in Sikandarabad Headquarter of Tehsil Nagar-2, Nomal and Gilgit city.

The power and energy have been estimated based on 10-day flows for all years from 1966 to 2015. For 10-Daily Power Curves, the optimum installed capacity would be 54 MW with environmental flow of 3 m^3/s having mean annual energy of 373.69 GWh. The plant factor will be taken as 79 %.

The calculated annual energy, for years 1998 (average year), 2011 (wet year) and 1996 (dry year), is 375.75, 449.49 and 333.87 GWh respectively. The energy calculated based on 10 daily flows for 50 year ranges between 333.87 GWh to 449.49 GWh. A mean value of 373.69 GWh has been taken as mean annual energy. The 10 daily power and energy for average, wet and dry years are presented below.

As in average year, the installed power of 54 MW would be available for 24 hours from May to October. Peaking power (4 hours) will be available throughout the year, however, off-peak power (20 hours) will vary from 14 MW to 54 MW and will remain full from May to October. When flow reduces due to winter in November, the power generation would also reduce, however, enough flows remain available to run one turbine unit during lowest flow period as indicated in Figure 2-34.

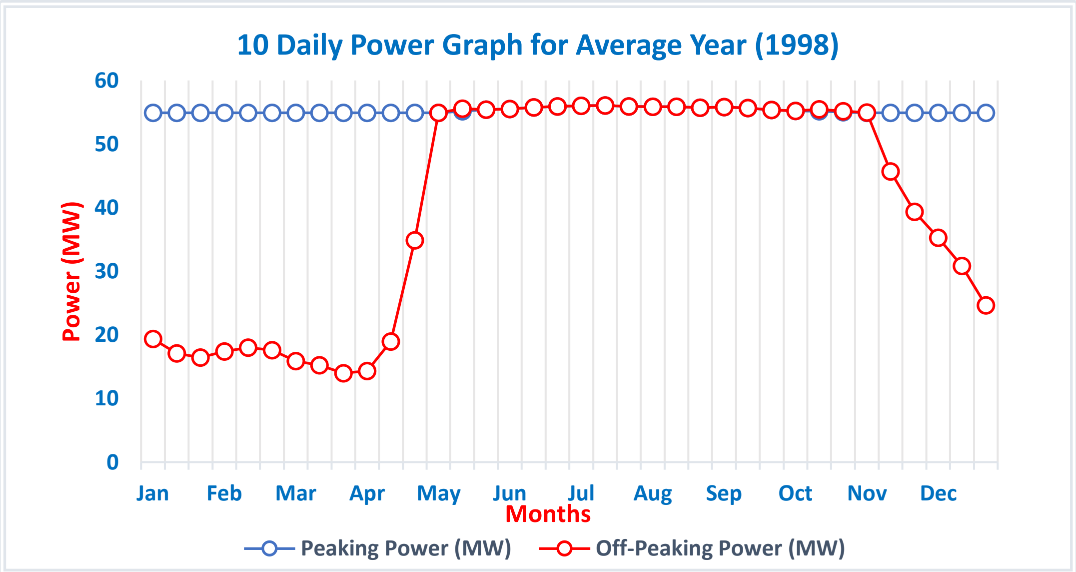


Figure 2-34 10-Daily Power Graph for Average Year (1998)

In wet year, installed power of 54 MW would be available from May to mid-December. Power may reach to full capacity during high flows of wet year even in February and March. In low flow period, the minimum power is estimated to remain at 20 MW as indicated in Figure 2-35.

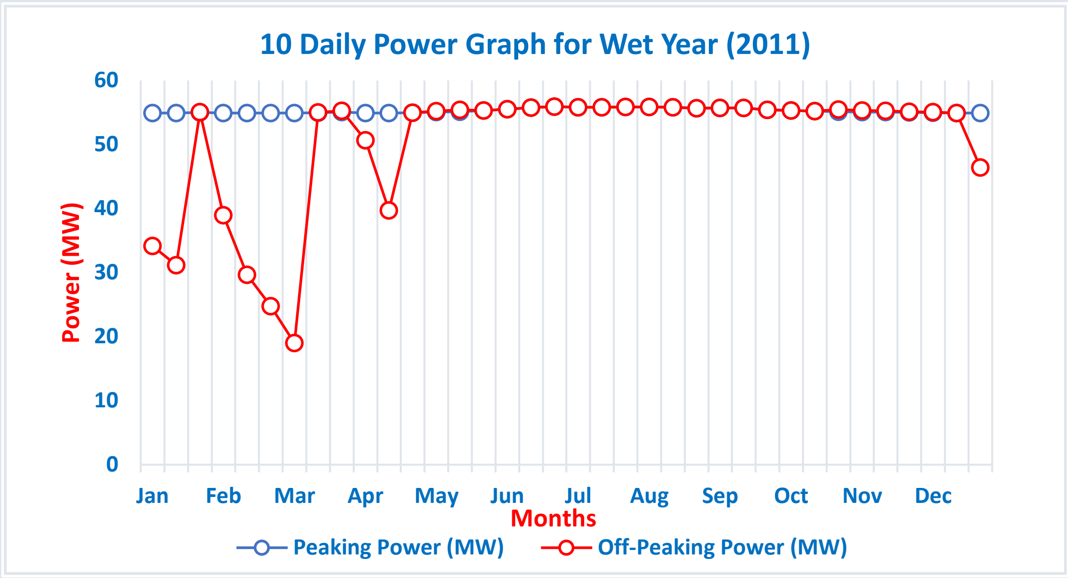


Figure 2-35 10-Daily Power Graph for Wet Year (2011)

In dry year, installed power of 54 MW will be available from June to mid-October and reduces as low as 9 MW when minimum flows are available. For dry year 1996, the power variation over the year is indicated in Figure 2-36.

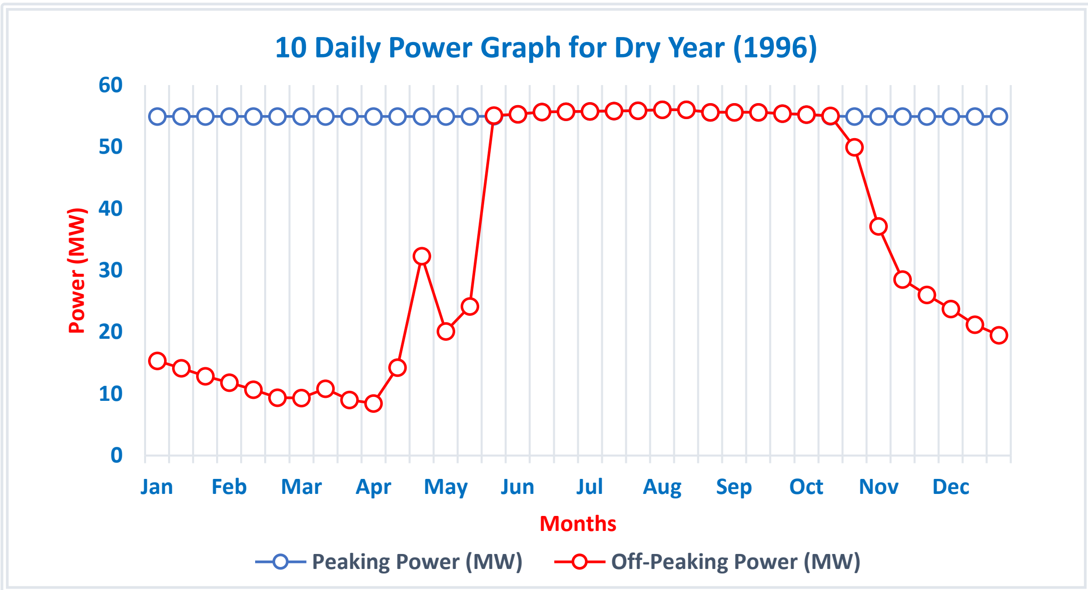


Figure 2-36 10-Daily Power Graph for Dry Year (1996)

The mean annual energy for the recorded period from 1966 to 2015 has been estimated and it is graphically presented in Figure 2.37. The graph indicates that the estimated annual energy over a period of 50 years does not vary much and remain quite consistent with little variation. It varies from 333.87 GWh to 449.49 GWh with mean value as 373.69 GWh. The plant factor for 54 MW power plant would be 79%. The low variation in mean annual energy and high plant factor indicate the reliability of hydropower from the lake.

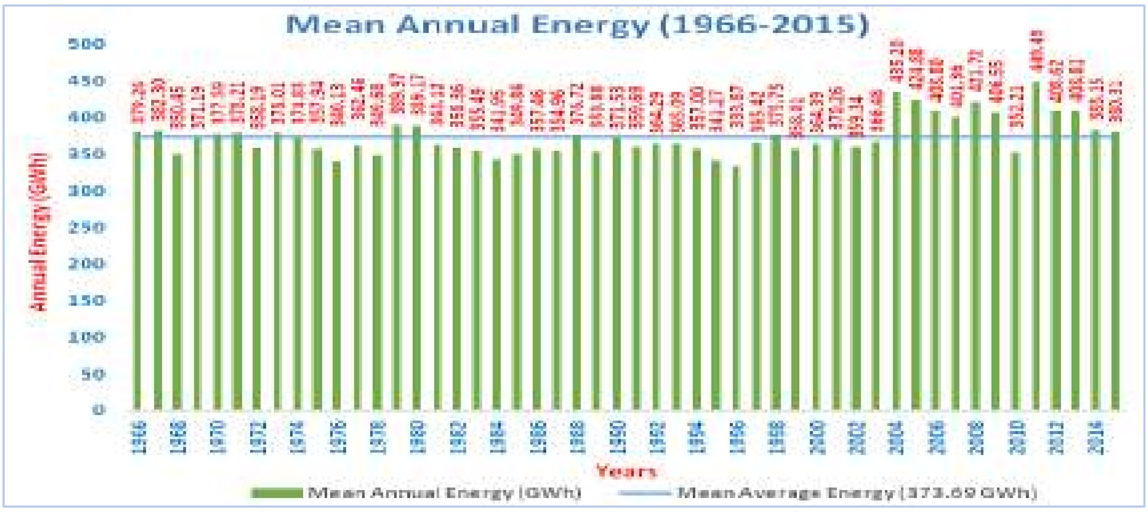


Figure 2-37 Mean Annual Energy from (1996 to 2015)

A comparison has also been plotted between monthly energy generations for Wet, Average and Dry years. Mean Annual Energy Curves indicate the trend of variations of monthly energies in GWh. The graph is shown at Figure 2.38.

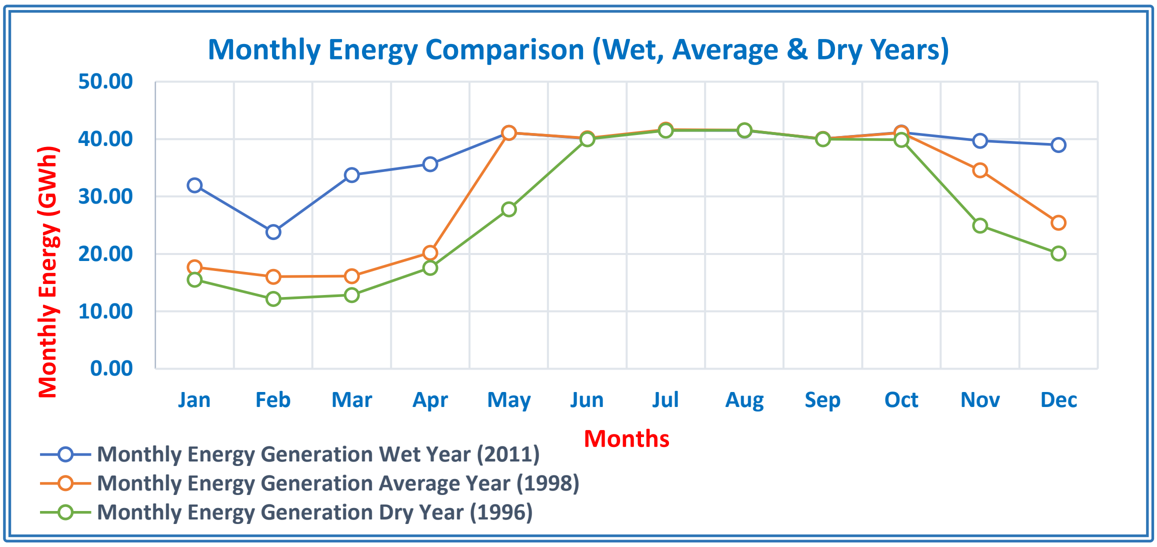


Figure 2-38 Monthly Energy Comparison (Wet, Average & Dry Years)

3 TOPOGRAPHIC AND HYDROGRAPHIC SURVEY

3.1 GENERAL

Topographic survey is imperative for planning and design of engineering projects. In order to prepare the Feasibility Design of a project, the site topography obtained through survey and mapping should not only accurate but also readily available in an acceptable format for use in the next stages of the project. For this Project, initially Survey of Pakistan Maps / GT sheets on 1:250,000 & 1:50,000 scale for the Project Area have been utilized for obtaining topographic information for preliminary studies and Project Layout. This information has been used to carry out field surveys. Moreover, these GT sheets have been used to assess the catchment area of the Project for hydrological assessment.

3.2 TOPOGRAPHY OF THE HUNZA RIVER

Hunza River, a left bank and major tributary of Gilgit River in Gilgit Baltistan (GB), originates from the confluence of the two rivers i.e. Khunjerab River and Ghujerab River, near a tunnel about 7 km upstream of an area named Shachkatr. The Khunjerab River begins in the snow-clad mountains and glaciers in the north and south of Khunjerab Pass. The river flows to the west then turns southward. It ends when it flows into the Hunza River. The Ghujerab River starts from small glaciers and snow-topped mountains of the Ghujerab Range, and flows to the west and later joins Hunza River.

Passing through the whole Gojal Valley, Hunza River falls into Attabad Lake near Shishkat Village and again emerges from it near Attabad Village. From there, Hunza River flows through main Hunza Valley and later on discharges into the Gilgit River at Danyore Village near Karakuram International University (KIU).

The catchment area of Hunza River upstream of the Project Site is about 8,900 km² which mostly consists of glaciers and snow deposits accumulated in the mountainous region usually during winter. Hunza River cuts through the Karakoram Range and flows approx. 250 km with an average slope of 0.90% from north to south before it merges into the Gilgit River. Many large size glaciers like Batura, Passu, Ghulkin, Gulmit, Bliglong, Minapin, Hasanabad and Muchlobel Glaciers drain in Hunza River. The water from main streams including Chaprot, Hasanabad and Molma Nullahs from large as well as small valleys also drains into the Hunza River. The discharge of Hunza River has its peak in months from May to September due to melting of snow/glaciers due to rise in temperature.

The main tributaries of Hunza River include Kilik, Chapurson, Shimshal, Hispar, Bar Budalas and Naltar River. Kilik River begins in the slopes of the mountains between Mintaka and the Kilik pass and flows to the south east and ends when it empties into the Hunza River. Chapursan River begins in the area of the Chilanji Pass and the slopes of Kampiri Diwar peak. It flows to the east and joins Hunza River near Khudabad. Shimshal River begins in the Shimshal Pass from Virjirab, Yezghil and Khurdopen Glaciers. It flows to the west and after reaching near Passu it joins the Hunza River. The Hispar River forms from the melt water of the Hispar Glacier flows northwest, passing through Hispar, Hopar and Nagar villages until the confluence with the Hunza River in the Hunza Valley. Naltar River begins from the Shani Glaciers and flows along Naltar Valley in south east direction to join Hunza River.

Hunza River is the main river of the Hunza Valley, which is a very scattered settlement with meager population, bordering with Khyber Pakhtunkhwa to the west and the Xinjiang Region of China to the north-east. It is surrounded by high peaks namely Rakhaposhi, Hunza, Darmyani peak, Ghenta Sar, Ultar Sar, Bojahagur Duanasir and Lady Finger peak. Karakoram Highway (KKH) (N-35) runs along the Hunza Valley, switching to the Khunjerab Pass at the border with China Xinjiang. The valley consists of three regions i.e. Upper Hunza, Central Hunza and Lower Hunza. The Upper Hunza (Gojal) is beautiful valley starts from Attabad Lake and extends to Misgar, Shimshal and Chapurson (border areas). Gulmit Village is capital city of upper Hunza and Sost is important village for commercial purposes. KKH runs from this region of Hunza and exit to neighboring country China, at Khunjareb Pass and from Chapurson Wakhan Corridor. Central Hunza is most populous Region of Hunza starts from village Murtazabad and ends at Attabad. Lower Hunza starts from a village Khizirabad and ends at Nasirabad. The Nasirabad's location on KKH makes it as a centre village of Lower Hunza. KKH enter into this Region on the first bridge of Hunza, at Nasirabad from Nagar Valley.

3.3 ATTABAD LAKE

In January, 2010, Attabad Lake was formed due to massive landslide near Attabad Village. The landslide disaster resulted in blockage of flow of Hunza River, complete submergence of Ainabad & Lower Shishkat Villages and partial flooding of Gulmit Village, displacement of population and submergence of about 19 km section of Karakoram Highway (KKH) along left bank of Hunza River. As the Hunza River backed up, the lake extended 22 km upstream and rose to a depth of 120 m. An open cut spillway 415 m long, 60 m wide and 54 m deep was constructed on the landslide mass by Frontier Works Organization (FWO) to pass flow of Hunza River over the spillway and to avoid further backing up of Hunza River in upstream Valley.

The Lake is surrounded with towering mountains on both sides and is now one of the main attractions in Hunza valley that leads to the tourism. KKH passes through 05 road tunnels (07 km long) on its left bank. The length of Attabad Lake varies from 9 km to 12 km depending upon the variation of summer and winter flows of Hunza River.

Figure 3-1: A view of Attabad Lake

3.4 PROJECT AREA

ALHPP is proposed on Attabad Lake along N-35 (KKH) in Hunza Valley. The Project Area generally comprises of loose material and fragmented terrain along the right bank of Hunza River whereas left bank is stable. The weir site has been proposed at existing spillway of Attabad Lake. The powerhouse site is about 2.5 km downstream of the Weir site, along the left bank of Hunza River.

3.5 ACCESSIBILITY

3.5.1 Roads Network

The Project is accessible from main cities of Pakistan, primarily Islamabad and Gilgit along the existing N-35 (KKH). KKH starts at Hassanabdal and passes through KPK and the GB and terminates at Khunjerab Pass in the Karakoram Range on the Pakistan – China border:

The route through KKH can also be alternatively accessed via Motorways from Islamabad to Burhan Interchange near Hassanabdal (M-1 Islamabad-Peshawar Motorway – 44 km) and from Burhan Interchange to Thakot (M-15 Hazara Motorway – 180 km). From there, the access onward to Gilgit and Hunza continues as a part of Karakuram Highway (Thakot to Gilgit – 390 km; Gilgit to Attabad Lake/Hunza along Hunza River – 120 km).

There is another route from Islamabad to Gilgit and Hunza via Babusar Pass, through National Highway (N-15). This route is although shortest than KKH through Besham, to reach upto Chilas but it usually remains closed for six months in a year due to heavy snowfall during the winter season. The road distances from various places within Project Area and other parts of country are tabulated in **Table 3-1:**

Distances of Important Places from Project Area

Sr. No.	Project Vicinity		Outside Project Area	
	Place	**Distance (km)**	**Place**	**Distance (km)**
1	Passu	36	Khunjerab	150
2	Hussaini	25	Gilgit	120
3	Gulmit	18	Chilas	240
4	Shishkat	15	Babusar Pass	275
5	Sarat	03	Besham	450
6	Salmanabad	3.5	Islamabad	735
7	Karimabad	15	Lahore	1,100
8	Aliabad	20	Karachi	2,300

3.5.2 Airport and Air Link

Gilgit Airport is the nearest facility to the Project Area. The Gilgit Airport is about 120 km from the Project Site. Domestic flights from Islamabad airport are schedule for Gilgit on daily basis but viability of the flight depends upon the weather conditions persisting there. Recently, flights from Lahore and Karachi are also operational to Gilgit Airport.

3.5.3 Project Layout

The weir site has been proposed at existing spillway of Attabad Lake alongwith sediment flushing structure. Water will be diverted to powerhouse through power intake, low pressure headrace tunnel, surge tank and penstock on the left bank. The coordinates of weir & powerhouse sites are listed below:

Site	Easting (m)	Northing (m)
Weir	484036.834	4018143.837
Powerhouse	481645.920	4017963.719

The proposed overflow weir / ungated spillway is 60 m wide overflow and a sediment flushing channel / undersluice 19 m wide on its left site. The powerhouse site is about 2.5 km downstream of the proposed overflow weir / ungated spillway along the left bank of Hunza River.

A design discharge of 60 m^3/s will be diverted towards the powerhouse through intake left bank waterway located upstream of overflow weir / ungated spillway. A 2.32 km long low pressure headrace tunnel having a diameter of 5.5 m would run along the left bank leading to a 10 m wide and 45 m high surge tank. From there, a 470 m long embedded steel penstock with 3.6 m diameter would be laid over the left bank slopes leading down to the surface powerhouse to generate 54 MW with 03 Francis turbines. From powerhouse, a 20 m long tailrace channel leading from each generation unit will discharge water back into the Hunza River.

The **Photographs 3.2, 3.3 & 3.4** presents a view of existing spillway of Attabad Lake, proposed intake, surge tank & powerhouse areas.

Figure 3.2: Spillway Area (Looking Upstream)

Figure 3.3: A view of Intake Area

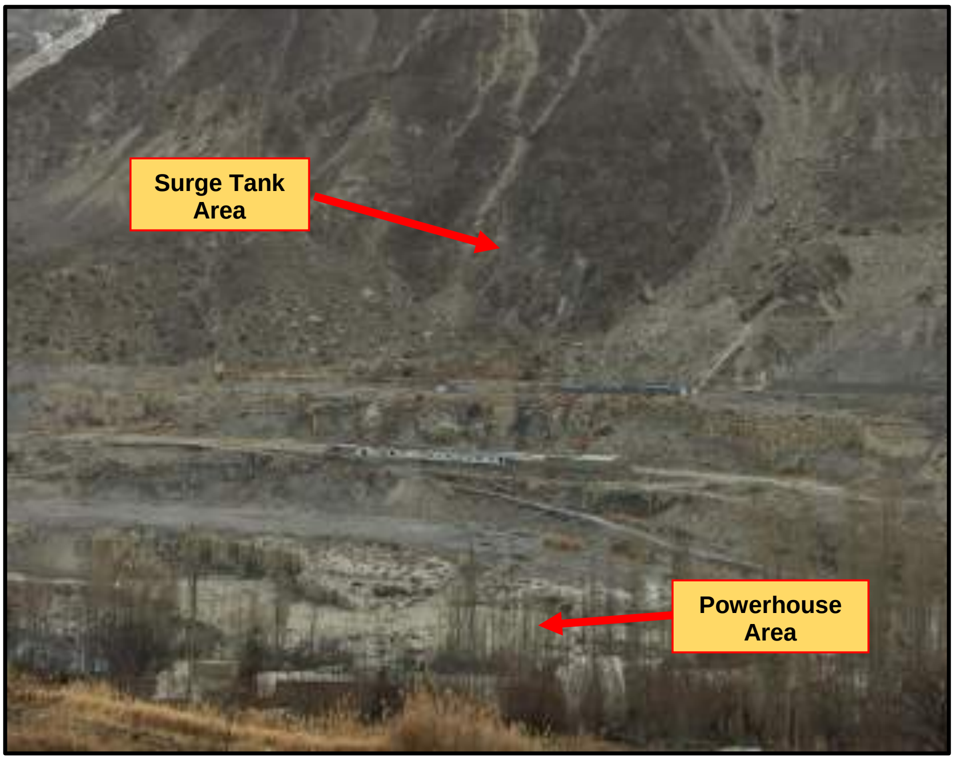


Figure 3.4: A view of Surge Tank and Powerhouse Area

3.6 TOPOGRAPHIC SURVEY

3.6.1 Available Topographic Information

Topographic information of the Project Area available at the beginning of the Study for the ALHPP comprised the following Survey of Pakistan (SoP) Maps:

GT Sheet 42-L with scale 1:250,000.

GT Sheets 42-L/11 and 42-L/15 with scale 1:50,000 (**Photo 3.5**).

These maps have been used in the preliminary project assessments e.g. to develop the general project layout to estimate the catchment area, study of topographical and geological features etc.

In addition to the study of Survey of Pakistan Maps, the Satellite based survey data has also been utilized to get first-hand information regarding the topography and contours of the Project Area. Additionally, a comprehensive terrestrial survey program was setup and executed by Survey Division Peshawar, HPO WAPDA equipped with state of the art equipment and experienced staff. The corresponding activities have been carried out in accordance with the requirements of the scope of work.

This section describes the topography of the Project Area, applied methodology, description of control points & benchmarks carried out during the Feasibility Study and the results of the topographic survey.

3.6.2 Scope of Work

For the development of an adequate Topographical Maps for ALHPP, depicting the existing features both natural and man-made and specific land areas with ground levels, the following major activities have been carried out:

- Setup a Project trigonometric network with a system of Benchmarks.
- Terrestrial survey of the area of Project components about 400 hectares at scale 1:1000 with contour interval of 2 m, covering 4 km downstream of weir site along Hunza River.
- Longitudinal profile of Hunza River, 4 km downstream from weir site.
- Terrestrial survey of valley cross sections along Hunza River, 4 km downstream of weir site at an interval of 200 m, covering the main river course and valley slopes upto 200 m on either side.
- Terrestrial survey of borehole locations.
- Satellite based survey of the Project Area

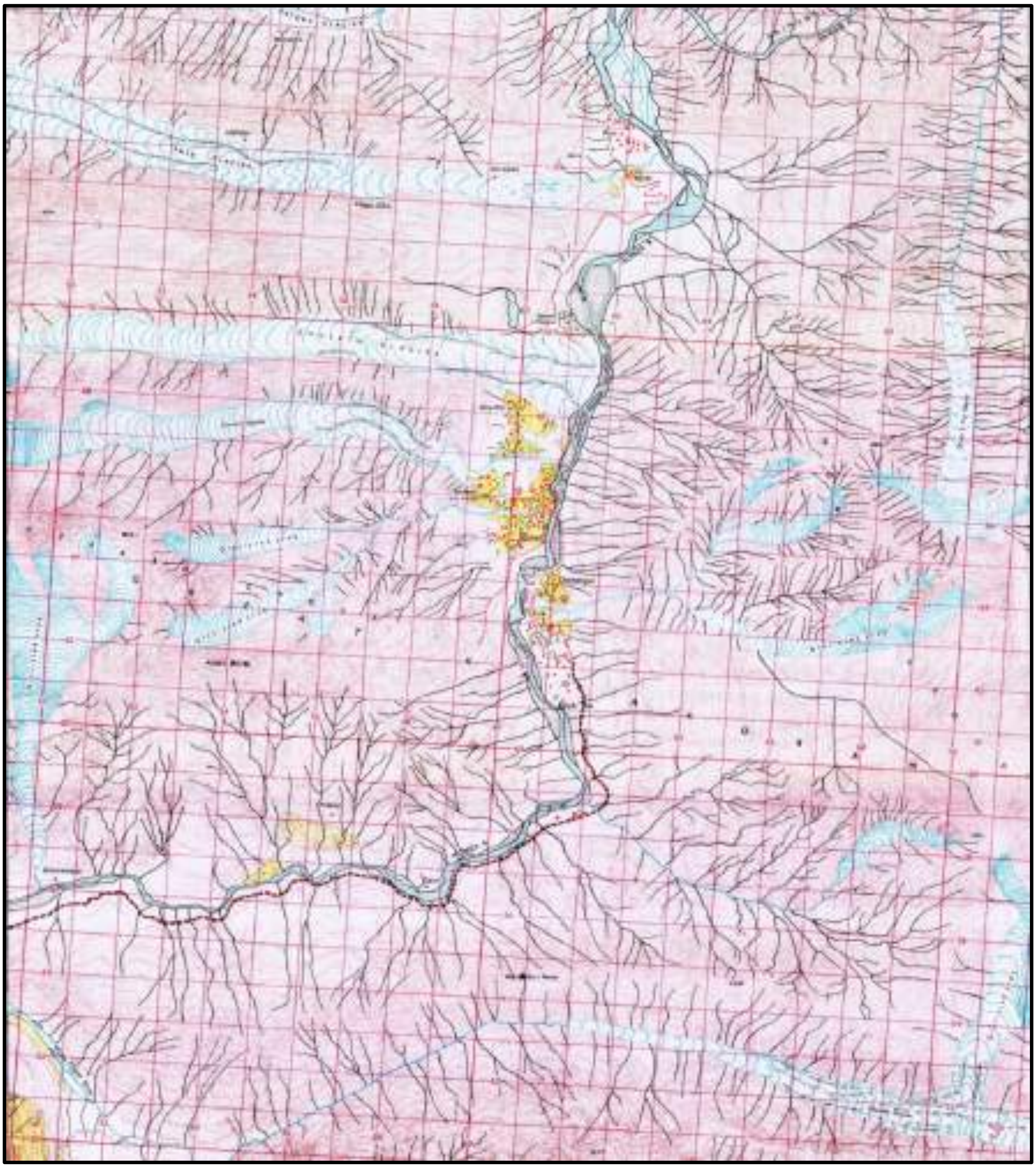


Figure 3-5 Map Section of Survey of Pakistan Sheet 42-L/15

3.6.3 Survey Standards and Requirements

All the survey work for the Feasibility Study of ALHPP has been conducted in accordance with the minimum Performance Standards and in line with the Survey Standards of Survey of Pakistan (SoP) in terms of "Accuracy and Precision". The Survey Standards and Pre-requisites to be observed during the survey work are as under:

3.6.3.1 General

The horizontal and vertical geodetic system to be introduced for the ALHPP based on Survey of Pakistan. Installed permanent stations, control points; traverse points etc. referred to those co-ordinates and elevations. To avoid unnecessary, long traverse lines control points have been established and determined as close as possible to the individual survey sites. Control points referred directly to control points of the Survey of Pakistan and determined by traverses or triangulation or any combination of them.

Traverse lines started and close at the nearest control points of the Survey of Pakistan at pre-installed and surveyed control stations. Permanently marked traverse points at interval of about 1 km. However, as many as possible fixed points shall be permanently marked out in the Project Area for later reference. All fixed points-control stations, permanent traverse points, benchmarks be marked by cast in bolt or steel pin for centering and elevation reference. The station with their designation be made clearly visible in the filed by enamel paint for easy identification.

3.6.3.2 Triangulation

In the chosen system all horizontal and vertical angles and all inclined distances have to be observed directly. The horizontal and vertical angles must be observed in three complete rounds. The mean of the rounds not exceed 2”. Inclined distances must be measured directly, in both fore-sighting and back sighting directions.

Total stations with a standard deviation for angle measurement of +1” and for distance measurement of +2mm+2ppm has been employed. For each point, station compensation has been carried out. The closing error of triangles with station compensated angles has not exceeded 5”. The inclined measured distances shall be reduced to the horizontal by the reciprocal-calculation method taking into consideration refraction and earth curvature. The same has to be employed for trigonometrically calculated differences of height.

3.6.3.3 Control Points Determination

For the determination of control points by traverses total station with a standards deviation for angle measurement for +1” and for distance measurement of +2mm+2ppm shall be employed. The horizontal angles shall be observed in two complete rounds with a mean of not exceeding 8”. Distance shall be measured in fore-and back-sight directions.

All traverses shall be connected and closed to co-ordinate points of the Survey of Pakistan (SOP). To minimize set-up errors, the forced centering method has been applied. The closing errors shall be distributed according to common survey standards. For closed-traverse lines the allowable error shall be:

- Horizontal-angle closing $\pm 2'' \sqrt{N}$
- Where “N” is the number of traverse stations distance closing ± 0.05 m $\sqrt{Dkmt}$
- Where “D” is the total distance of traverse line (in km).

3.6.3.4 Technimetrics Traverses

Technimetrics traverses necessary for the connection of the topographic area and section surveys at the powerhouse site has been carried out by total stations. All tachometric traverses have been closed to prior coordinated stations and their closing errors distributed.

The closing errors shall not be larger than:

Horizontal-angle closing	±1" √ N
Where "N" is the number of traverse stations.	
Distance	± 1.0 m √ Dkm
Where "D" is the total distance of the line (in km)	
Height	± 0.2 m √ Dkm
Where "D" is the total distance of the line (in km)	

3.6.3.5 Precise Leveling

For precise leveling, SOP level with plan-parallel plate, with at least a count of 0.1 mm, or equivalent digital leveling instruments has been employed, using invar-leveling staffs. All leveling loops have been leveled in fore and back directions. Special care has to be taken that the distances of back and fore-sights are equal and not longer than 30 m. All back and fore-sight distances have to be recorded. No intermediate readings have been taken.

Pf error has to be allowable error	±1.0 mm √ Dkm
Where "D" is the total length of the line	

The distribution made proportional to the length of the sights.

3.6.3.6 Ordinary Leveling – 3rd Order

All the lines have been surveyed in fore and back sight directions. It have been aimed that distance for back and fore sights do not differ very much. Intermediate observations to bench marks have been avoided. All level loops have been started, connected and compensated to prior determined benchmarks. The accuracy for survey have been shall be:

Between fore and back-leveling	(6 √ Dkm) mm
Loop between two bench marks	(2+6 √ Dkm) mm

Where "D" is the total length of the line (in km)

The error distribution is to be made either proportional to the length of the sight or to the number of instrument settings.

3.7 METHODOLOGY APPLIED TO THE TOPOGRAPHIC SURVEY

For the topographic survey of ALHPP, the following two approaches have applied comprising:

- Conventional terrestrial survey used for detailed topographic maps with high accuracy.
- Satellite based survey used for overview project maps:
- Google Earth Method.
- Geographic Information System (GIS) Method.

The following surveying works have been carried out during the Feasibility Study:

Establishment of ground control points;

- Terrestrial survey works of weir and powerhouse site covering Project components including weir & sediment flushing channel, power intake, power tunnel, surge tank, penstock, powerhouse and tailrace area;
- Longitudinal profile of Hunza River;
- Terrestrial survey works of valley cross sections along Hunza River;
- Survey of locations of bore holes;
- Development of Topographic Maps at the required scales.
- Development of Digital Elevation Model (DEM) based on high resolution satellite images.

3.7.1 Reference System

In order to start the topographic field survey work, the reference grid of Survey of Pakistan (SOP) is required to be connected. However, there was no standard Benchmark (BM) established by SOP in the vicinity of Project Area and its surroundings. Due to the non-availability of the SoP BM, the reference BM has been established in the Project Area by using Differential Global Positioning System (DGPS).

The benchmarks established through DGPS have been verified with the Total Station. The terrestrial survey of the Project Area has been carried out with reference to these benchmarks to prepare topographic features of ALHPP.

3.7.2 Instruments Used

The terrestrial topographic survey has been conducted using Electronic Total Stations. The conditions of the survey instruments have been checked prior survey to ensure high accuracy of the record data. The following instruments have been used for the terrestrial survey works:

- Topcon Total Station W 0303.
- Trimble R8s GNSS.

3.7.3 DGPS Survey of Project’s Reference Points

The surveying campaign commenced in the early stage of the Feasibility Study in August, 2020. Due to non-availability of the SOP BM as a reference point, it has been decided to use the DGPS-Receiver called Trimble R8s to establish reference points at Project Site. 03 locations have been identified, making triangulations.

The starting point established over a pre-constructed BM along old Karakoram highway, 190 m upstream of SCOM office located near Tunnel-1 inlet. This BM has been named as BM-1 and the receiver has set as “Base Station” at BM-1 for longer duration in static mode of observation, to collect its coordinate data.

For the static surveying, Trimble R8s receiver is capable of giving the following accuracy:

- Horizontal 3 mm + 0.1 ppm RMS
- Vertical 3.5 mm + 0.4 ppm RMS

Keeping the "Base Station" in observation mode, another receiver "Rover" has moved to other two points i.e. BM-2 & H-35, one by one for 60 minutes to collect coordinate data. To receive the signals from satellite, it has been ensured that both the receivers have minimum obstructions like building, trees, power lines etc. The signals have received at minimum cut of angle of 15° or more. The Base Station receiver measured the errors in the GPS signals and transmitted the corrections to the Rover receiver.

The data from both the Base Station and Rover receiver then downloaded for processing and conversion from grid to ground parameters. The accuracy achieved in the DGPS survey of reference points was 50 cm. The values of these established reference points verified by the survey team using Total Station through triangulation. The coordinates and elevation of reference points BM-1 & BM-2 have further been used as Project's Permanent Reference BM to start the survey activities in the Project Area.

Figure 3-2 Survey of Project's Permanent Reference Benchmark BM-1

3.8 TERRESTRIAL TOPOGRAPHIC SURVEY OF PROJECT AREA

During the survey campaign, the survey of Project Area covering all the Project components, Valley Cross-Sections and Longitudinal Profile along Hunza River has been conducted as specified in the scope of work, to provide reliable data for the study of Project Layout.

The terrestrial survey work has been carried out by two experienced survey teams of Survey Division Peshawar, WAPDA. In the course of Feasibility Study, a comprehensive terrestrial survey has been conducted to achieve topographic information to the required level. One of the major objectives is the elaboration of detailed topographic maps at scale 1: 1,000 with contour interval of 2 m of the area of the project structures as specified in the scope of work.

The terrestrial survey works carried out comprise weir and powerhouse site, covering the project components:

- Overflow Weir & Sediment Flushing Channel.
- Power Intake.
- Low Pressure Headrace Tunnel.
- Surge Tank.
- Penstock.
- Powerhouse.
- Tailrace Channel.

The terrestrial survey of Project Area has been completed in September, 2020. The 02 number concrete monuments BM-1 & BM-2 form the basis for a new triangulation system. All the terrestrial surveyed areas tied into the Project's Permanent Reference Benchmarks i.e. BM-1 & BM-2 near weir and powerhouse site.

Figure 3-3 Terrestrial Topographic Survey in progress

3.8.1 Horizontal Control

The horizontal control has been done through a combination of triangulation and traversing method supported by the use of reference points established through DGPS. All the survey work conducted with digital display infrared beam Total Station. The triangulation network consists of well balance quadrilaterals or center point polygons and also well balance triangles.

The traversing has been in the closed loop form. All traversing lines measured in two directions (forward and backward) and mean value has been used. The linear measurement units used in the survey work and mapping work are metric and the angular measurement in degree, minutes and seconds of arc.

3.8.2 Vertical Control

The Reference Datum i.e. the mean sea level established by SOP was not available in the vicinity of Project Area; therefore, the vertical control datum of Project's Permanent Reference Benchmark BM-1 has been used as the reference datum and utilized in survey of the Project Area.

3.8.3 Traverse Survey

Before carrying out the topographic survey, a traversing network for the project was prepared. It included a plan of the temporary benchmarks / control points network across the project. The traverse survey started from reference points established through DGPS i.e. BM-1 & BM-2. The accuracy of horizontal control has been achieved with traversing using total station. With traversing, sixty eight (68) traverse stations / control points have been established by the survey team in the entire area of interest to acquire the field survey data in digital format.

The traverse stations / control points have been established on the available rocks and existing drainage structures such as culverts in the project area by marking with engraved circle or triangle and a nail driven or engraved dot at the center of either mark. All the traverse stations / control points were properly labeled with red paint.

Survey Division Peshawar, WAPDA also conducted closed loop survey which connects the traverse between the control points with the permanent benchmarks used for the survey works for the ALHPP.

Control network diagram is presented in **Figure 3.8** and the list of traverse stations / control points is given in **Table 3-1**.

Table 3-1 Traverse Station / Control Points Coordinates

Sr. No.	Point ID	Easting (m)	Northing (m)	Elevation (m.a.s.l)
1	H1	481219.010	4017664.199	2395.493
2	H2	481316.503	4017685.054	2401.955
3	H3	481234.627	4017720.891	2404.297
4	H4	481208.544	4017700.529	2396.713
5	H5	481207.521	4017649.336	2394.247
6	H6	481155.351	4017596.546	2390.609
7	H7	481067.386	4017555.005	2387.171
8	H8	481366.571	4017758.322	2392.405
9	H9	481507.726	4017724.318	2381.848
10	H10	481641.130	4017625.234	2400.877
11	H11	481723.047	4017643.665	2398.740

Sr. No.	Point ID	Easting (m)	Northing (m)	Elevation (m.a.s.l)
12	H12	481754.223	4017702.743	2362.396
13	H13	481937.494	4017821.742	2361.025
14	H14	482112.760	4017983.292	2360.351
15	H15	481877.785	4018005.462	2326.289
16	H16	482026.702	4018092.896	2322.609
17	H17	481936.766	4018078.820	2326.115
18	H18	481733.176	4017959.549	2319.386
19	H19	481459.525	4017895.827	2314.159
20	H20	481393.770	4017994.438	2309.371
21	H21	481513.855	4018067.421	2326.376
22	H22	481678.359	4017799.827	2334.528
23	H23	481874.743	4017894.523	2335.437
24	H24	482338.056	4018023.919	2358.811
25	H25	482115.210	4017956.484	2373.939
26	H26	481546.606	4018136.405	2330.802
27	H27	481511.528	4018209.542	2337.769
28	H28	482583.422	4017872.307	2354.598
29	H29	482762.508	4017925.426	2364.108
30	H30	482962.406	4018027.410	2372.087
31	H31	483285.338	4018027.670	2407.801
32	H32	483292.996	4018113.798	2410.373
33	H33	483362.495	4018089.701	2415.424
34	H34	483404.048	4018082.722	2424.795
35	H35	483614.843	4018068.728	2488.864
36	H36	483693.079	4018030.816	2516.953
37	H37	483326.100	4018033.572	2410.711
38	H38	483560.133	4018147.964	2410.505
39	H39	483686.987	4018185.536	2424.069
40	H40	483761.281	4018168.847	2429.451
41	H41	483870.869	4018145.434	2432.829
42	H42	483906.838	4018135.625	2432.418
43	H43	483737.347	4018080.162	2501.220
44	H44	483734.333	4018090.725	2495.450
45	H45	483830.176	4017982.229	2512.200
46	H46	483944.550	4017876.574	2506.413
47	H47	483981.604	4017859.367	2495.696
48	H48	484015.395	4017905.324	2489.082
49	H49	484041.794	4017964.620	2478.943
50	H50	484004.629	4017954.352	2486.987
51	H51	482167.582	4017890.217	2408.422
52	H52	482249.332	4017903.423	2411.156
53	H53	481724.009	4017598.961	2399.555
54	H54	481544.398	4018247.745	2353.586

Sr. No.	Point ID	Easting (m)	Northing (m)	Elevation (m.a.s.l)
55	H55	481352.229	4018204.355	2367.864
56	H56	481165.994	4018143.351	2376.892
57	H57	482121.169	4018482.184	2359.034
58	H58	482316.677	4018427.092	2364.145
59	H59	482577.583	4018307.879	2378.900
60	H60	481182.345	4018060.014	2362.644
61	H61	484078.421	4017922.132	2473.744
62	H62	484080.523	4017847.832	2471.363
63	H63	484108.774	4017936.913	2459.167
64	H64	484158.301	4017963.964	2439.110
65	H65	484149.613	4017961.179	2441.517
66	H66	484161.563	4018032.721	2418.575
67	H67	484029.993	4018100.567	2428.459
68	H68	483963.947	4018121.981	2432.581

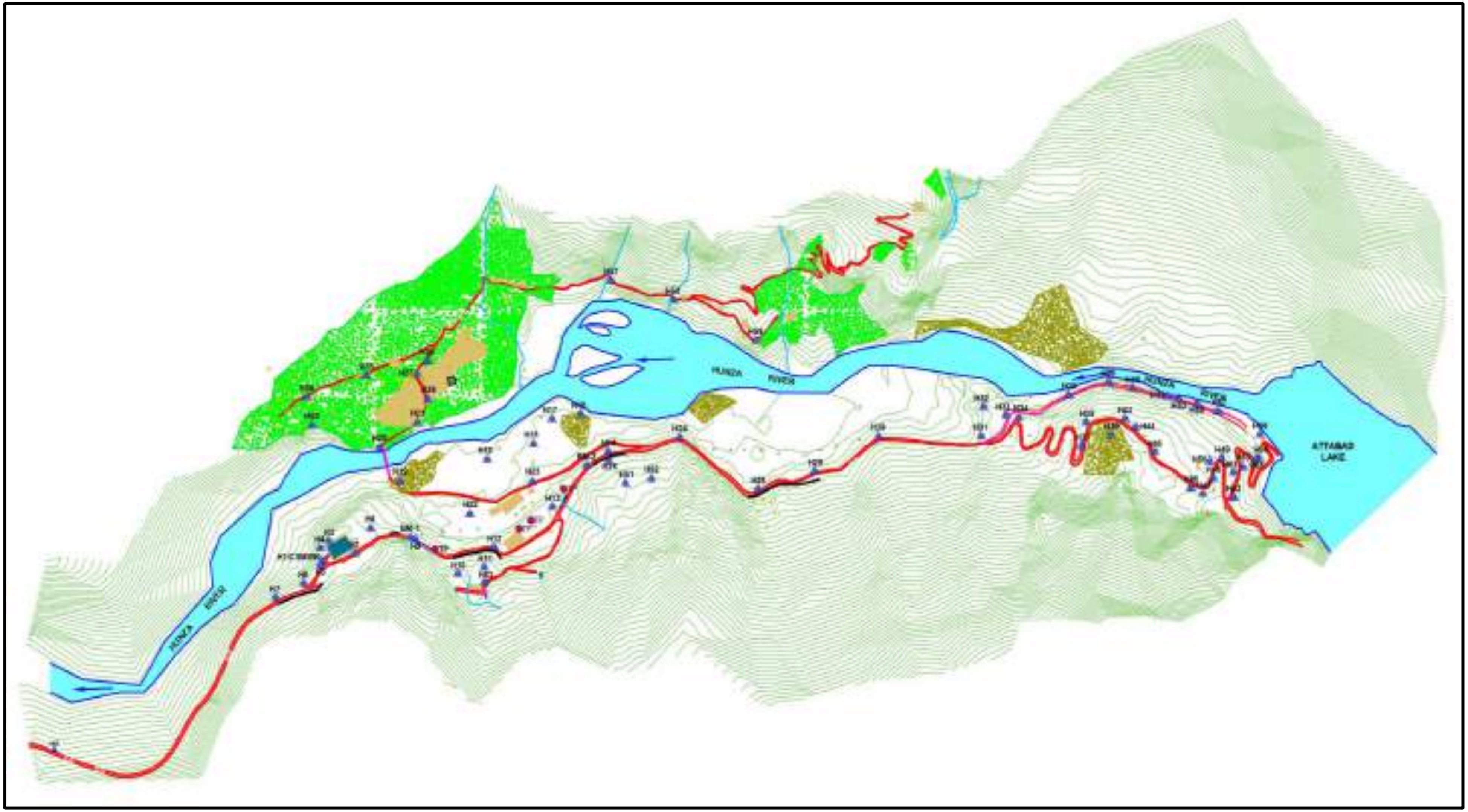


Figure 3-4 Control Network Diagram

3.8.4 Survey of Weir and Powerhouse Site

The terrestrial survey at the Weir and Powerhouse site was performed based on a temporary benchmarks / control points network which were tied to the two reference points i.e. Project's Permanent Reference Benchmarks BM-1 & BM-2, located about 2.8 km & 2.1 km downstream of the Weir site respectively along the old Karakoram highway.

The survey works performed at Weir site covers an area of overflow weir and sediment flushing section, power intake and headrace tunnel area. The survey works performed at Powerhouse site covers an area of powerhouse itself, surge tank, penstock and tailrace channel. The survey of Weir and Powerhouse site covers part of valley slopes on left and right bank of the Hunza River.

3.8.5 Survey of Valley Cross Sections and Longitudinal Profiles

During the survey campaign, the Survey Division Peshawar, HPO, WAPDA conducted a detailed terrestrial topographic survey of valley cross sections and longitudinal profile along Hunza River. The valley cross sections covers upto 4 km downstream Hunza River reach from the weir axis. The valley cross-sections taken at an interval of 200 m. The surveyed data of each cross-section includes left and right valley slopes down to the water level of the Hunza River. The topographic survey of these cross-sections have been conducted based on temporary benchmarks / control points network which have been tied to the two Project's Permanent Benchmarks i.e. BM-1 & BM-2.

The longitudinal water profile of Hunza River, 4 km downstream of weir axis has been surveyed to establish the river drop. The water levels are taken on the left bank of the river.

3.8.6 Survey of Locations of Geotechnical Investigations

As part of the geotechnical field investigation program of 06 boreholes core drilling and 08 test pits have been carried out for geological investigation. The location of the boreholes and test pits has been based on temporary benchmarks / control points network tied to the two Project's Permanent Benchmarks i.e. BM-1 & BM-2. The borehole and test pits locations have been marked at major project components prior to start of drilling work.

In some cases, platforms have erected for safe installation of the drilling rig in sloped terrain. Therefore, the recorded ground level of the borehole may deviate from the elevation of natural ground upto 5m.

3.9 RESULTS OF TERRESTRIAL TOPOGRAPHIC SURVEY

3.9.1 The Attabad Lake Hydropower Project's Reference System

The reference system of the ALHPP is based on Differential Global Positioning System (DGPS). The results of all terrestrial topographic surveys are tied to the reference points i.e. Project's Permanent Benchmarks established in the Project Area through DGPS.

3.9.2 Benchmarks of Attabad Lake Hydropower Project

Due to non-availability of SOP BM in the vicinity of Project Area, the DGPS based Project's Permanent Benchmarks are established in the Project Area, comprising of 02 concrete monuments (BM-1 & BM-2) covering the Project Area. The two monuments were newly constructed at carefully selected sites to meet the demands of the project.

The new constructed concrete monuments are of rectangular shape and painted in white colour with their nominations indicated in red colour at two sides**.** On top of the monument a steel bolt is incorporated into the massive concrete. This steel bolt is the reference point of the monument. For protection of the steel bolt from mechanical damage the bolt is placed in a hole of the monument some 5 cm below the top.

Table 3.2 provides detailed information alongwith the corresponding photographic images about the individual monuments of ALHPP.

Table 3-2 Permanent Benchmarks in the Project Area

Name	Easting (m)	Northing (m)	Elevation (m.a.s.l)	Description
BM-1	481492.694	4017731.980	2384.000	Along old Karakoram highway, 190 m upstream of SCOM office building located near Tunnel-1 inlet.
BM-2	482045.533	4017941.757	2360.841	697 m upstream of BM-1 along old Karakoram highway.

3.9.3 Detailed Topographic Maps

The results of the survey campaigns have been processed to elaborate corresponding topographic maps of the Project Area. The contour lines have been interpolated using the survey software “Eagle Point”. Further the observed data has been digitized in the AutoCAD software. The digitization of the features has been done by creating the feature layers in the software. The different layer features have the unique colour and symbols so that they can be easily well distinguished from the other feature.

In the detailed terrestrial survey, natural and man-made structures were recorded. The main features that have been recorded in the topographic survey of the Project area are:

- Slided area at the right bank of Hunza River near weir site
- Rock outcrop at the power intake area.
- Section of Old KKH downstream of Attabad Lake.
- Access road to Sarat & Attabad village.
- Bridge over Hunza River for access to Sarat & Attabad village located some 200 m downstream of proposed powerhouse.
- Flat and boulders area at powerhouse site.
- Old Chinese Camp.
- Helipads near powerhouse area.
- Tracks, paths, road culverts, protection walls and electric poles.
- Inlet & Outlet of transportation tunnel 1.

- Inlet & Outlet of transportation tunnel 2.
- SCOM Office Building near inlet of Tunnel 1.
- Alignment of nullahs on left and right bank of Hunza River.

Changes in slope such as roads along the hillside and at the edges of waterways have been surveyed in detail and defined as break lines for the interpolation of contour lines. The scale of the topographic maps is 1: 2,000 with 2 m contour intervals. Based on maps at that scale, all relevant design drawings of the project structure are prepared.

The survey output at scale 1: 2,000 topographic maps of the Project Area produced based on the terrestrial survey are presented in **Volume-2** (Drawings) in 20 sheets (A3 format). All features important for the Feasibility Design of the permanent Project components are included in the survey works.

3.9.4 Survey of Valley Cross Sections and Longitudinal Profiles

21 valley cross sections surveyed along the Hunza River at an interval of 200 m d/s of weir axis. The surveyed data of each cross-section includes left and right valley slopes (ranges from 175 m to 250 m on either side) down to the water level of the Hunza River. The **Figure 3.9** gives an overview of cross sections surveyed. The left and right end points of the cross-section are given in **Table 3.3.** The drawings of each cross section at scale 1: 2,000 are presented in **Volume-2 (Drawings)** in 10 sheets (A3 format).

The longitudinal water profile has been observed along Hunza River and is placed in **Volume-2 (Drawings)**. The longitudinal profile along Hunza River is presented in 11 sheets (A3 format) at scale 1: 1,000. The total length of longitudinal profile along Hunza River is 4.05 km and there is a drop of 142 m.

3.9.5 Survey of Locations for Geotechnical Investigations

The coordinates, elevations and locations of each borehole drilled at main weir, sediment flushing channel, headrace tunnel and powerhouse are given in Section-5 (Geological and Geotechnical Studies). The survey of locations of boreholes recorded in the early phase of the Project based on temporary benchmarks / control points which have been tied to the two Project's Permanent BM i.e. BM-1 & BM-2. The different spreads of control points have been established to locate the position of boreholes in the entire Project Area.

Table 3-3 Coordinates of Left and Right End Points of Valley Cross Sections

	Easting (m)	Northing (m)	Elevation (m.a.s.l)	Remarks
0+000	484077.365	4017941.320	2470	Left
	484205.810	4018320.698	2490	Right
0+200	483885.506	4017976.367	2502	Left
	484006.588	4018355.031	2490	Right
0+400	483719.739	4018047.813	2510	Left
	483785.170	4018391.765	2490	Right
0+600	483577.857	4018017.414	2470	Left
	483515.202	4018416.293	2470	Right
0+800	483299.359	4018076.046	2406	Left
	483463.127	4018438.753	2470	Right
1+000	483146.204	4018016.188	2380	Left
	483188.056	4018437.080	2430	Right
1+200	483004.758	4018007.143	2380	Left
	482954.053	4018407.700	2450	Right
1+400	482934.019	4017977.650	2380	Left
	482708.504	4018312.614	2364	Right
1+600	482479.398	4017897.855	2370	Left
	482619.378	4018339.828	2378	Right
1+800	482348.418	4018010.660	2360	Left
	482403.348	4018436.239	2370	Right
2+000	482207.685	4017980.708	2360	Left
	482155.249	4018462.863	2353	Right
2+200	482085.488	4018002.977	2340	Left
	481855.273	4018441.588	2343	Right
2+400	481984.360	4017916.143	2340	Left
	481699.521	4018218.715	2340	Right
2+600	481676.984	4017805.103	2334	Left
	481602.212	4018158.829	2330	Right
2+800	481527.774	4017818.831	2330	Left
	481351.268	4018134.832	2356	Right
3+000	481351.380	4017750.629	2392	Left
	481176.516	4018084.672	2364	Right
3+200	481190.382	4017674.022	2380	Left
	481009.968	4017943.860	2340	Right
3+400	481134.673	4017603.367	2370	Left
	480793.191	4017768.011	2360	Right
3+600	480952.946	4017433.204	2390	Left
	480733.056	4017620.875	2360	Right
3+800	480855.228	4017276.855	2360	Left
	480606.025	4017454.702	2360	Right
4+000	480561.414	4017119.775	2360	Left
	480551.091	4017454.839	2360	Right

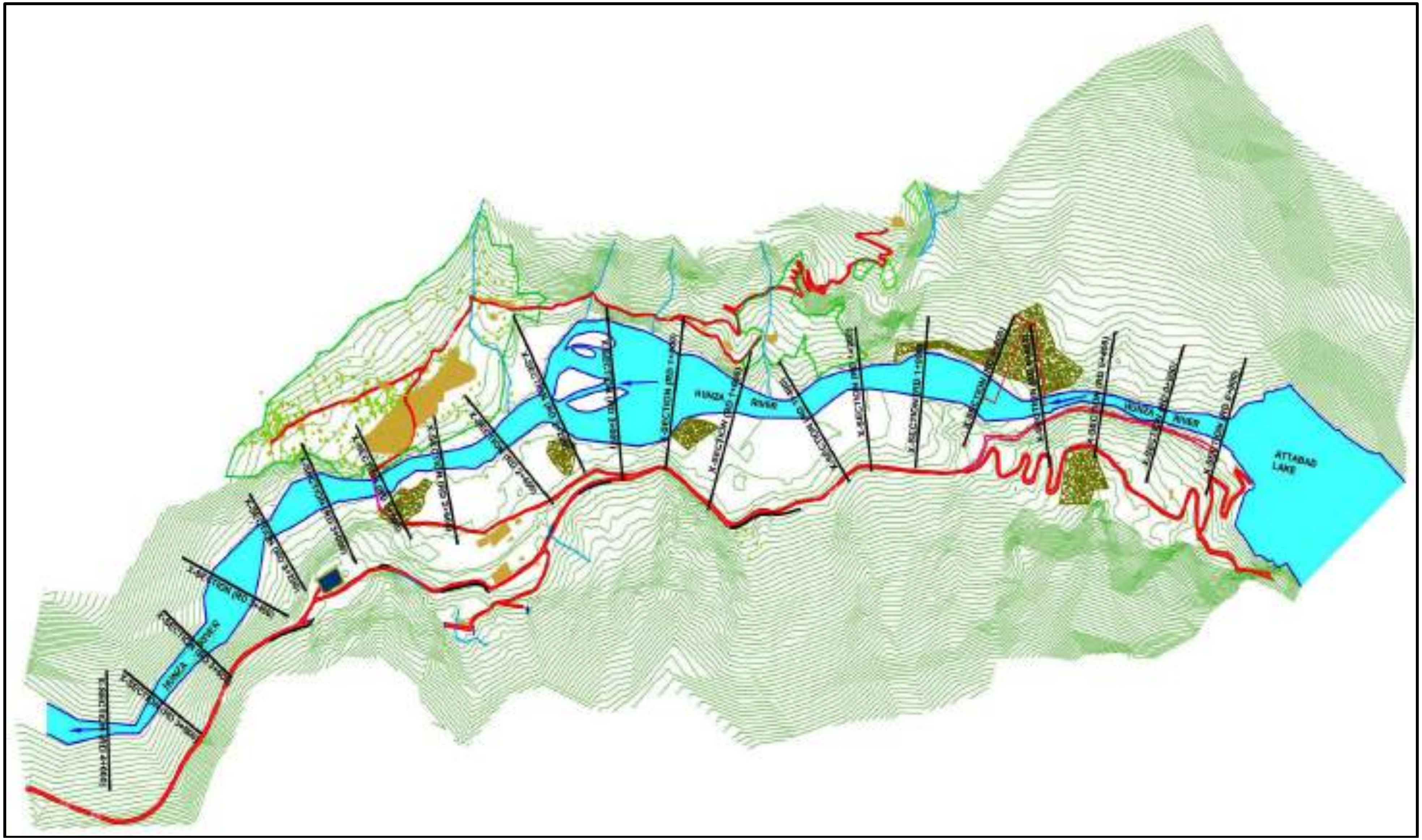


Figure 3-5 Valley Cross Sections along Hunza River

3.10 SATELLITE BASED SURVEY OF PROJECT AREA

The Satellite based survey is a most advanced system for such purposes where several types of Geographical and Geo-physical information about the earth are observed through Satellites. Several types and forms of data from the satellite imageries are processed, analyzed and used for the specific purposes.

3.10.1 Google Earth Method

Google Earth is a geo-browser that accesses satellite and aerial imagery and other geographic data over the internet to represent the Earth as a three-dimensional globe. It renders a 3D representation of Earth based on satellite imagery. The program maps the Earth by the superimposition of images obtained from satellite imagery, aerial photography and GIS data onto a 3D globe, allowing users to see cities and landscapes from various angles.

3.10.2 Methodology

For the preliminary working, topographic data has been collected through Google Earth Pro and relevant elevations were computed through web based applications for this purpose.

3.10.3 Geographic Data

Google Earth Pro has built in tools which gives the 3-dimensional value of any location. Using this tool numerous points have been taken in the Area of Interest (AOI). All the features e.g. river boundaries, roads, inhabitation/dwellings etc. have been demarcated on Google and saved as Keyhole Markup Language (KML) files for exporting to other software for further analysis. The google earth model of the AOI is presented in **Figure 3.10**.

3.10.4 Geographic Information System (GIS) Method

Geographic Information System (GIS) refers to Satellite based Geospatial Technology which is a tool use to acquire, store, analyze, manage, and present all types of geographical information in a variety of contexts, operations and applications. The use of Geospatial Information is becoming widely used in everyday life through Satellite Navigation and Geographical Information Systems (GIS). It is used to determine precise locations all over the globe, in any weather conditions and at any time of the day.

GIS geodetic surveying equipment for land surveyors has become smaller and easier to use being faster to use than other surveying methods. GIS technology combines database, mapping and statistical methods to integrate georeferenced data into visual displays where the relationships, patterns and trends in the data can be more easily identified.

3.10.5 Fundamental Components of GIS

Geospatial technology combines key data and visual information from multiple sources and integrates everything into databases to create intelligent maps. GIS is based on two fundamental components:

- Data (Satellite Imagery / DEM); and
- Computer software to perform calculations and analysis.

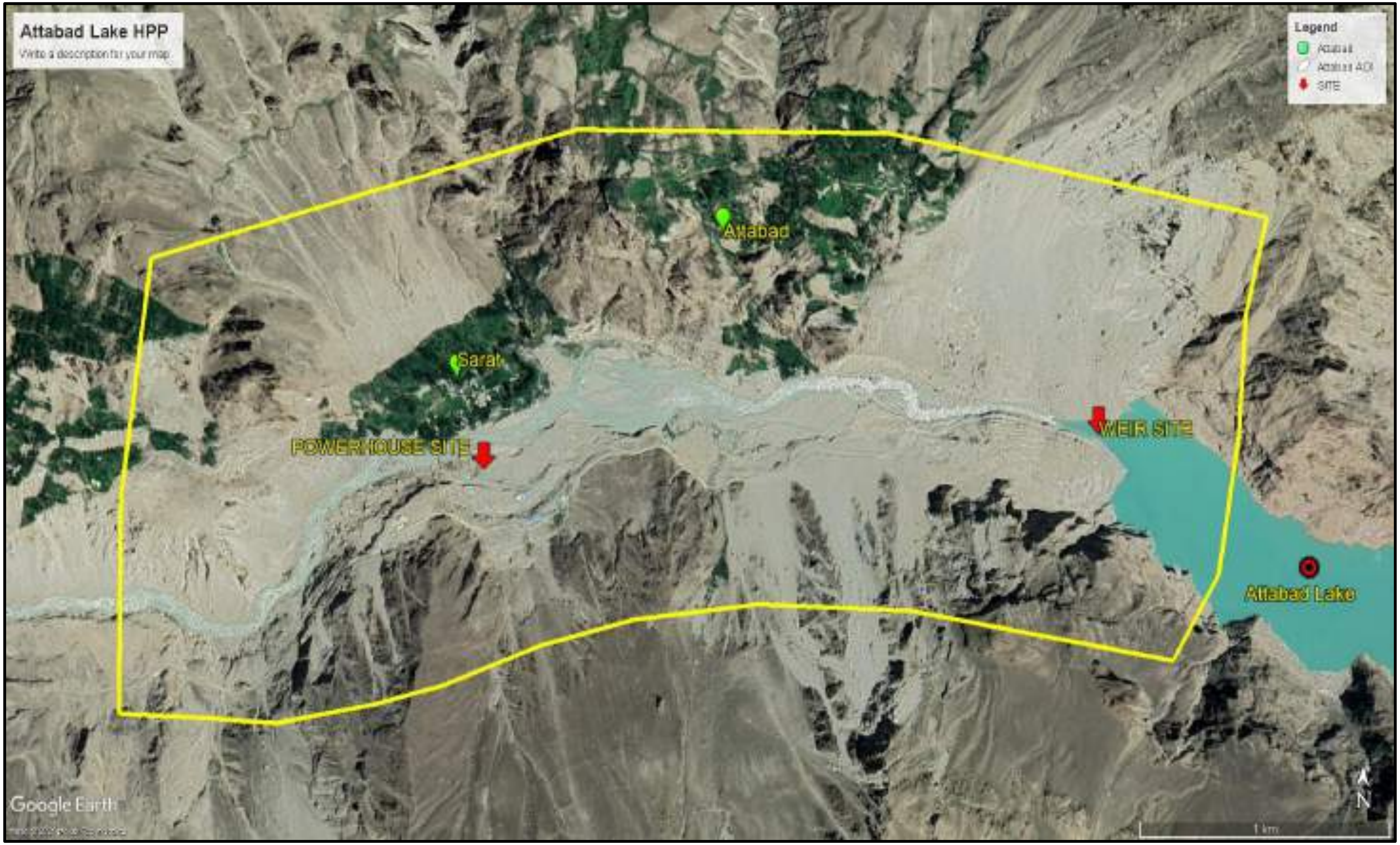


Figure 3-6 Google Earth Model

3.10.6 Satellite Imageries

A Satellite Imagery contains data hidden in each pixel, which when unlocked, can tell a lot about what is looking at. There are many analysis techniques that can be applied to multispectral imagery to extract specific features of interest. These algorithms rely on the same principles of reflectivity and absorption at various wavelengths that allow seeing certain features when visualizing them with different band combinations. The various satellite imageries are: -

- Landsat 8 Satellite Images
- Shuttle Radar Topography Mission (SRTM)
- ASTER instrument

3.10.7 Data Acquisition and Assembly

In the initial stages, it was apparent that there would be a need for a number of different data sources. This process was simplified by making a list of the data that would be required. Thereon, for the pertinent Area of Interest, various necessary High Resolution Satellite Imageries / Digital Elevation Models (DEMs) acquired through United States Geological Survey (USGS) and ESRI Portals. These were processed and analyzed using ArcGIS, AutoCAD Civil 3D and Erdas Imagine etc. The following satellite imageries were acquired and processed for geospatial analysis and processing: -

- Landsat 8 OLI TIRC C1 Level-1
- Landsat Look Images with Geographic Reference
- Landsat Look Natural Color Image
- Landsat Look Quality Image
- Landsat Look Thermal Image
- Level-1 GeoTIFF Data Product
- SRTM / SRTM 1 Arc-Second
- Google High Resolution Imageries

3.10.8 Procedure and Methodology

ArcGIS and ERDAS Imagine, top of the line software for GIS working has been used for analysis and processing of Satellite Images. ArcGIS Explorer is a GIS viewer which can work as a client for ArcGIS Server, ArcIMS, ArcWeb Services and Web Map Service (WMS). ArcGIS Online is a web application allowing sharing and search of geographic information, as well as content published by Esri, ArcGIS users, and other authoritative data providers. For introduction the steps involved are very briefly mentioned as under:

3.10.9 Coordinate Transformation

Coordinate Transformation has been carried out to transform the coordinates of the satellite image from WGS84 to projected Coordinates System of WGS 1984 UTM Zone 43N.

3.10.10 Geo Referencing

The term, Geo Referencing, is commonly used in the GIS field to describe the process of associating a physical map or raster image of a map with spatial locations. It is the process of scaling, rotating, translating and deskewing the image to match a particular size and position.

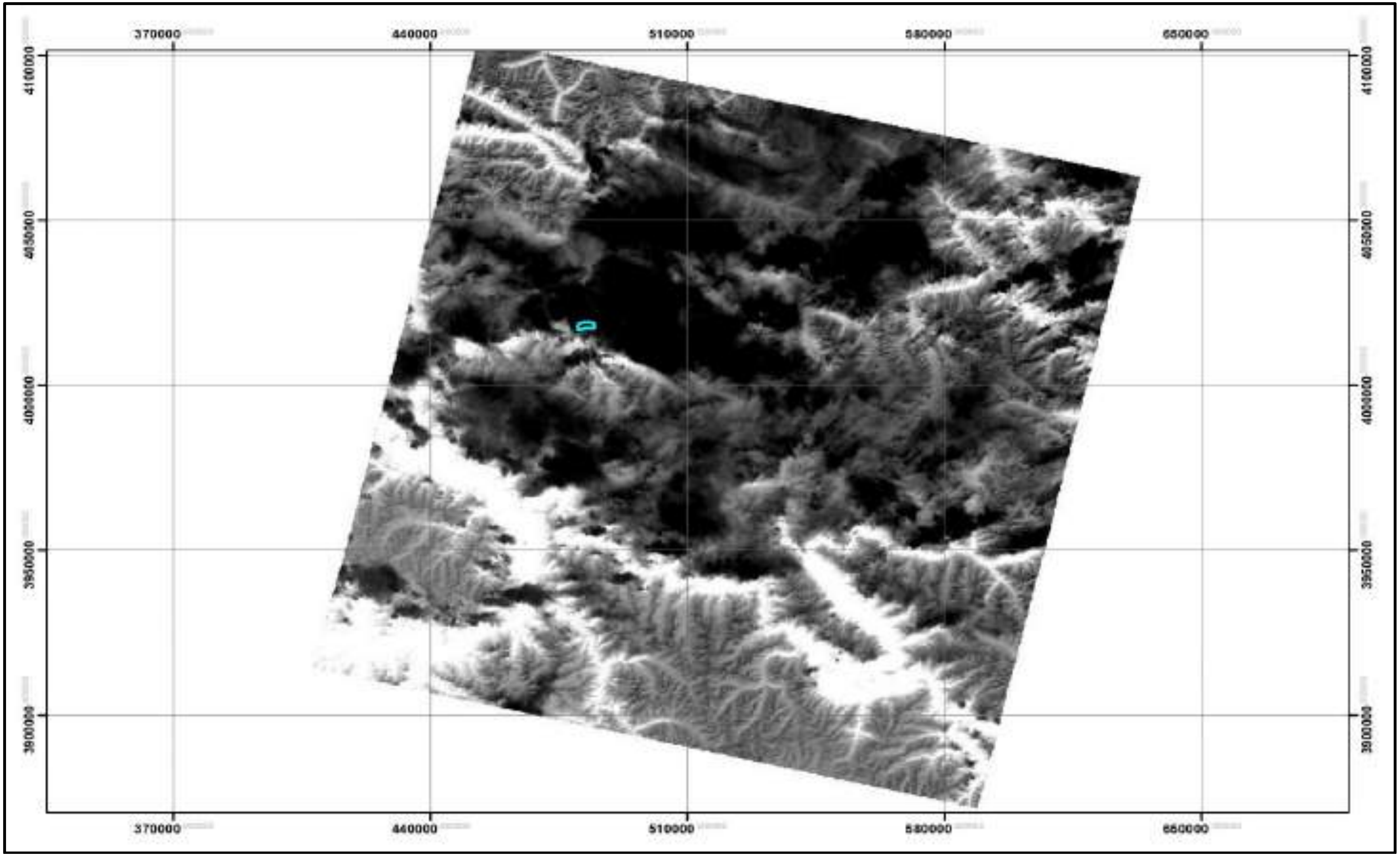


Figure 3-7 Landsat 8 Panchromatic Image

Geo Referencing of the existing features, observed through Google Earth and with physical Site measurement, on the satellite imageries has been carried out. Proper geo-referencing done with the help of SOP Maps and exact coordinate values from the field survey.

3.10.11 Raster Mosaic

An overall Raster Mosaic from Raster Datasets covering the entire Project Area has been created. Mosaic clipping of the Raster conducted to extract the AOI.

3.10.12 Image Corrections

The applicable image corrections applied for image enhancement including the correction for Atmospheric Scattering and distortions.

3.10.13 Band Combination

As defined earlier to visualize different features, e.g. water bodies, vegetation, roads, inhabitation etc. the prescribed combinations of band were created and image classification carried out to identify features on ground.

3.10.14 Image Classification

Image classification refers to the task of extracting information classes from a multiband raster image. The resulting raster from image classification can be used to create thematic maps. Depending on the interaction between the analyst and the computer during classification, there are two types of classification: supervised and unsupervised. As a matter of fact, Object-Based (or Object-Oriented) Image Analysis Classification which is a hybrid form of classification has been used. Various features including roads, rivers and villages etc. have been digitized from panchromatic satellite images and Google Earth Pro and have been superimposed over the base map in respective layers.

3.10.15 Digital Elevation Model (DEM)

Earth observation data comes in form of 2D flat imagery. For realistic appearance, elevations are required to rectify and make those images three-dimensional. The most common digital data of the shape of the earth's surface is cell-based called Digital Elevation Model (DEM). This data is used as input to quantify the characteristics of the land surface.

A DEM is a raster representation of a continuous surface, usually referencing the surface of the earth. The accuracy of this data is determined primarily by the resolution (the distance between sample points). Other factors affecting accuracy are data type (integer or floating point) and the actual sampling of the surface when creating the original DEM. The DEM of AOI is presented in **Figure 3.12**.

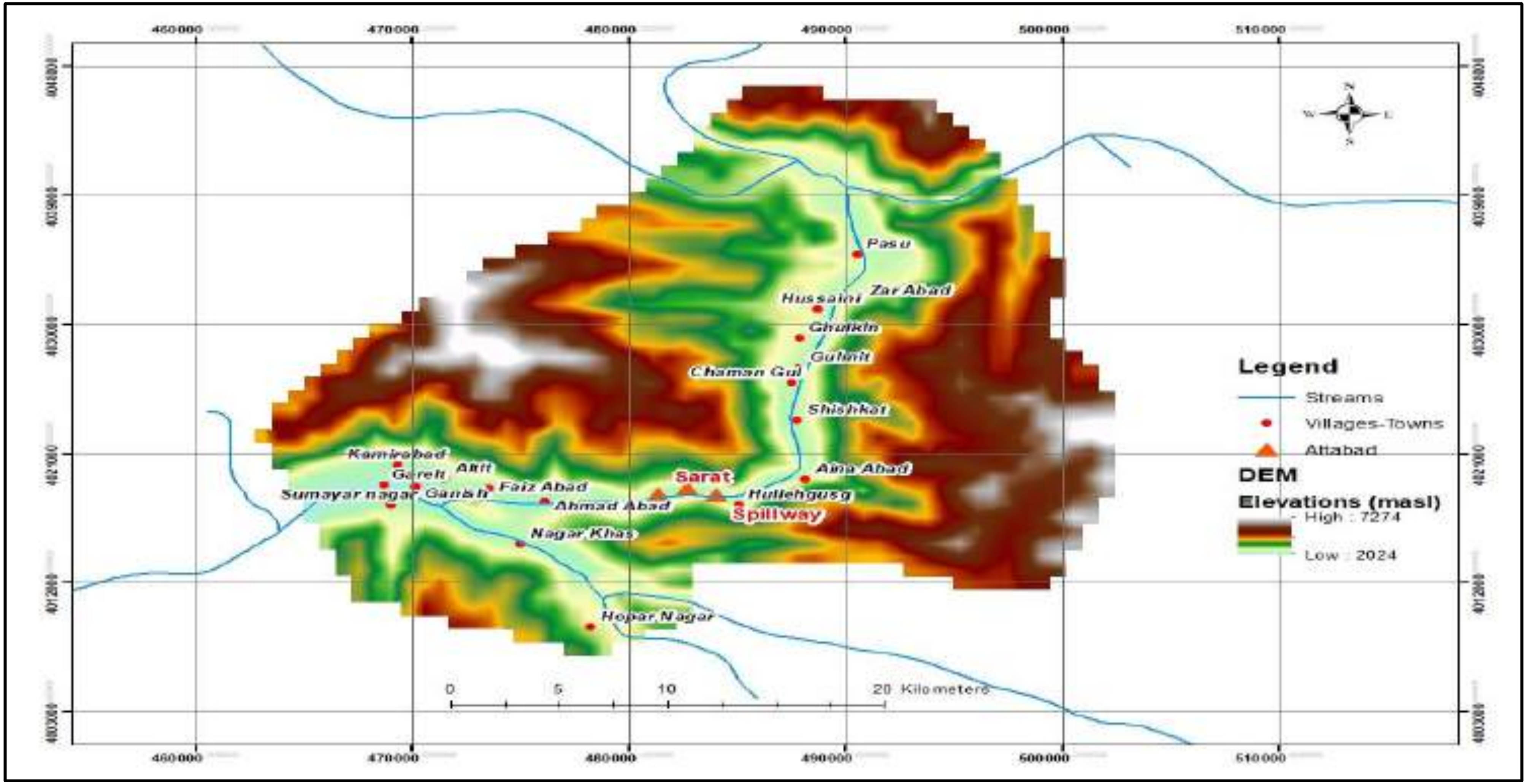


Figure 3-8 Digital Elevation Model

3.11 HYDROGRAPHIC SURVEY

Hydrographic Survey refers to the under-water survey involving water depth measurements. In order to determine the capacity of the Attabad Lake, the hydrographic survey of the Lake has been carried out by International Sedimentation Research Institute, Pakistan (ISRIP), WAPDA during September and October, 2020.

3.11.1 Scope of Work

III. The Hydrographic Survey of Attabad Lake includes the following major activities:

IV. Cross-sections of the lake along range lines from left to right bank, at 250 m interval for first 3 km & 500 m interval for rest of the lake.

V. Computation of existing storage capacity of the lake.

VI. Development of area-capacity curve.

VII. Development of contour maps of the Lake.

VIII. Discharge Measurement at Ganish Bridge.

3.12 METHODOLOGY APPLIED TO THE HYDROGRAPHIC SURVEY

3.12.1 Instrument Used

For surveying the submerged part of the lake, an inflatable Rubber Boat and Echo Sounding equipment including a recorder, a transmitting & receiving transducer and power supply has been used. For surveying the exposed bed of the lake, Total Station and Global Positioning System (GPS) have been utilized.

3.12.2 Horizontal and Vertical Control of Cross Sections

To carry out the hydrographic survey of the lake, the horizontal and vertical control points near water edge at left bank has been established by ISRIP survey team. All the cross-sections are connected to the geodetic network used in the topographic survey.

3.12.3 Hydrographic Survey

The hydrographic survey consists of depth sounding by manual or electronic sonar equipment and position determination relative to measured depth. The reservoir depth along range lines has been determined by the sonic sounder. The accuracy of sonic sounder used in the survey is 0.5% ± 1 inch of indicated depth.

First of all the boat positioned at left bank of the lake, such that it is in line of already established range line, then sounding instrument turned on and mark has been placed on the sonic chart in order to show the starting position and depth with reference to water edge. Thereafter, the depths plotted on sonic chart with reference to left bank distance and simultaneously observed and noted the corresponding coordinate from the GPS. GPS has been used to keep the position of the boat straight as it move continuously across the range line. This process has continued until the boat touched the opposite bank and finally marked the right bank water edge.

Figure 3-9 Observation of under-water Cross-Sections

Figure 3-10 Equipment showing continuous Trace of Bed Profile

3.12.4 Capacity Computations by TIN Method using ArcGIS

For the capacity computation of Attabad Lake, Triangular Irregular Network (TIN) method using ArcGIS have been utilized, which provides most accurate and reliable results.

Triangular Irregular Network (TIN) is preferred to represent the reservoir bed surface using the available data in more accurate manner. ArcGIS has the ability to do volumetric calculations from these surface models. TIN model is a surface representation derived from points with an X, Y co-ordinate and a Z value or surface value. TINs are a form of vector-based digital geographic data and are constructed by triangulating a set of vertices (points). The vertices are connected with a series of edges to form a network of triangles. There are different methods of interpolation to form these triangles, such as Delaunay triangulation or distance ordering. ArcGIS supports the Delaunay triangulation method. A TIN expects units to be in feet or meters, not decimal degrees. Delaunay triangulations are not valid when constructed using angular coordinates from geographic coordinate systems.

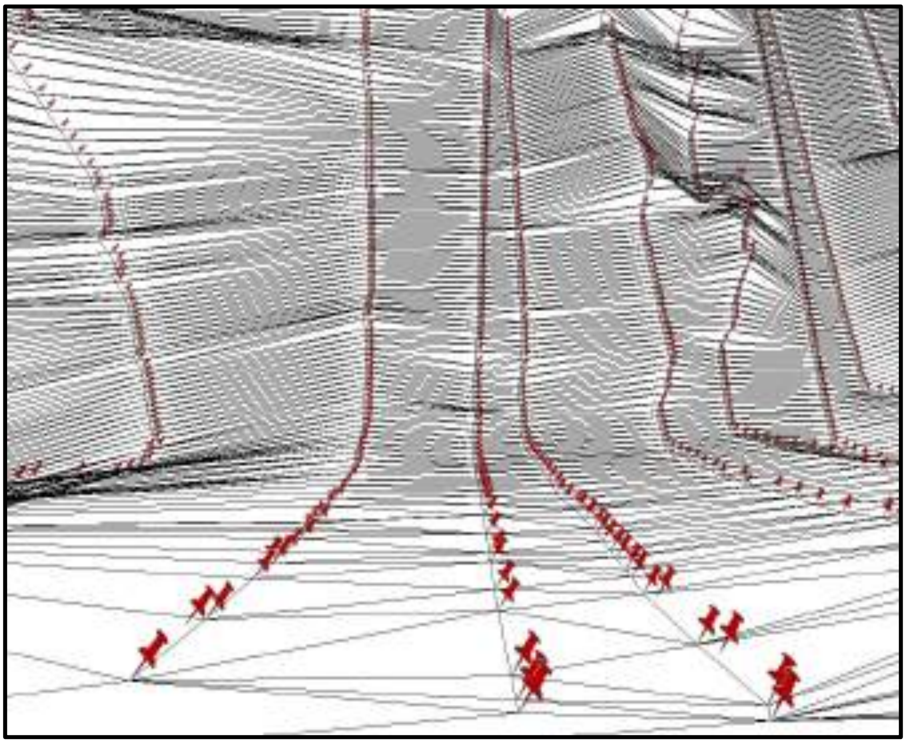


Figure 3-11 Cross-sectional Points and Triangles formed from Hydrographic Data

3.12.4.1 Displaying TIN Surfaces

Triangulated Irregular Networks (TINs) represent continuous surfaces such as terrain elevation or temperature gradient. The surface is represented as a set of facets formed by connecting data points at nodes to create adjacent triangles. Typically, a TIN can be displayed using color-shaded relief to depict elevation. Shaded relief simulates the sun's illumination of the earth's surface. By adding color to this, the ridges, valleys, hillsides and their respective heights can easily be seen. The Elevation map is presented in **Figure-3.16**.

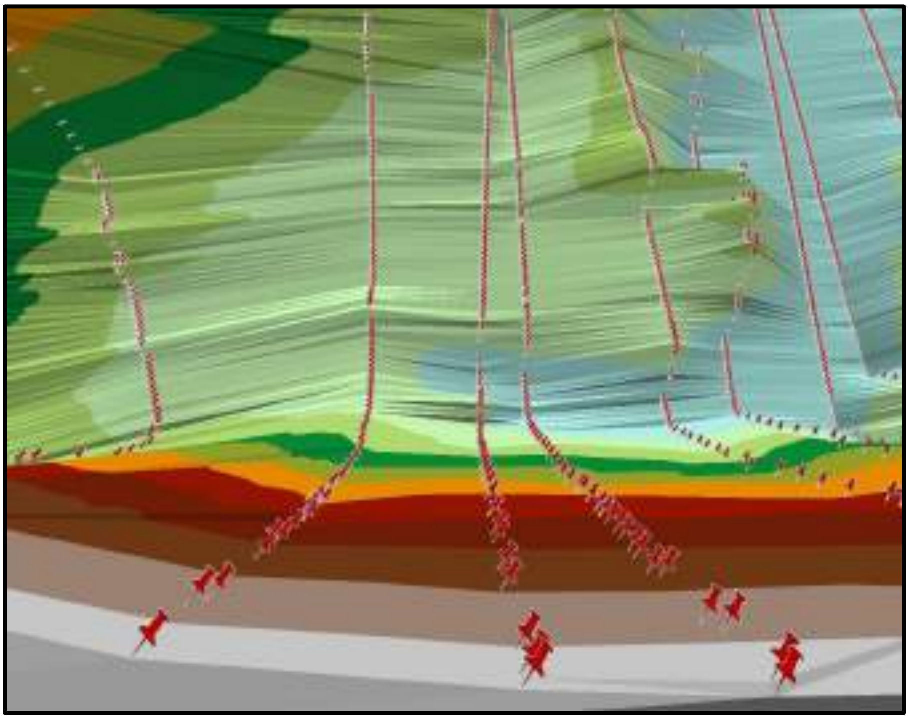
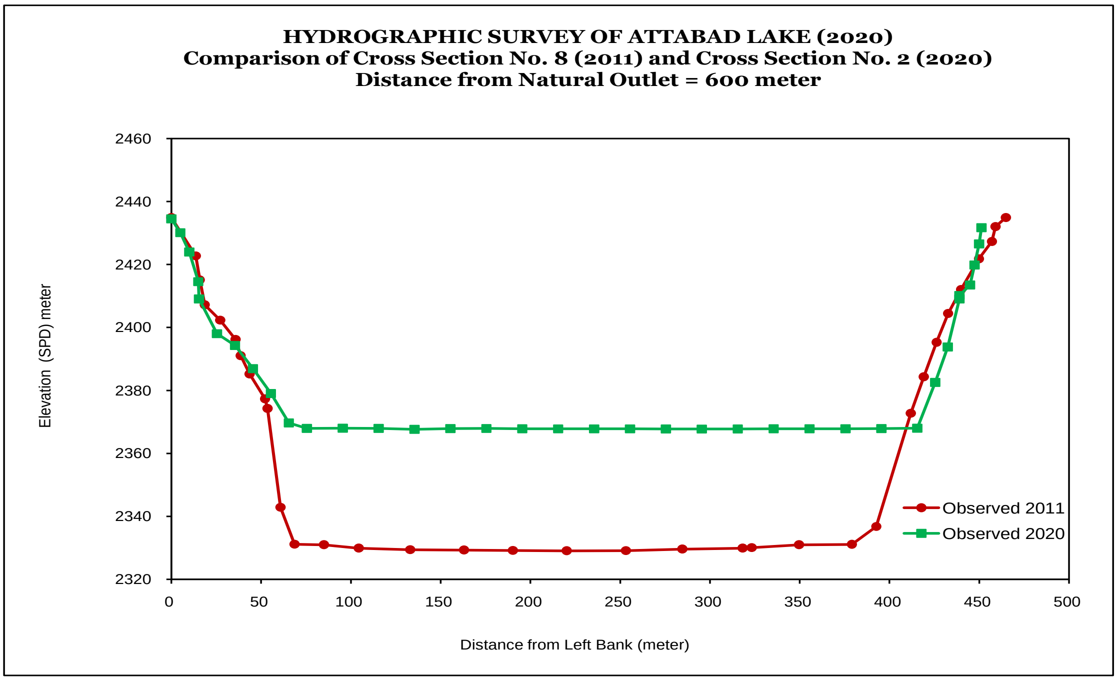


Figure 3-12 Elevation Map

3.13 RESULTS OF HYDROGRAPHIC SURVEY

The storage capacity at Maximum Conservation Level (El. 2409 masl) comes to be 99,249 Acre Feet (122.42 Mm^3). The present water surface area of lake at El. 2409 masl is 1088.7 Acres (4.41 km^2). Comparison of current data with previous survey report of year 2011 showed that on an average there is 30 to 40 m deposition in 9 years.



3.13.1 Cross Sections & Surveyed Plan of Lake

The X-Sections along 40 range lines covering a total lake length of 12,450 m have been taken. The spacing of the range lines varies between 75 m to 500 m. The width of cross-sections ranges from 245 m to 1289 m upto El. 2430 masl. The surveyed data of the observed cross-sections is presented in Volume-7 Appendix-I (A). The drawings of each cross-section are presented in **Volume-2 (Drawings)** in 40 sheets (A3 format). To give an idea about the geometry of the lake area, the contour plan and elevation bands have also been developed and presented in **Volume-2 (Drawings)**.

3.13.2 Comparison of Selected Cross Sections

For comparison of depth, the 04 X-Sections at a distance of 600 m, 1,400 m, 9,720 m and 11,920 m from natural outlet (spillway) selected and superimposed with previous observed survey data of 2011. The comparison of these cross-sections is presented in **Volume-2 (Drawings)** in 04 sheets.

3.13.3 Longitudinal Bed Profile

Longitudinal bed profile have been observed, using sonic sounder. At the time of longitudinal profile observation, water surface level has also been observed to facilitate the computation of bed levels from echo sounding data. Digitized sonic profile data and mean bed levels of the cross-sections were used to prepare longitudinal profile, presented in **Volume-7 Appendix-I (C)**.

3.13.4 Thalweg Profile

The minimum bed elevation at each cross section along the length of the lake has been used to plot the Thalweg profile of lake and is presented in **Volume-7 Appendix-I (D)**.

3.13.5 Capacity and Surface Area

The capacities and surface areas have been computed from ArcGIS using Trianguled Irregular Network (TIN) Method. The capacity and surface area of the lake at different elevations has been calculated. The area-capacity data is presented in **Volume-7 Appendix-I (B)**.

3.13.6 Discharge Measurement at Ganish Bridge

The discharge observations have been taken at Ganish Bridge in the month of September and October 2020. The cross-sectional data and discharge sheets are presented in **Volume-7 Appendix-I (E)**.

3.14 QUALITY CONTROL

The topographic and hydrographic survey has been conducted by qualified and experienced team of Survey Division, Peshawar, HPO WAPDA and ISRIP respectively in accordance with the scope of work. Before the start of survey activities, the survey equipment has been calibrated to avoid any error. Apart from this, certain check measurements has also taken during the survey campaign for assuring the quality work.

4 HYDROLOGY AND SEDIMENTATION

4.1 GENERAL

Northern Areas of Pakistan is unique in its geographical configuration and layout which houses confluence of three major mountain ranges i.e. Hindukush, Karakorum and Himalayans and 5 out of 14 peaks above 8000 m.a.s.l. The Hindukush-Karakoram-Himalaya (HKKH) Region, often called “Water Towers of Asia,” provides natural reserves of fresh water in the form of snow and glaciers that sustain water availability in mountainous or Himalayan Areas, as well as in adjacent areas.

These mountain ranges are characterized for their slope instability due to the inherent topographic, geological, geomorphological, seismological, hydrological and anthropogenic reasons. Consequently, hazards like earthquakes, landslides, mud slides, debris slides, rock avalanches, erosions, glaciated drifts and glaciated lake outburst floods (GLOF) are common phenomena. Water channels like rivers, nullahs and streams, lines of communication like highways, roads and tracks and built up areas like towns, villages, hutments and isolated houses, agriculture farms and orchard remains exposed to these hazards with variable level of vulnerability. The interaction between hazard and vulnerability leads to disaster in the form of blocking water channels like rivers, disrupting line of communications and washing away farms and orchards causing physical, social, psychological, political, economic and environmental impacts on those communities and people along with their infrastructure who suffer from these events.

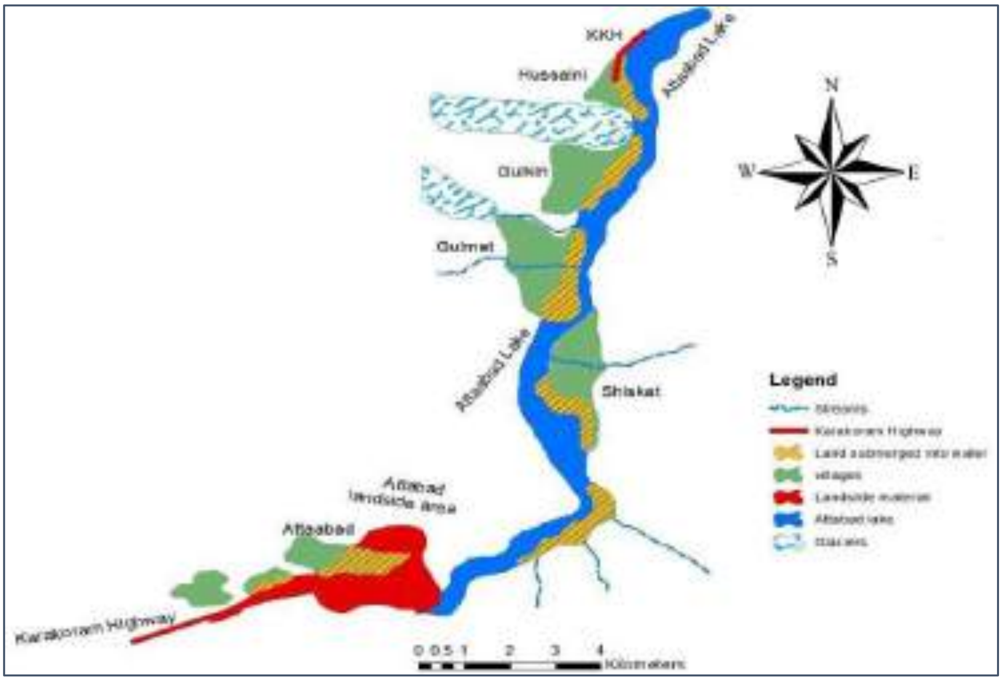


Figure 4-1 Attabad Landslide Area & Extent of Lake

January 4, 2010 is a day which witnessed a landslide hazard meeting with the vulnerabilities of Attabad and Sarat Villages, 109 km north-east of Gilgit and 20 km upstream from Karimabad in

Hunza Valley, their farms and orchards, the River and Karakorum Highways (KKH) resulting into a historical event of creation of huge lake subsequently engulfing most parts of the villages like Ainabad, Shishkat, Gulmit, Gulkin and Hussaini into its fold.

4.2 HUNZA VALLEY

Karimabad, the capital of the Hunza Valley offers a panoramic view of high peaks like Rakaposhi. Nagar is the large kingdom across the river from Hunza. Passu is a village of farmers and mountain guides about 15 km away from Gulmit. This is the setting-off point for climbing expeditions up the Batura, Passu, Kurk and Lupgar groups of peaks, and for trekking trips up the Shimshal Valley and Batura Glacier.

4.2.1 Gojal Valley

Gojal with an area of about 8,500 km² is the largest tehsil of the Northern Areas of Pakistan. Lying in Upper Hunza, it shares border with China in the northeast and with Afghanistan in the northwest. Gulmit is the largest settlement of Gojal, commonly referred to as the capital of the tehsil. The main villages are Gulmit, Borit, Ghulkin, Hussaini and Passu which are well connected with other parts of the Region through KKH. Gojal has a population of about 20,000 with different ethnic groups of Wakhi and Burushaski. The dwellers of the area have mostly moved from Pamir areas of China, Afghanistan and Tajikistan and central part of Hunza.

There are parallel glaciers extend down to the main river valley from the upper catchments of mountain range between Gulmit and Passu. The Region is home to lofty ice capped peaks, roaring rivers, lush green pastures and long glaciers.

4.3 HUNZA RIVER

Hunza River is one of the main tributary basins of the Indus Basin River that contributes about 12% of the upper Indus flow, upstream of Tarbela Dam. About 80% of the total inflow into this dam originates from less than 20% of its contributing area, essentially from areas of heavy snowfall and glacierized basins above 3500 m a s l. About 50% of the basin area has elevations higher than 4700 m a s l.

The tributaries joining the Hunza River are Chapursan, Khunjerab, Ghujerab, Shimshal and Hispar Rivers.

Figure 4-2 Hunza River

4.4 HUNZA RIVER CATCHMENT

The Hunza River Basin lies in the high Karakoram Range within longitudinal range from 74º02' to73º03' and latitudinal range 35º54' to 37º05' in the Northern Area of Pakistan. It is bordered in the west by Gilgit River Basin, in the north by Afghanistan and China, and in the south by Shigar and Indus River Basins. The small portion in the north east of this basin drains in the Chinese territory. Most of the terrain of the basin falls in the elevation range of about 1,500m.a.s.l to more than 7,500 m a s l. The basin occupies an area of 16,389.4sq.km. The glacier cover of the basin is about 4,677.3 sq.km. The basin comprises of major valleys like Naltar, Nagar, Shimshal and Chapursan and hanging glaciers in the high Karakoram Range. A part of KKH passes across this basin linking Pakistan with China through Khunjerab Pass.

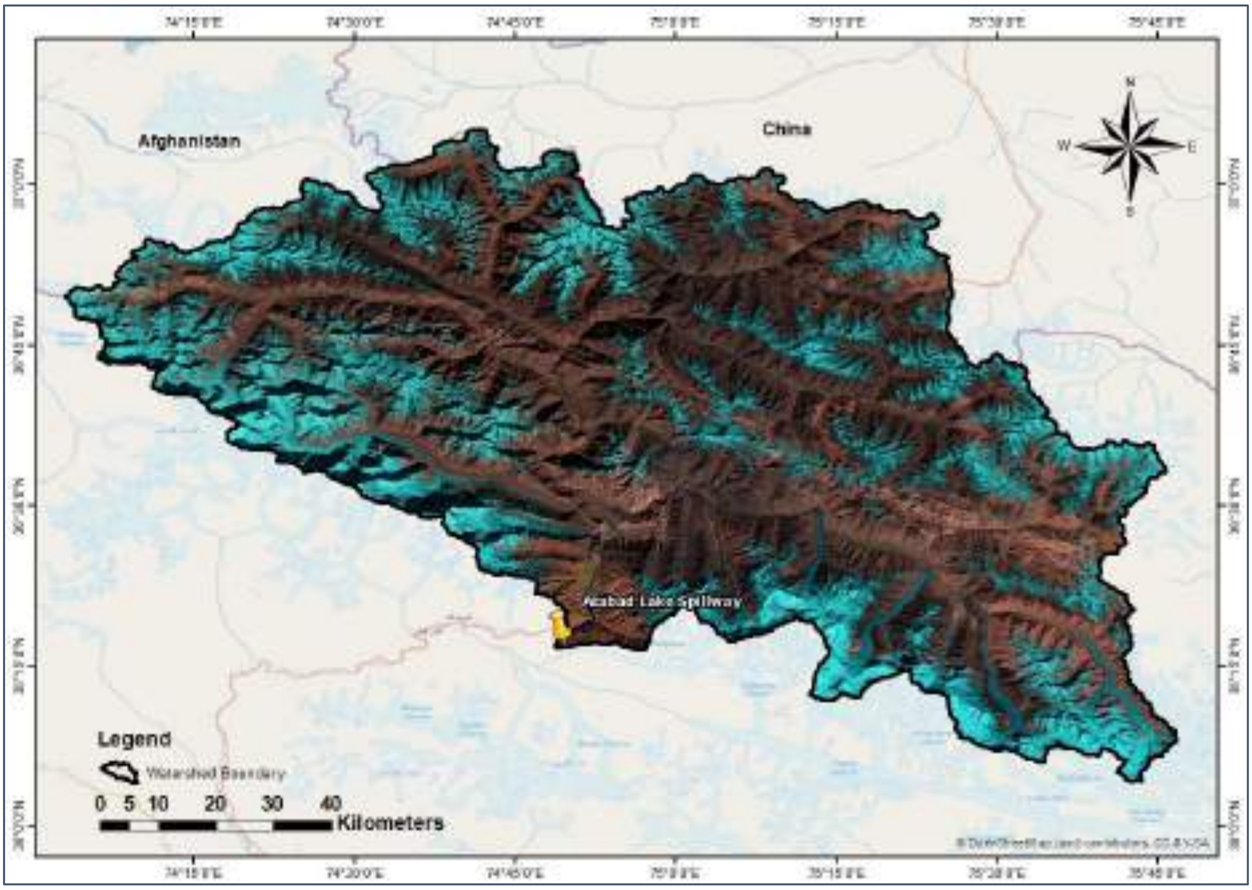


Figure 4-3 Attabad Lake Catchment Area with Landsat Imagery

4.5 CLIMATE

The Karakoram-Himalayan Region is glaciologically complex with high altitude source are as (above 4,500 m a s l) having perma frost and annual precipitation in excess of 2,000 mm while some of the large glaciers nouts extending down to semi-arid valley floors (2,700 m a s l) receive annual precipitation of less than 200 mm. The Karakoram area is influenced mainly by abroad scale weather system originating primarily from the Mediterranean or from the area of the Caspian Sea during the winter and spring seasons.

The Gilgit Meteorological Station is the nearest station to Hunza Valley that has a sound historical record covering more than five decades. Monthly temperature variations (maximum, minimum and mean) at Gilgit indicate parabolic trend with peak in the month of July. Summer prevails in months from June to August. In July and August, mean maximum and minimum temperatures are normally above 35˚C and 15˚C respectively. The winter is cold and chilly that starts from November and remain still end of March. The lowest temperatures are in the month of January when mean maximum and minimum temperatures reaches below10˚C and (-) 2˚C respectively.

The mean monthly rainfall data of Gilgit Climatological Station is available for the period 1951 to 2014. The available data has been processed to achieve annual, monthly and % monthly distribution of rainfall at Gilgit. The results so achieved are presented in Table 4 1. The mean annual precipitation for the period 1951 to 2004 is 186 mm. March and May are the months of maximum rainfall while the lowest rainfall occurs in the month of November. The graphical representation of average monthly and Min, Max and Average precipitation is given in **Figure**

4-4. The maximum daily precipitation recorded during the historic period is 48.3 mm in October 1987. The Project Area receives precipitation in the form of rain in summer and snow in winter.

Table 4-1 Annual & Monthly Distribution of Precipitation (mm) At Gilgit (1951 to 2014)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean
1951	3.7	-	-	-	21.4	-	27.8	-	-	-	-	-	17.63
1952	3.7	6.1	10.2	18.1	20.2	26.2	26.3	27.6	22.8	-	-	-	17.91
1953	-	-	-	-	-	-	31.3	-	19.6	13.2	8.3	4.9	15.46
1954	-	-	-	-	20.7	23.8	26.4	25.5	23.2	15.8	9.4	4.4	18.65
1955	3.2	8.3	12.7	15.1	19.6	23.7	25.9	28.3	23.2	16.3	10.8	7	16.18
1956	3.6	7.4	12.5	17.6	23.6	24.2	29.5	25.1	24.4	17.0	10.7	5.3	16.74
1957	4.1	5.6	11.8	14.3	18.2	22.6	27.9	25.8	21.8	15.6	9.7	5.8	15.27
1958	6.1	7.9	13.3	18.4	18.8	23.2	27.1	24.8	24.4	17.9	10.6	7.4	16.66
1959	4.6	5.9	12.6	18.9	18.6	24.5	26.2	27.6	26.5	19.4	10.4	5.1	16.69
1960	3.3	9.9	11.1	14.8	19.4	23.2	27.9	29.2	23.8	17.7	10.5	5.3	16.34
1961	4.7	5.9	13.4	16.8	21.9	25.7	29.6	27.7	24.3	16.6	8.0	1.8	16.37
1962	2.7	6.9	12.6	16.4	19.9	24.1	25.2	26.4	20.4	15.4	8.9	4.2	15.26
1963	2.2	8.2	11	16.1	20.8	26.7	27.9	27.7	22.4	17.0	9.8	4.7	16.21
1964	2.3	5.7	12.7	15.6	18.8	22.6	26.3	27.9	23.1	17.2	8.8	4.1	15.43
1965	5.2	6.1	11.8	15	19.8	23.6	27.3	24.3	21.9	16.8	10.9	2.8	15.46
1966	3.1	8.7	10.8	15.2	18.9	25.5	26.2	26.4	20.8	14.7	7.6	3.2	15.09
1967	2	6.5	10.9	16.2	17.5	24.5	28.8	28.2	22.8	14.2	8.6	5.1	15.44
1968	3.5	6.2	12.9	16.3	18.7	25.5	29.2	30.5	22.7	14.9	7.9	4.5	16.07
1969	2.4	6.3	13.9	15.6	20.5	24.2	28.2	27.6	22.2	16.4	9.9	3.9	15.93
1970	3.9	6.5	10.9	17.5	19.8	24.6	26.5	27.4	23.2	16.7	8.4	3.6	15.75
1971	2.1	5.4	12.6	18.1	21.2	28.6	27.6	27.1	21.3	16.1	9.4	4.3	16.15
1972	3.8	4.3	12.0	15.7	18.4	23.9	25.4	24.9	21.1	14.6	9.9	4.9	14.91
1973	2.1	6.4	10.1	16.6	20.5	27.2	28.4	27.9	23.8	15.4	9.2	3.6	15.93
1974	2.3	5.1	13.1	18.3	19.8	23.3	26.3	26.1	20.9	15.5	8.6	3.2	15.21
1975	2.3	5.1	10.1	16.4	19.2	24.3	25.9	26.3	22.4	16.8	7.5	3.9	15.02
1976	5.5	5.5	10.7	17.2	21.5	24.9	30.1	25.1	21.9	15.5	9.5	3.7	15.93
1977	3.1	5.9	13.5	18.2	15.5	27.7	30.7	27.7	22.9	17.5	11.1	5.0	16.57
1978	2.7	6.3	10.3	17.5	21.8	26.9	27.3	27.5	22.3	17.1	8.7	5.1	16.13
1979	3.9	7.2	10.5	17.3	17.1	24.1	28.2	24.9	21.1	16.9	10.4	5.4	15.58
1980	3.7	6.3	11.3	18.6	20.9	25.1	27.3	26.1	21.4	16.6	9.6	5.7	16.05
1981	3.9	7.4	11.9	16	21.9	23.1	27.5	25.7	20.5	15.4	8.9	6.4	15.72
1982	3.8	4.9	11.0	17.7	21.1	23.6	27	28.5	21.1	16	9.0	3.9	15.63
1983	2.9	4.7	9.3	16.9	21.7	23.3	26.7	27.5	24.3	16.2	9.7	4.6	15.65
1984	2.7	4.8	13.1	16.5	19.5	26.3	27.3	29.4	20.3	15.5	8.7	3.7	15.65
1985	3.5	6.6	13.5	17.9	19.8	24.0	29.2	26.9	22.3	15.9	9.6	5.1	16.19
1986	2.9	6.5	10.1	15.7	19.4	23.7	27.3	24.7	21.7	16.1	9.7	4.1	15.16
1987	2.5	7.1	12.5	16.3	18.2	22.5	25.1	26.1	23.1	14.3	9.0	4.8	15.13
1988	5.5	6.8	10.9	17.3	22	24.0	28.4	25.6	23.0	15.3	10	5.5	16.19
1989	2.7	4.8	11.8	15	17.5	23.2	24.2	22.9	21.6	15.7	9.2	6.3	14.58
1990	5.2	6.3	10.7	15.4	23.1	25.3	28.5	26.9	23.2	15.2	9.5	5.1	16.20
1991	5.1	6.9	11.7	15.7	18.3	23.8	25.3	25.4	22.2	14.7	9.1	7.2	15.45
1992	4.4	6.3	9.7	16.1	20	24.1	26.7	26.1	21.1	15.3	11.5	7.5	15.73
1993	3.4	8.1	10.4	17.9	21.2	23.6	25.1	25.3	22.9	15.5	9.5	5.8	15.73

1994	4.3	5.9	13.1	14.8	21.1	24.2	28.7	28.9	21.5	15.5	10.1	4.5	16.05
1995	1.1	5.9	11.7	16	20.8	24.1	27.3	27.1	22.5	16.1	9.5	3.7	15.48
1996	2.7	7.5	12	16.3	19	22.8	24.7	27.3	23.9	15.1	8.7	3.1	15.26
1997	3.9	6.1	11.1	17.8	20	24.9	28.9	25.5	22.9	16.3	9.7	5.7	16.07
1998	3.7	7.4	11.9	17.1	20.9	23.1	28.1	26.4	22.7	18.1	11.3	5.2	16.33
1999	5.1	7.7	12.5	16.6	21.4	24.2	27.5	25.5	23.5	15.5	9.4	3.9	16.07
2000	3.3	5.5	11	17.1	23.4	24.9	25.7	24.7	21.1	16.2	9.9	5.8	15.72
2001	3.5	8.2	12.6	18.1	23.8	25.5	27.9	25.1	20.2	16.1	8.7	5.9	16.30
2002	3.3	7.2	13.2	16.5	20.9	24	25.3	26.0	19.5	17.3	11.0	5.9	15.84
2003	5.1	6.9	11.5	17.1	17.9	24.5	27.7	26.3	22	15.3	9.5	5.2	15.75
2004	5.7	8.3	15.1	17.3	20.7	24	25.5	25.1	22.1	15.4	10.9	6.7	16.40
2005	11.2	14.1	12.4	58.9	32.6	2.7	9.3	2.1	2.1	0	4.0	0.4	12.48
2006	15.4	6	2.1	23	1.5	11.1	8.1	39	11.9	5.7	4.0	5.8	11.13
2007	0	1.3	11.9	15.2	12	18.8	12.5	6.4	6.3	0	0	0	7.03
2008	2.9	0	0	8.3	75.8	15.6	3.5	10.9	8.3	12.9	0.6	31.5	14.19
2009	33	10.1	7	43.6	2	14.6	2	1	16	1	0	9	11.61
2010	0	14	22	24.6	60.7	23.2	52.9	71.8	10.4	1	0	0	23.38
2011	2.7	60.3	12.7	6.2	18.8	20.8	14.8	13.8	37.2	4.9	0.2	2.3	16.23
2012	0	9	36.9	11.3	18.6	2.6	0.5	8.2	25.1	0.2	1.2	5.1	9.89
2013	3.1	3.6	3.2	0.9	52.2	15.6	0.3	61.1	13.8	0	11.7	0	13.79
2014	0.5	0.4	7.7	0.5	11.1	4	21.2	22.4	2.1	35.4	3.8	0	9.09
Avg	4.11	7.41	11.76	17.10	21.46	22.58	24.99	26.08	20.87	14.42	8.40	4.96	15.45

As regarding the temperature data, it is also available for the period of 1951 to 2014. The same has been processed to compute, mean, maximum and minimum temperature. The results are presented in the Table 4-2.

Table 4-2 Average Max & Min Monthly Temperature at Gilgit

Month	Mean Min Temp (^oC)	Mean Max Temp (^oC)
Jan	2.4	9.4
Feb	0.7	12.6
Mar	5.7	18.2
Apr	9.5	24.1
May	12.1	28.6
Jun	15.1	34
Jul	18.4	36.1
Aug	17.8	35.3
Sep	12.7	31.7
Oct	6.8	25.5
Nov	0.9	18.2
Dec	-1.9	11.5
Annual Mean	7.9	23.8

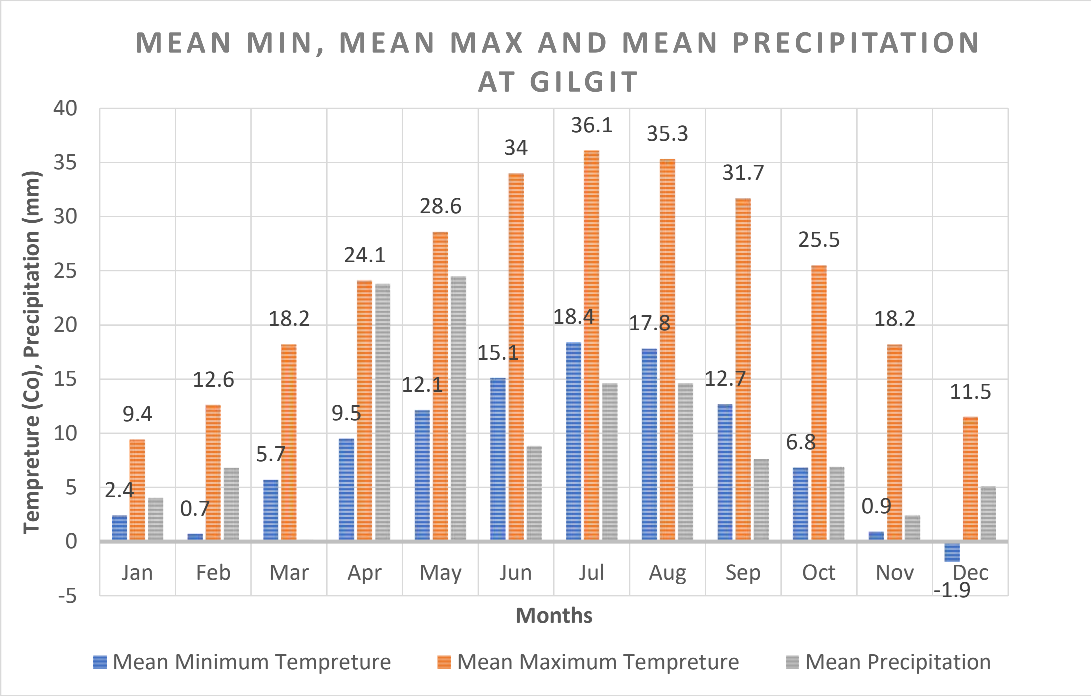


Figure 4-4 Mean Max, Mean Min and Mean Precipitation at Gilgit

4.6 ISOHYETAL MAP OF ATTABAD LAKE CATCHMENT

Although no data has been available to depict the precipitation pattern of the Hunza Basin, therefore, gridded precipitation data is used for the preparation of the isohyetal map to have a picture of precipitation distribution in the basin. Climate Hazards Group Infra-Red Precipitation with Station (CHIRPS) data for the last 20 years (2000 - 2019) is used for this purpose. CHIRPS was formed in collaboration of USGS Earth Resources Observation and Science (EROS) Center for reliable and up-to-date data sets.

The isohyetal map shows the mean annual rainfall of the basin for the last 20 years (2000 – 2019). Mean Annual Precipitation values vary from 88 to 485 mm. It is assessed that. precipitation is maximum near the Khunjerab Area and lower in the entire middle portion of the basin being the minimum near Misgar Village. Volume

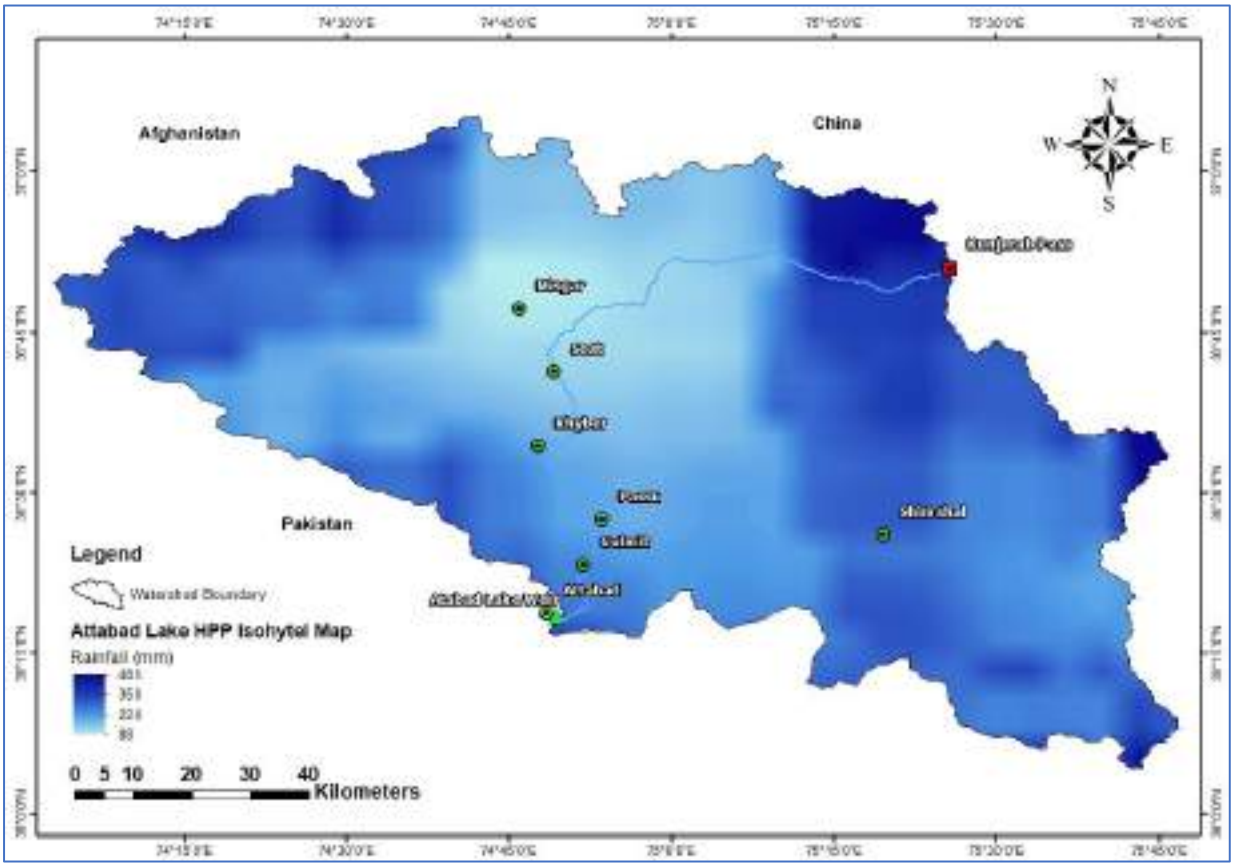


Figure 4-5 Isohyetal Map of Hunza Catchment

4.7 HYDROLOGY

The Karakoram and Himalayan mountains form the main source of snow and ice melt runoff to the Indus River System. The precipitation enhancing and shadowing effects of the main mountain ranges provide dramatic contrasts that greatly complicate the hydrological picture. The main tributaries of Hunza River are; Chapursan, Kilik, Bola, Das joining the Hunza River from the west and Khunjerab along with Ghujerab, Shimshal and Hispar Rivers joining river from the east of the valley. The river flows of Hunza are usually maximum in the month of July when snow and glacier melt is at its peak while these are minimum in the month of March when snow and ice melting is in significant.

4.7.1 Hydrologic Measurement Station

The hydrological data has been collected from Danyor station from the Surface Water Hydrology Project (SWHP), WAPDA located on Hunza River at Danyor Bridge.

Table 4-3 hydrologic Measurement Station at Hunza River

No	Name	River	Basin	Sub-basin	Latitude	Longitude	Elevation (m.a.s.l)	Catchment Area (km^2)
1	Danyor Br.	Hunza	Indus	Hunza	35°55'40''	74 °22'35"	1,494	13,157

4.8 FLOW MEASUREMENT

There is no hydrological gauging station on Hunza River except one at Danyor Bridge being operated by SWHP-WAPDA. This station is located at about 107 km downstream of Attabad Land Slide Dam. The catchment area of Hunza River upto Danyor gauging station is 13,157 km^2, whereas it is14,083 km^2 upto its confluence with Gilgit River. Hunza River catchment area is 8,901 km^2 upto Attabad Landslide Dam. Therefore, river flows are transposed and estimated from documented discharge data from hydrological station at Danyor. Daily discharge data from 1966 to 2015 is available and processed for the calculations. Data for year 2016 was incomplete, therefore, it was not used in the calculations.

Mean annual flows are calculated and drawn in the figure below for the period 1966-2015. Average value for mean annual flow has been calculated as 208.36 m^3/s. Year 1973 witnessed the highest average flow of 310 m^3/s whereas, year 1997 witnessed the lowest average flows of 127 m^3/s.

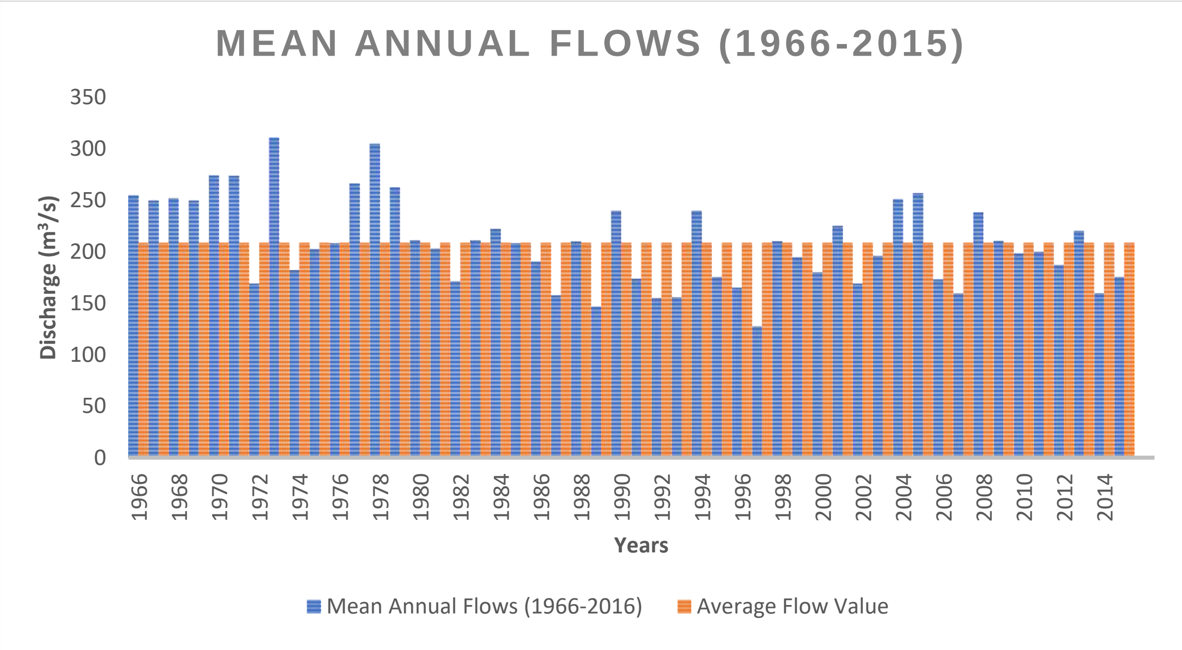


Figure 4-6 Mean Annual Flows

Mean monthly flows are estimated and plotted in the graph below. Flows are generally maximum in July and August reaching 700 m^3/s. Whereas, flows are low from December to April each year when snow falls in the catchment. The graph shows that design discharge of 60 m^3/s is available for about half year (almost 6 months). Graph shows that flows are exceeding the design discharge from June to October which shows the potential of hydropower generation.

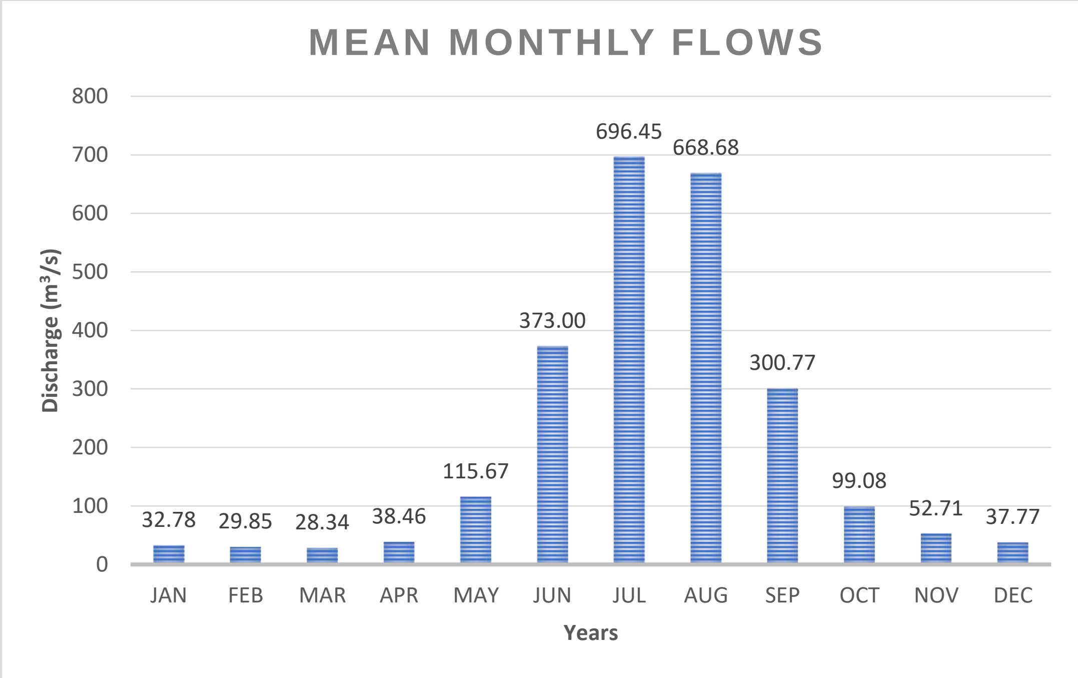


Figure 4-7 Mean Monthly Flows

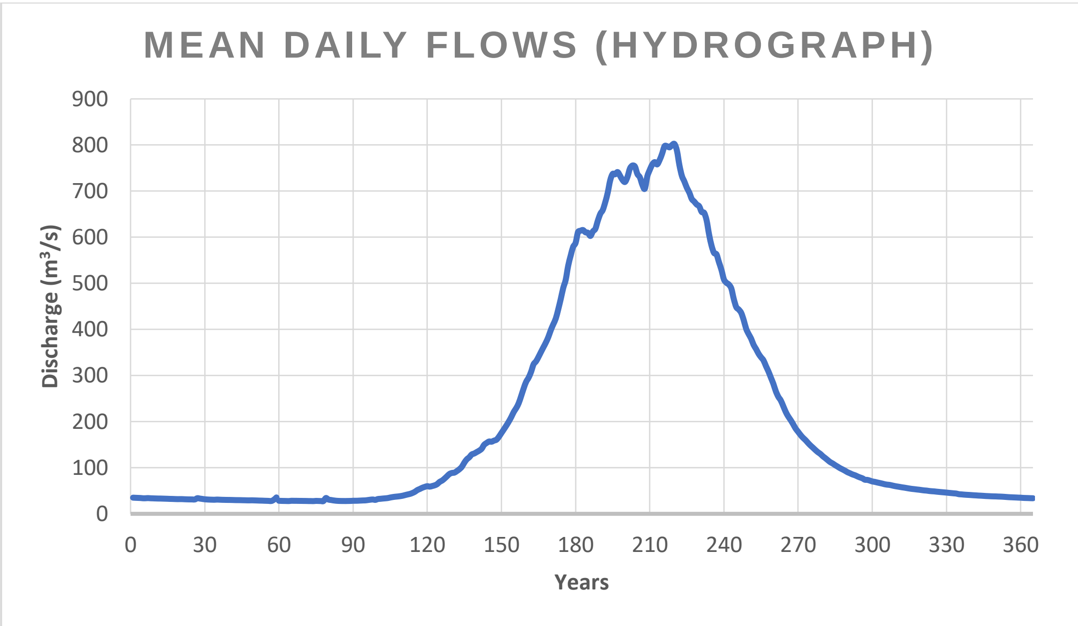


Figure 4-8 Mean Daily Flows

Mean daily flows are plotted in **Figure 4-8** which shows the sudden increase in flows after the fifth month and reaches to peak in July and August. Maximum, Mean and Minimum daily flows for the period 1966-2015 are also plotted in the **Figure 4-9**.

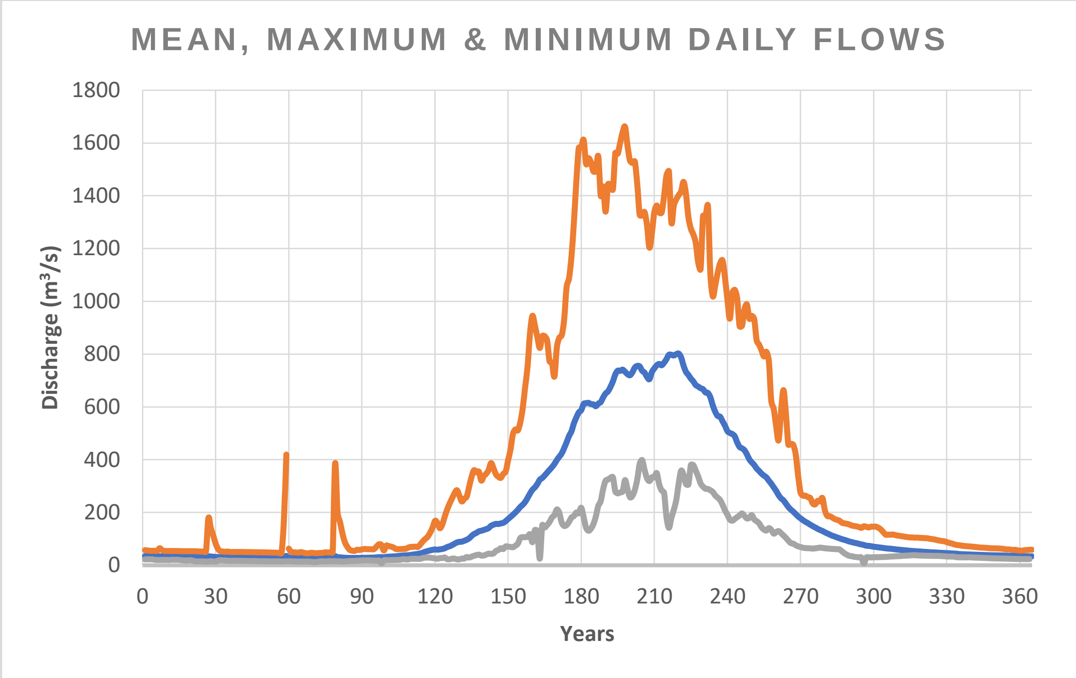


Figure 4-9 Mean, Maximum & Minimum Daily Flows

4.8.1 Flow Duration Curve (FDC)

FDC for ALHPP is plotted on the basis of almost 51 years (1966-2016). From FDC it us evident that design discharge of 60 m^3/s is available for almost 50% of the time. Therefore, design discharge of 60 m^3/s is justified for the generation of 54 MW power.

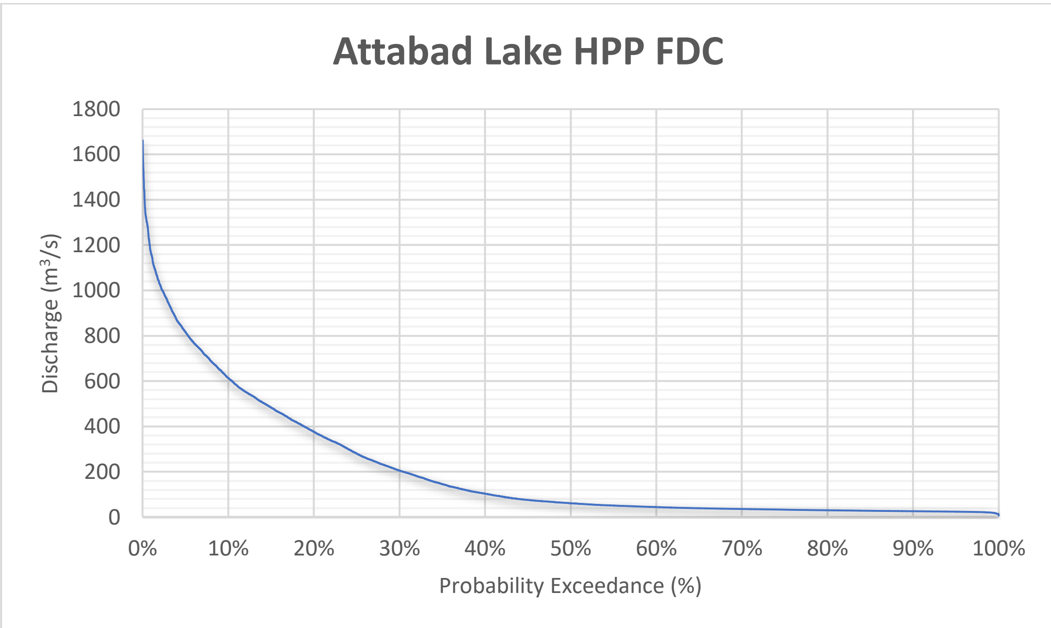


Figure 4-10 Attabad Lake Flow Duration Curve (FDC)

Table 4-4 Flow Duration Curve Results

Probability Exceedance (%)	Flow (m^3/s)	Probability Exceedance (%)	Flow (m^3/s)
10	613.4	60	44.3
20	376.6	70	36.0
30	205	80	30.3
40	103.3	90	26.2
50	61.3	99	20.5

4.9 WATER LEVELS

The available head for power generation has been determined from normal operative level and the water level where tailrace channel joins Hunza River.

4.9.1 Upstream Water Levels

Upstream water levels have been determined keeping in view the operation of the Attabad Lake. For power and energy estimates, the normal operative level varies from 2,408 m.a.s.l to 2,412 m.a.s.l.

4.9.2 Downstream Water Levels (Tail-water Rating Curve)

The tail-water rating curve for downstream of the powerhouse at Hunza River is obtained using the water levels, historic discharges and cross section of Hunza River. Calculations are tabulated at **Table 4 5** and the tailwater rating curve is plotted at **Figure 4 11**. The downstream tail water rating has been adopted for stage estimation downstream of power house. The head losses expected to occur in the power scheme have been calculated to determine the net head available for power generation.

Table 4-5 Tailwater Curve Analysis

Water Surface Elevation (m.a.s.l)	Discharge (m^3/s)	Velocity (m/s)	Flow Area (m^2)	Wetted Perimeter (m)	Top Width (m)
2300.10	29.50	1.29	22.80	51.31	51.18
2300.35	98.27	1.87	52.53	68.02	67.77
2300.75	215.19	2.38	90.39	81.51	81.11
2301.35	394.73	3.00	131.40	83.59	82.93
2301.95	616.04	3.55	173.32	85.68	84.76
2302.55	876.00	4.05	216.15	87.76	86.58
2303.12	1172.50	4.51	259.90	89.85	88.40
2303.62	1503.99	4.94	304.55	91.93	90.23
2304.06	1869.31	5.34	350.12	94.02	92.05
2304.47	2267.56	5.72	396.61	96.10	93.88
2304.92	2698.06	6.08	444.00	98.19	95.70
2305.40	3049.87	6.17	494.07	106.72	104.05
2305.95	3525.16	6.44	547.06	110.79	107.93

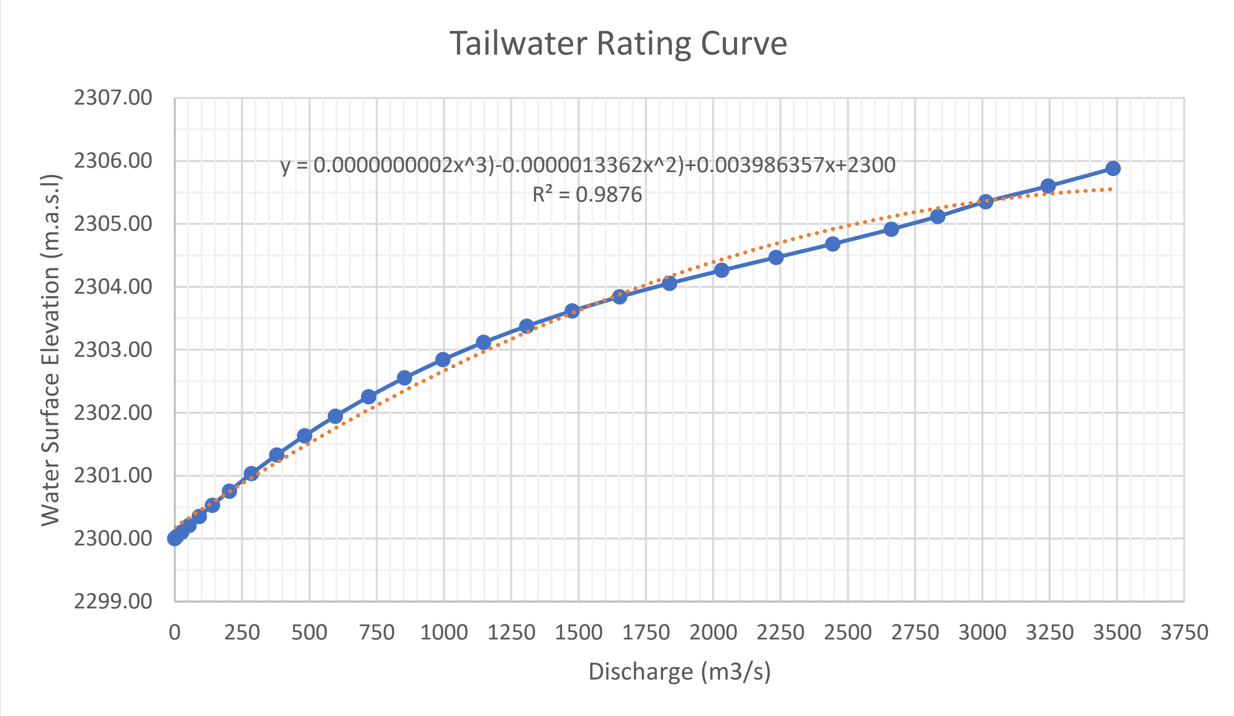


Figure 4-11 Tailwater Rating Curve

4.10 FLOOD ESTIMATION

Flood has been estimated from the available record. The maximum peak discharges of mean daily for every year recorded. The instantaneous peaks will definitely be higher than the measured daily flows and can be enhanced while execution accordingly. Instantaneous peak flows for the period 1966 to 2015 has been calculated and plotted as well.

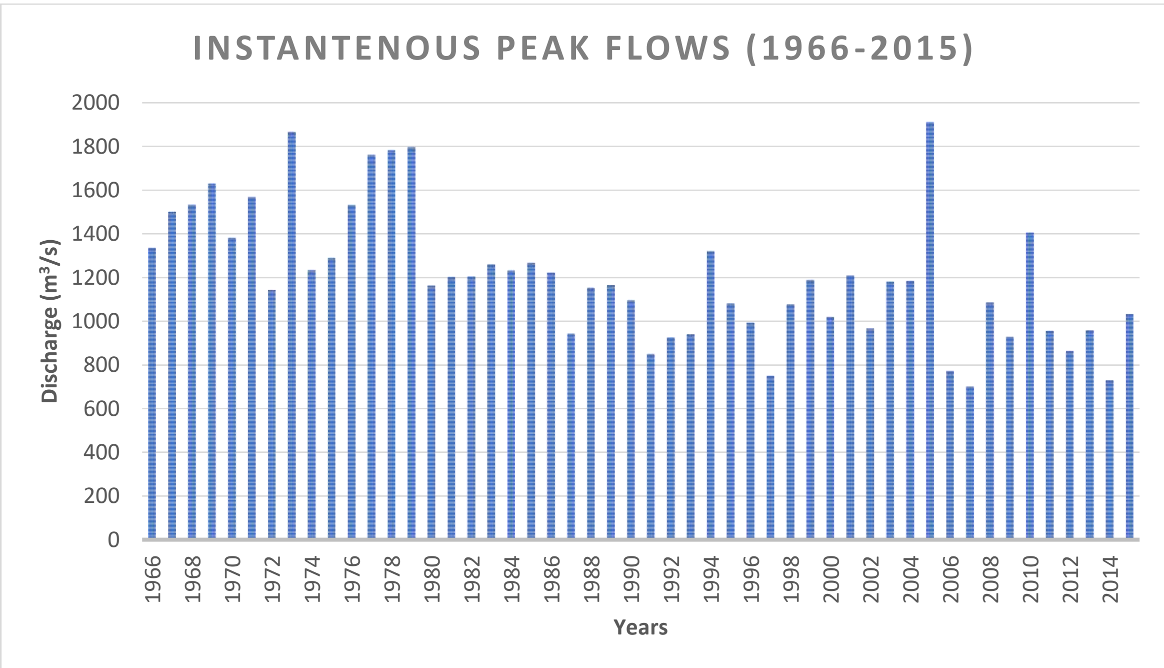


Figure 4-12 Instantaneous Peak Flows at Attabad Lake HPP Site

4.10.1 Flood Estimation by Flood Frequency Analysis (FFA)

Flood Frequency Analysis (FFA) has been carried out to estimate the flood at different return periods. Three types of distribution series namely Gumble, Normal and Log Pearson Type-III Distribution series have been used to estimate the flood.

The estimated values of floods from FFA of various return period at Attabad Lake site are tabulated in Table 4 6.

Table 4-6 Flood Frequency Analysis

Return Period (Years)	Gumble Distribution Estimated Flood (m^3/s)	Normal Distribution Estimated Flood (m^3/s)	Log Pearson Type-III Estimated Flood (m^3/s)
2	1,142	1,232	1,155
5	1,411	1,426	1,428
10	1,589	1,579	1,596
25	1,813	1,767	1,796
50	1,980	1,910	1,939
100	2,145	2,073	2,077
1,000	2,691	2,520	2,518
10,000	3,237	2,984	2,915

Log scale graph has been plotted with respect to the peak flows at **Figure 4-13**.

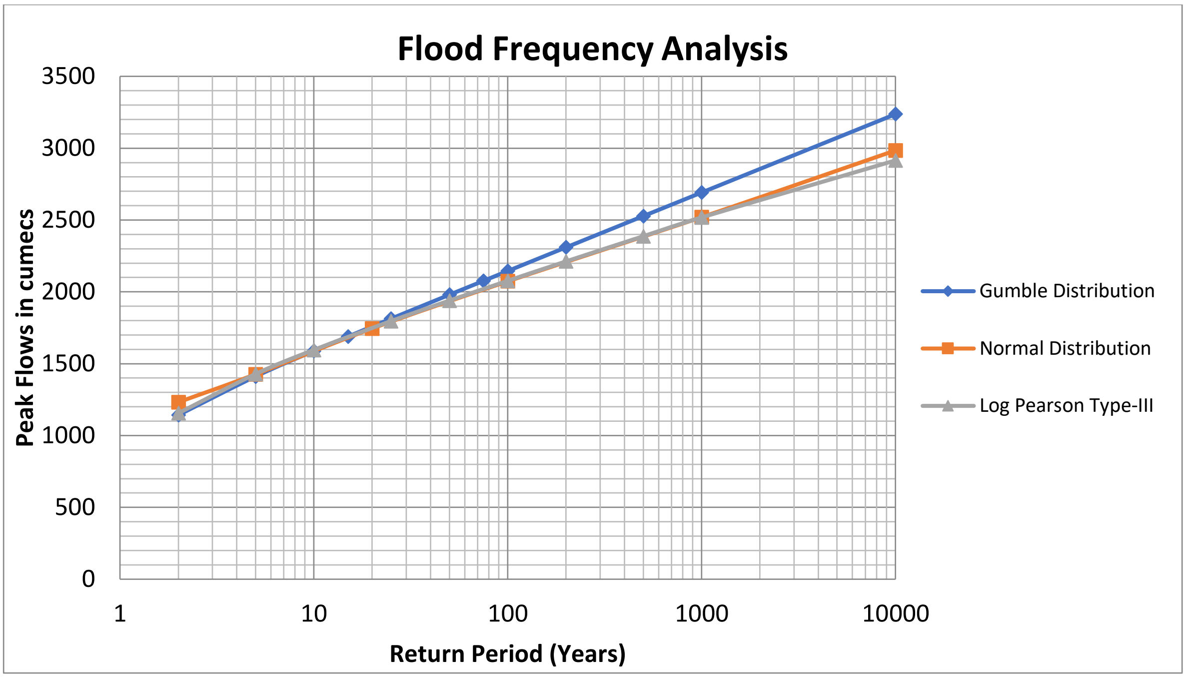


Figure 4-13 Flood Frequency Analysis Graphs

4.10.2 Flood Estimation by USACE HEC-SSP Model

Flood has also been estimated using the statistical model. The US Army Corps of Engineers (US-ACE) HEC SSP Model is used for this purpose. 17B Bulletin Method has been selected with Weilbul Plotting pattern in the model. Results of peak floods against percent chance exceedance been calculated and shown in **Figure 4-14**.

HEC-SSP 2.1.1 - Attabad Lake HPP

Frequency Curve for: Attabad Lake HPP

Percent Chance Exceedance	Computed Curve Flow in cfs	Expected Prob. Flow in cfs	Confidence Limits Flow in cfs	
			0.05	0.95
0.01	3016.3	3291.9	3652.3	2606.2
0.1	2559.0	2696.3	3030.7	2256.5
0.5	2236.4	2314.2	2567.6	2008.7
1.0	2096.0	2153.4	2396.2	1897.4
5.0	1759.1	1780.7	1952.6	1622.2
20.0	1430.6	1436.5	1543.1	1342.6
50.0	1154.0	1154.0	1224.7	1067.3
95.0	761.0	752.0	625.0	686.0
99.0	641.5	625.6	706.6	562.0

Statistics

Log Transform: Flow

Statistic	Value
Mean	3.063
Standard Dev	0.111
Station Skew	0.023
Regional Skew	
Weighted Skew	
Adopted Skew	0.023

Number of Events

Event	Number
Historic Events	0
High Outliers	0
Low Outliers	0
Zero Or Missing	0
Systematic Events	51
Historic Period	

Figure 4-14 Flood Estimation using HEC-SSP Model

Flood Estimation using HEC-SSP Model. Confidence intervals of 5% and 95% have been used for the calculations.

As per the model, flood for 1000-year return period from computed curve has been calculated as 2,559 m^3/s and from expected probability curve it is 2,695 m^3/s. Flood for 10,000-year return period, it is 3,016 m^3/s from computed curve and 3,292 m^3/s from expected probability curve. With the confidence interval of 5% and 95%, maximum flood values are 3,682 m^3/s and 2,606 m^3/s.

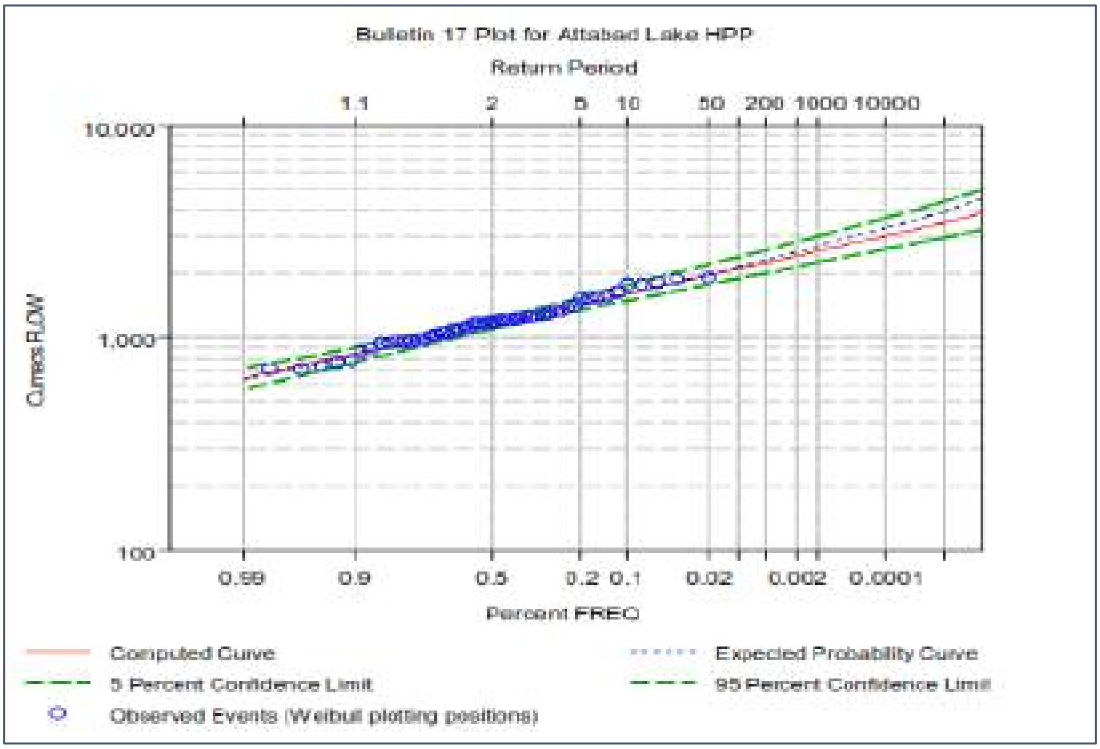


Figure 4-15 HEC-SSP Model Graph

4.10.3 Statistical Model Analysis

Statistical model results are tabulated at Table 4 7.

Table 4-7 HEC-SSP Model Results

Return Period (Years)	Computed Flood from Curve (m^3/s)	Expected Probable Flood (m^3/s)
1.01	641	626
2	1,154	1,154
5	1,431	1,436
20	1,759	1,781
100	2,098	2,153
200	2,238	2,314
1,000	2,559	2,698
10,000	3,016	3,292

4.10.4 Recommended Design Flood

Keeping in view the different types flood estimations and generation of high peaks due to GLOFs, it is recommended to adopt design flood of 10,000 years return period at weir site. Therefore, design flood of 3,250 m^3/s at weir site has been assumed for the calculations of design of structures.

4.11 HYDROLOGIC FLOOD ROUTING

Flood routing is a mathematical procedure for predicting the changing magnitude, speed, and shape of a flood wave as a function of time (i.e., the flow hydrograph) at one or more points along a waterway. Although, the lake has not much storage capacity but still it can lag and attenuate the peak generated by floods to minimize the adverse impacts on the downstream structures and areas. The temporarily stored water is then released through an outlet or spillway after the peak has passed.

U.S. Army Corps of Engineers' (USACE) Hydrologic Center's hydrologic Modeling System (HEC-HMS) is used for this Project. HEC-HMS uses level pool method also known as Modified Puls Routing method to route the flood wave. It uses the one-dimensional approximation of the continuity equation.

$$(Iavg - Oavg) \quad = \frac{\Delta S}{\Delta t}$$

I_{avg}	=	Average inflow during time interval
O_{avg}	=	Average outflow during time interval
ΔS	=	Storage Change
Δt	=	Time Change

4.11.1 Establishment of the HEC-HMS Model

Attabad Lake catchment has been delineated using the ArcGIS tool which is then exported to HEC-HMS model. To model a reservoir, source, reservoir and sink elements are incorporated. Catchment area is shown at **Figure 4-16**. To setup the HEC-HMS model, Storage-Discharge relationship has been developed for the reservoir keeping the proposed outflow system. Storage-Elevation relationship is available from the hydrographic survey of the lake which is then used as paired data along with Storage-Discharge relationship for the hydrologic model. Inflow hydrograph has been generated keeping in view the peak discharge of 3,250 m^3/s. Time interval of 2-hours has been used for the hydrograph and simulation.

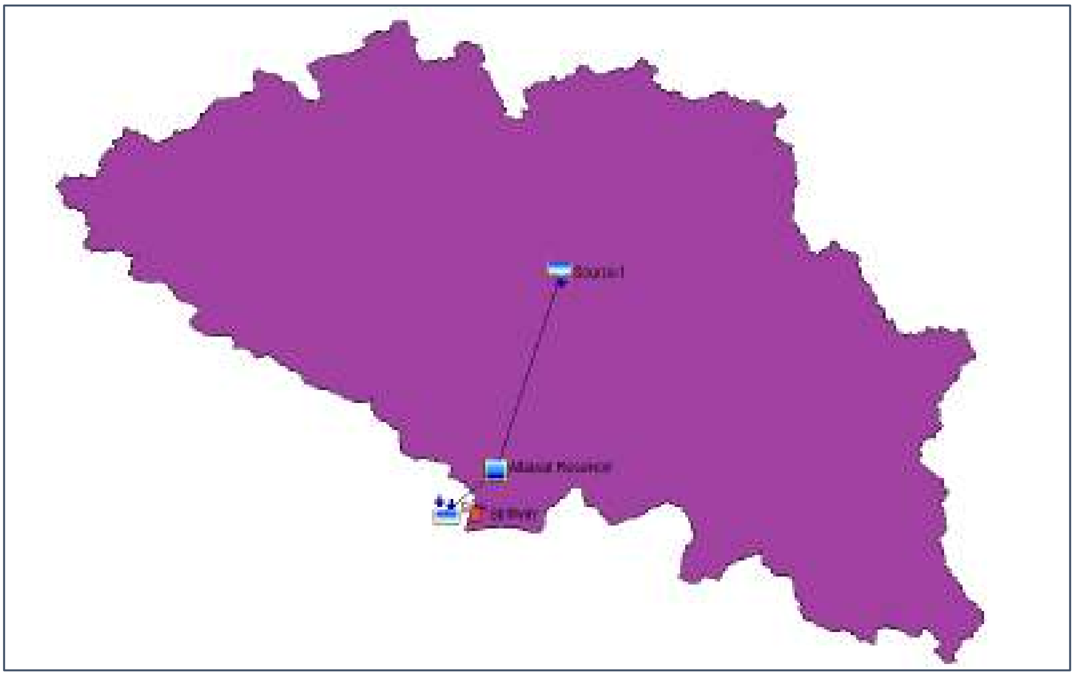


Figure 4-16 Attabad Lake Catchment Area Marked in HEC-HMS

4.11.2 Assumption for the Routing

The treatment of routing in this method is based on the assumption that the reservoir is level. This means that both the outflow and the storage depend only on the water level in the reservoir. It is not valid in reservoir where the backwater effect is such that a significant percentage of the temporary storage occurs as wedge storage between the sloping backwater surface and a horizontal plane extending upstream from the water surface elevation at the weir.

4.11.3 Results of Flood Routing

The routing exercise of the design flood was carried out with such scenario that outflow is being done by overflow weir (60 m in length) and assuming sediment flushing channel gates are not operating in case of flood. Under this scenario of discharge, the routed hydrograph is presented at **Figure 4-17** and results are tabulated at Table 4 8. As evident from the graph and table, it is deducted that the hydrograph with the peak of 3,250 m^3/s has been entered in the lake as inflow and attenuated peak of 3,085 m^3/s is attained after 4 hours of the inflow peak. The attenuated peak is attained at an elevation of 2421.3 m a s l. Thus, being a small level reservoir, Attabad Lake can play lag and attenuate the flood wave upto some extent as shown in the graph and table.

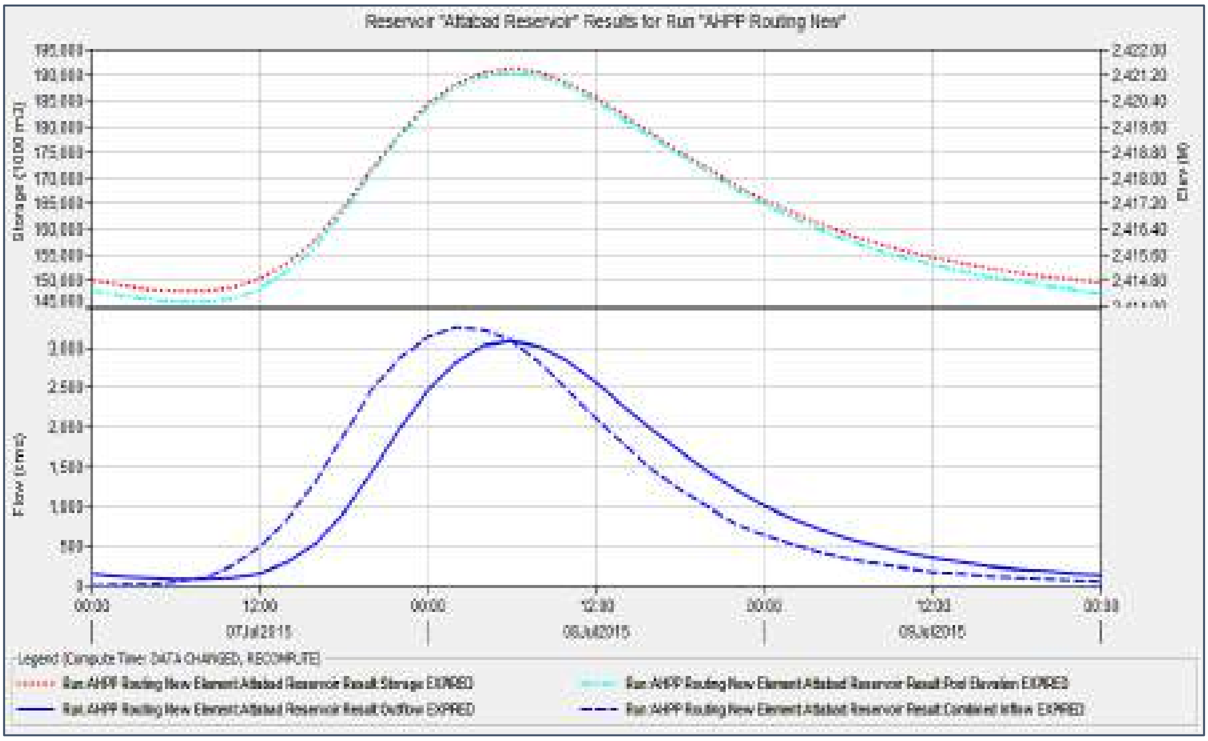


Figure 4-17 Attabad Lake Flood Routing Graph

Table 4-8 Attabad Lake Flood Routing Table

Sr. No.	Days	Time (Hours)	Inflow (m^3/s)	Storage (1,000 m^3)	Elevation (m.a.sl)	Outflow (m^3/s)
1	Day-1	0:00	2	150,000	2414.5	142
2	Day-1	2:00	4	149,094	2414.3	113
3	Day-1	4:00	17	148,432	2414.2	92
4	Day-1	6:00	43	148,036	2414.2	79
5	Day-1	8:00	94	147,973	2414.1	77
6	Day-1	10:00	225	148,508	2414.2	94
7	Day-1	12:00	472	150,144	2414.5	148
8	Day-1	14:00	832	153,290	2415.1	281
9	Day-1	16:00	1,325	158,137	2415.9	529
10	Day-1	18:00	1,907	164,555	2417	920
11	Day-1	20:00	2,449	171,778	2418.2	1,430
12	Day-1	22:00	2,867	178,673	2419.3	1,971
13	Day-2	0:00	3,138	184,367	2420.2	2,452
14	Day-2	2:00	3,250	188,414	2420.8	2,811
15	Day-2	4:00	3,222	190,717	2421.2	3,021
16	Day-2	6:00	3,074	191,400	2421.3	3,085
17	Day-2	8:00	2,794	190,584	2421.2	3,009
18	Day-2	10:00	2,441	188,462	2420.8	2,816
19	Day-2	12:00	2,092	185,472	2420.4	2,549
20	Day-2	14:00	1,763	182,061	2419.8	2,254
21	Day-2	16:00	1,464	178,514	2419.3	1,958
22	Day-2	18:00	1,200	175,013	2418.7	1,678
23	Day-2	20:00	969	171,663	2418.1	1,421
24	Day-2	22:00	775	168,530	2417.6	1,193
25	Day-3	0:00	624	165,685	2417.2	996
26	Day-3	2:00	504	163,164	2416.7	831
27	Day-3	4:00	406	160,951	2416.4	693
28	Day-3	6:00	327	159,014	2416.1	578
29	Day-3	8:00	264	157,316	2415.8	485
30	Day-3	10:00	213	155,833	2415.5	404
31	Day-3	12:00	172	154,533	2415.3	341
32	Day-3	14:00	139	153,393	2415.1	286
33	Day-3	16:00	112	152,396	2414.9	241
34	Day-3	18:00	90	151,517	2414.8	205
35	Day-3	20:00	73	150,742	2414.6	173
36	Day-3	22:00	59	150,071	2414.5	145
37	Day-3	0:00	48	149,482	2414.4	126

4.12 GLACIAL LAKE OUT BRUST FLOOD (GLOFS)

The most extensive glacier covers of the world outside Alaska and the Arctic is located in the Himalayan and Karakoram mountains. Pakistan is a home of more than 5000 snow reservoir and glaciers along with the second largest Siachen Glacier. The fresh water is preserved in these reservoir during the winter season and feed to the river in the summer season due to the gradual melting of ice and snow in upper parts of the country. They cover a surface area of 16,600 km2.Their runoff feeds the Hunza, Nagar, Gilgit and Indus rivers which in turn provide fresh water for about more than 100 million people residing in Indus Valley.

Lakes are water reservoirs existing in, under, beside or in front of a glacier, originated due to glacier ablation properties and retreat processes or damming of river valleys by advancing and/or surging glaciers. GLOFs result from the failure of natural dams formed from glacier ice and/or lateral and terminal moraines, which have impounded water. The moraines may be ice cored and contain unconsolidated debris, silt and large boulders. The lakes formed by these natural dams may vary in size from small marginal ice pools to lakes of several billion cubic meters.

The dams grow progressively owing to the glacier flow and deposition of debris. The advance and retreat process of a glacier contribute to the size and physical features of the moraine dams. They can rise to a few hundred meters in height. However, they are structurally unstable and likely to fail, as a result of overtopping, as a result of waves generated by avalanches and snowmelt and rainfall run-off, piping and sliding. The flood hydrographs arising from failure of glacial dams are attributable to several factors, such as the volume of the water in the lake, the height of the dam, the failure mechanism and the transient characteristics of the breach profile.

GLOFs are not a new phenomenon, however, with the current environmental and climatic changes, their probability has risen in most mountain ranges. Glacial lakes are particularly dangerous in the Karakoram ranges as they occur at low elevations and close to settlements. In some cases, potential outbursts allow only 10 to 40 minutes to trigger an alarm for the threatened population to evacuate to safety.

GLOFs can create two types of flooding:

- Upstream flooding as a result of impoundment, less dangerous for human life due to slow rise in water level but property damage can be substantial.
- Downstream flooding as a result of dam failure, significant threat to life and property.

Major glaciers of Hunza Watershed are:

Table 4-9 Major Glaciers of Hunza River Watershed

Major Glaciers	Area (km^2)	Length (km)	Elevations (m.a.s.l)
Hispar	497	53	3040 - 7885
Batura	323	60	2540–7795
Khurdopin	280	41	3200–7760
Virjerab	189	36	3600–6600
Yazghil	145	30	3055–7880
Barpu	136	34	3050–7880
Bualtar	105	22	2450–7200

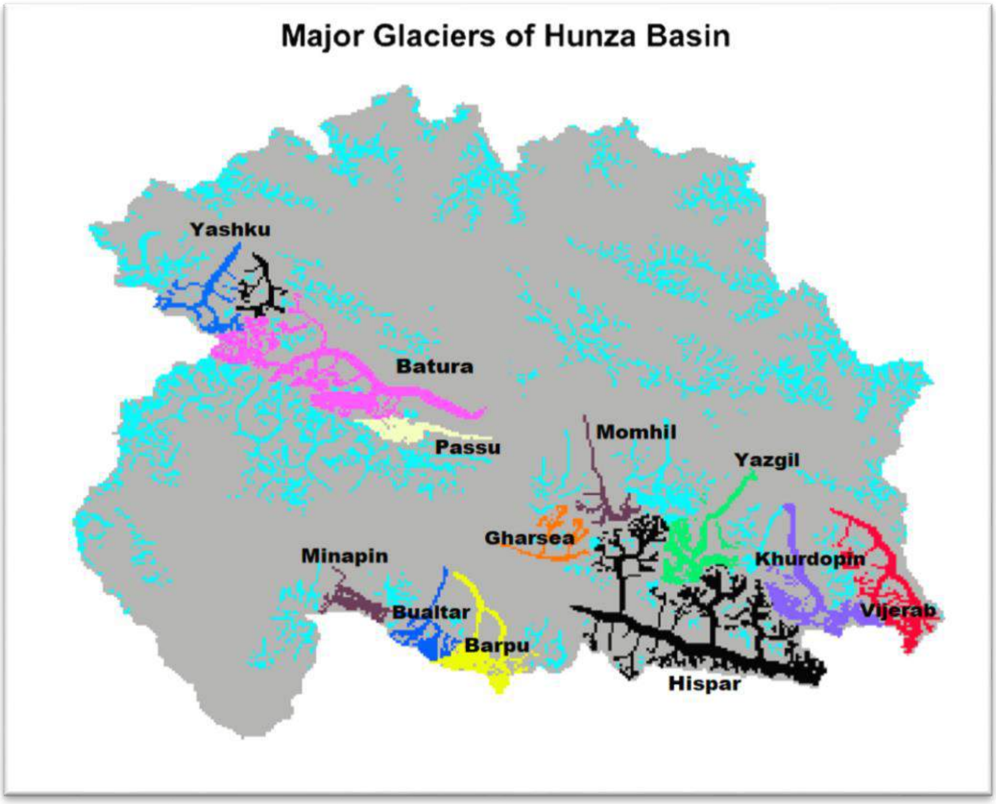


Figure 4-18 Major Glaciers in Hunza River Watershed

Table 4-10 Historical GLOFs in Gilgit-Baltistan

Year	Date	Glacier River
1994	29-Jul	Sosot/Gupis Gilgit
1999	6-Aug	Khalti/Gupis Gilgit
2000	10-Jun	Shimshal Hunza
2000	27-Jul	Kand/Hushe Indus
2005	25-Jul	Sosot/Gupis Gilgit
2007	5-Apr	Ghulkin Hunza
2008	6-Jan	Passu Hunza
2008	2-Apr	Ghulkin Hunza
2008	22-May	Ghulkin Hunza
2008	24-May	Ghulkin Hunza
2008	14/15 June	Ghulkin Hunza
2009	26-Mar	Ghulkin Hunza
2012	08-Jul	Sosot/Gupis Gilgit

Source, Archer 2001, UNDP 2007, NARC 2008, Pamir Times June 2008. FOCUS, 2012)

4.12.1 Update on Glacial Hazards in the Upper Indus Basin

A study has been carried out by Reynolds International, through Diamer Basha Dam Company, using numerical simulations for the possibility of GLOFs in the Upper Indus Basin and their impacts on Diamer Baha Dam Project (DBDP). Numerical simulations have highlighted that a sudden breach of Shisper ice-dammed lake under the current condition should not pose a major threat to the safety of the Diamer Basha Dam (DBD). As per the report, using observational information available for a significant outburst from Shisper Glacier in May 2020, the dataflow software simulation outputs have been cross-checked and found to give reasonable agreement. The simulation shows that the 2020 Shisper outburst, the flood would only propagate for about 20 km downstream from the source.

It is suggested to have close monitoring of Glaciers in Hunza Region should be undertaken to have better judgment of GLOFs and remedial measures for the safety of Attabad Lake and downstream areas and comprehensive study will be undertaken during Detailed Engineering Design of the Project.

4.13 SEDIMENTATION STUDIES

4.13.1 General

Most of the rivers of Pakistan carry large amounts of sediment in suspension and as bed load. Much of the land in Pakistan is highly erodible because of sparse vegetal cover, steep slopes, and non-resistant soils and rocks. As a result, serious consideration must be given to the sediment aspects of rivers and sediment records imperative for a good design of water sector and hydropower projects.

The glacial lakes filled by moraines and ice core of retreating glaciers may breach suddenly due to unstable moraine 'dams', resulting in discharge of huge amounts of water and debris - known as 'Glacial Lake Outburst Flood (GLOF)'. The frequency of natural hazards like flash floods and GLOFs has increased in the Himalayan Region of Pakistan due to the global warming in recent decades. They often have catastrophic effects immediate downhill; even a small glacial lake associated with hanging glaciers poses high risk of a GLOF event.

According to Chaudhry, Mahmood, Rasul and Afzaal (2009), Pakistan experienced 0.76°C rise in temperature during the last 40 years. The frequency and persistence of heat waves in glaciated mountains has risen drastically causing rapid melting and sudden discharge of bulk of water to terminal lakes of glaciers increasing the risk of outburst. According to Goudie (1981) and Miller (1984), among 339 disastrous incidents identified along KKH in Hunza Valley in 1980, the most destructive ones were related to glacial movement that led to outburst floods of ice-dammed lakes.

The morphology of Hunza River has an important impact on the pattern of sediment transport. The River is a mountain river, where 98% of the catchment is built by mountains. The morphology of the River is characterized by boulders and gravels. The flow regime is mostly turbulent at lower reaches. The bed load of Hunza River and its flow regime are strongly influenced by the morphological structures of the area. The longitudinal water level profile is a parameter of the energy and shear stresses acting on the river bed and initiating sediment transport.

Sediment sources are glaciers, precipitation in the form of storms and heavy rains, hill slopes, landslides and gully erosion etc. The suspended load is influenced by availability of sediment sources and triggering events. In Karakorum and Himalayas large amounts of yearly suspended sediments per square kilometers of the catchment area (more than 2,000 tons/year/ km2) are reported in the river system. Based on the morphology, climate and flow regime of the area, the sediment load of the concerned catchment is thoroughly assessed.

The average sediment concentration is about 0.321% (by weight) or 3,210 ppm and the average suspended sediment yield per year is about 20.06 million metric tons. The observed minimum concentration is 2 ppm and observed maximum concentration is 21,300 ppm. Almost all of the suspended sediment is brought down by the river during the period of June to September. The river carries on the average, about 27% sand, 50% silt and 21% clay. The unit weight of fresh deposits of this sediment is about 1122.4 kg/m3.

4.13.2 Suspended Sediment Concentration

Normally, suspended sediments load and discharge observations are used to develop Sediment Rating Curve for the estimation of annual sedimentation of the reservoir. A relation between sediment concentrations and discharge is developed from available data of each year, and that relation or equation is then applied to daily flow series of each year to estimate annual sediment load at dam site. In this case for ALHPP, data of suspended load sediment concentrations is available from 1966 to 2015 at Danyor Station for the estimation of the annual suspended load calculation.

4.13.3 Sediment Sampling

The suspended sediment sampling of the Attabad Lake HPP at Daniyor is carried out from year 1966 to 2015. As per observed data, the number of suspended sediment observations taken during Low-Flows period and High- Flows periods in each year are presented below in Table 4.11.

Table 4-11 Suspended Sediment Load Observations at Danyor

Year	Number of Observations During		Total Observations	Year	Number of Observations During		Total Observations
	Low Flows (Oct - Apr)	High Flows (May - Sep)			Low Flows (Oct - Apr)	High Flows (May - Sep)	
1966	5	4	9	**1990**	19	9	28
1967	5	12	17	**1991**	15	13	28
1968	9	17	26	**1992**	11	12	23
1969	13	20	33	**1993**	12	13	25
1970	10	16	26	**1994**	14	10	24
1971	13	15	28	**1995**	12	15	27
1972	14	16	30	**1996**	13	17	30
1973	13	17	30	**1997**	10	-	10
1974	5	17	22	**1998**	12	10	22
1975	11	17	28	**1999**	9	-	9
1976	10	12	22	**2000**	12	13	25
1977	9	15	24	**2001**	14	7	21
1978	7	4	11	**2002**	13	11	24
1979	4	12	16	**2003**	12	15	27
1980	4	6	10	**2004**	8	3	11
1981	6	6	12	**2008**	10	16	26
1982	10	17	27	**2009**	13	17	30
1983	5	13	18	**2010**	27	30	57
1984	12	15	27	**2011**	23	24	47
1985	13	13	26	**2012**	25	20	45
1986	5	7	12	**2013**	18	17	35
1987	14	15	29	**2014**	28	34	62
1988	9	8	17	**2015**	14	34	48
1989	17	12	29				

4.13.4 Sediment Grading

The particle size distribution of the sediment is an important parameter as it will determine the amount of the sediment that will be deposited in the reservoir and where and how long it will take to flush the reservoir. Very fine sediment may not be deposited in the reservoir and will pass through the turbines, or spilled when there is surplus inflow. On the other side, the coarsest sediment being carried by the river will be dropped first in the reservoir and will take longer to flush.

4.13.5 Available Data

There was limited sediment grading data available at the commencement of the study. The source of data came from the Surface Water Hydrology Project SWHP, (WAPDA) sampling at the Danyor Gauging Station between 1966 and 2015 and was in the form of proportions of sand, silt and clay, which have the following particle sizes:

- Clay (< 0.0055 mm)
- Silt (between 0.0625 mm to 0.0055 mm)
- Sand (> 0.0625 mm)

The frequency of the readings is variable. In some years there were only a few readings and in others there are weekly readings. The percentage of sand in these readings varies between 36 and 85 %. The sieve analysis of suspended sediment samples carried out by SWHP (WAPDA) at Danyor Station showing mean fractions of sand, silt and clay of each year are given below in Table 4 12. The average percentage for all year of sand, silt and clay is 27.6 %,50.3 % and 21.6 % respectively.

As storage of a reservoir is mainly depleted due to the deposition of sand and coarse materials, while clay and fine silt remain in suspension even in low flow velocities.

Table 4-12 Mean Fractions of Sand, Silt and Clay at Danyor Station

Year	Fraction (%age)			Year	Fraction (%age)		
	Sand	Silt	Clay		Sand	Silt	Clay
1966	24.6	49	26.4	**1990**	52.3	36.2	14.2
1967	29.9	50.5	19.5	**1991**	26.1	38	35.9
1968	33.6	43.2	23.1	**1992**	20.7	52.9	26.4
1969	32.3	45	23.8	**1993**	32.5	46	21.5
1970	28.6	47.5	19.7	**1994**	45.1	43.8	11.1
1971	32	49.3	18.7	**1995**	40.2	42.1	17.7
1972	25.5	51.3	23.2	**1996**	29.2	53.9	16.9
1973	27.5	54.9	17.5	**1997**			
1974	27.6	46.7	26.2	**1998**	21.8	59.2	19
1975	22.9	53.5	23.6	**1999**			
1976	25.3	44.4	32.8	**2000**	24.5	57.3	18.2
1977	27.9	41.6	28.6	**2001**	5.3	61	17
1978	46	38	16	**2002**	12.4	71.7	15.9
1979	27.5	49	17.8	**2003**	15.5	67.4	17.1
1980	24.8	61	14.3	**2004**	6	70.6	23.4
1981	28	46.4	25.6	**2008**	7.5	49	43.5
1982	45.8	41.8	12.4	**2009**	3	85.5	11.5
1983	25.9	48	26.1	**2010**	7.8	68.3	24
1984	45.2	38.4	16.4	**2011**	13.8	63	23.2
1985	12.1	52.4	35.5	**2012**			
1986	28.1	48.8	23.2	**2013**	7	64	29
1987	20.3	52.5	27.3	**2014**			
1988	27.1	46.4	26.3	**2015**	42.7	44.8	12.5
1989	24.3	47.8	28				

4.13.6 Suspended Discharge Rating Curve

The sediment load versus river flow is a complex phenomenon. For the same value of discharge different values of the sediment concentrations in PPM can be obtained due to high variability of soil erosion on spatial and temporal scales. This is illustrated in **Figure 4 19** where discharge is plotted against observed sediment concentration in PPM to observe the variability of data. This scatter in values can be explained by initial flood flushes, the variability in the landslide triggering rates and abrasion of glacier fragments while sliding over the loose soil slopes. Intense rainfall over the lower part of watershed may also produce the variability in sediment discharges.

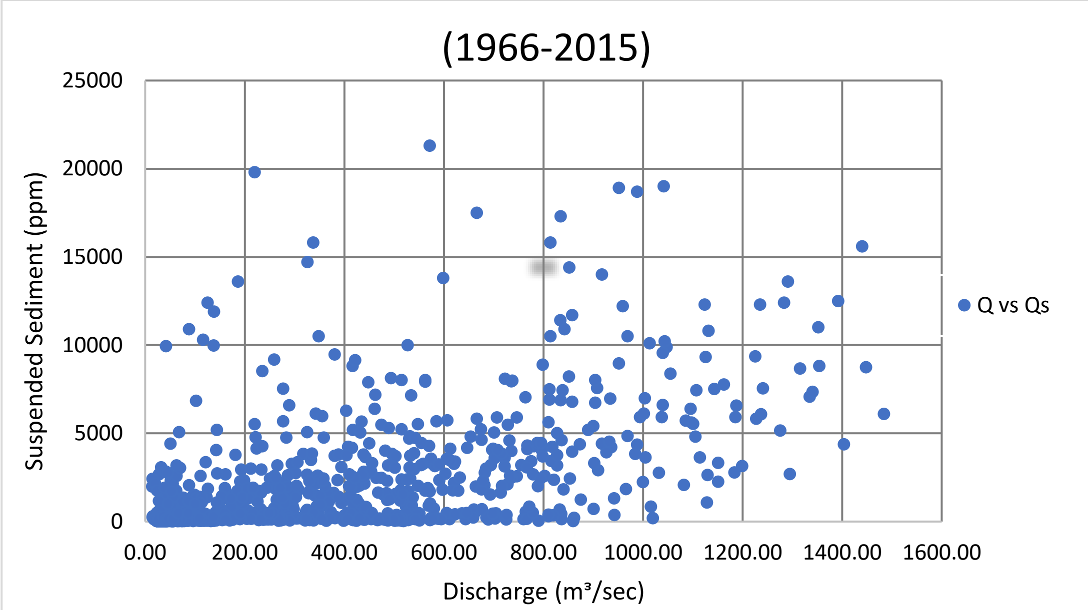


Figure 4-19 Danyor Sediment Concentration Data

Due to this variability, it is difficult to drive the relationship between discharge and sediment concentration as continuous and multiple recording of sediment concentrations would be required to obtain a complete understanding of the sediment regime. However, a general understanding may be obtained by pooling all the data and examining it on plot to obtain a trend line relationship, hence averaging the concentrations. Here, in this section, the suspended sediment rating curve is developed to estimate suspended sediment load at ALHPP site. The curve is developed by using data taken from Surface Water Hydrology Project (SWHP) WAPDA between sediment concentrations and corresponding discharge records as observed at Danyor station from year 1966 to 2015. The suspended sediment load in terms of metric tons per day is drown on scale against observed flows in Cumecs to get a relation between discharge (Q) vs sediment concentration (Qs) as shown is **Figure 4-20**.

The below Rating Curve is plotted based on 3 years' sedimentation concentration observations against their respective discharge. The equation of rating curve is applied to long daily flow series of each year to get annual suspended load as shown in Table 4 14 at Danyor station for year 1966 to 2015, thus the total average annual suspended load comes 33.43 Million Metric Tons with the range between 8.50 M Metric Ton and 90.35 M Metric Ton. The maximum annual suspended load for Danyor station is observed in 1978 i.e. 90.35 M Metric Ton.

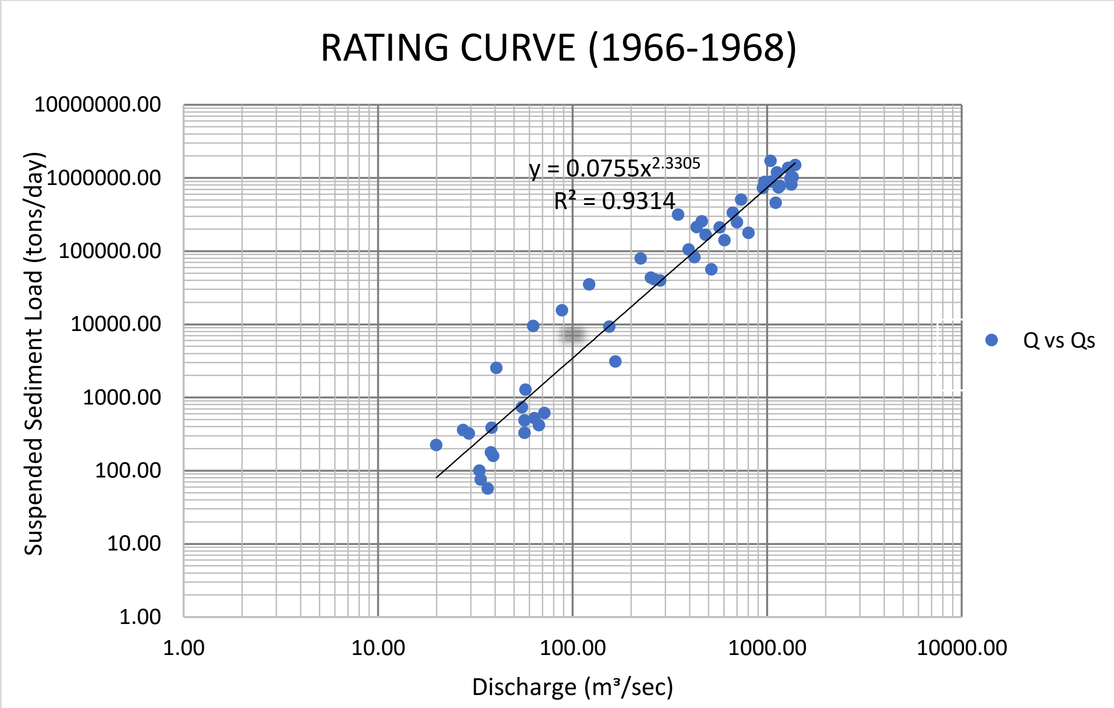


Figure 4-20 Suspended Sediment Rating Curve at Danyor Station

4.13.7 Sediment Yield

Hunza River is one of the rivers with highest annually sediment load due to major glaciers covering 18% of catchment area. Sediment load of the whole year and June to September is given in **Table 4-13** and sediment load computed at project site is available in **Table 4-14**. The table shows that river carries more than 89% sediment load during the four months of high temperature i.e. June to September.

Table 4-13 Percentage of Sediment yield for the Period of Jun to Sep to Total Yield of Year

Years	Jan to Dec	Jun to Sep	Percentage
	M Metric Ton	M Metric Ton	%
1966	46.74	46.44	99
1967	53.24	52.97	99
1968	61.58	61.32	99
1969	58.81	58.34	99
1970	58.51	57.73	98
1971	62.96	62.14	98
1972	17.36	17.02	98
1973	83.55	83.02	99
1974	23.48	23.13	98
1975	31.12	30.82	99
1976	38.37	37.96	98
1977	68.20	67.76	99
1978	90.35	89.77	99
1979	72.30	71.97	99

Years	Jan to Dec	Jun to Sep	Percentage
	M Metric Ton	M Metric Ton	%
1980	30.18	29.70	98
1981	32.11	31.16	97
1982	24.38	23.98	98
1983	35.19	34.76	98
1984	44.43	44.30	99
1985	35.18	34.90	99
1986	27.06	26.62	98
1987	15.22	14.94	98
1988	32.32	31.84	98
1989	12.15	11.90	97
1990	36.59	35.43	96
1991	17.94	17.75	98
1992	15.39	15.14	98
1993	12.75	12.41	97
1994	50.29	49.90	99
1995	23.33	23.06	98
1996	18.24	18.04	98
1997	8.50	8.27	97
1998	27.70	27.11	97
1999	28.05	27.78	99
2000	17.59	16.54	94
2001	35.14	34.17	97
2002	15.47	15.07	97
2003	25.64	25.38	98
2004	12.41	11.93	96
2005	62.54	61.57	98
2006	14.29	12.78	89
2007	11.15	10.04	90
2008	31.22	30.64	98
2009	21.18	20.40	96
2010	31.13	30.83	99
2011	18.77	17.90	95
2012	19.52	18.93	96
2013	27.09	26.36	97
2014	13.93	13.59	97
2015	21.01	20.57	97

The catchment area of Hunza River at Central Hunza is 8,920 km^2. The bulk of runoff occurs during May to September during to snow melt.

Table 4-14 Annual Suspended Load of each year at Danyor

Year	Suspended load (M Metric ton)	Year	Suspended load Million Metric Ton(MMT)
1966	46.74	**1991**	17.94
1967	53.24	**1992**	15.39
1968	61.58	**1993**	12.75
1969	58.81	**1994**	50.29
1970	58.51	**1995**	23.33
1971	62.96	**1996**	18.24
1972	17.36	**1997**	8.50
1973	83.55	**1998**	27.70
1974	23.48	**1999**	28.05
1975	31.12	**2000**	17.59
1976	38.37	**2001**	35.14
1977	68.20	**2002**	15.47
1978	90.35	**2003**	25.64
1979	72.30	**2004**	12.41
1980	30.18	**2005**	62.54
1981	32.11	**2006**	14.29
1982	24.38	**2007**	11.15
1983	35.19	**2008**	31.22
1984	44.43	**2009**	21.18
1985	35.18	**2010**	31.13
1986	27.06	**2011**	18.77
1987	15.22	**2012**	19.52
1988	32.32	**2013**	27.09
1989	12.15	**2014**	13.93
1990	36.59	**2015**	21.01
	Average		**33.43**

The mean annual suspended load (million metric tons) as shown in above table is also presented in bar chart in **Figure 4-21**.

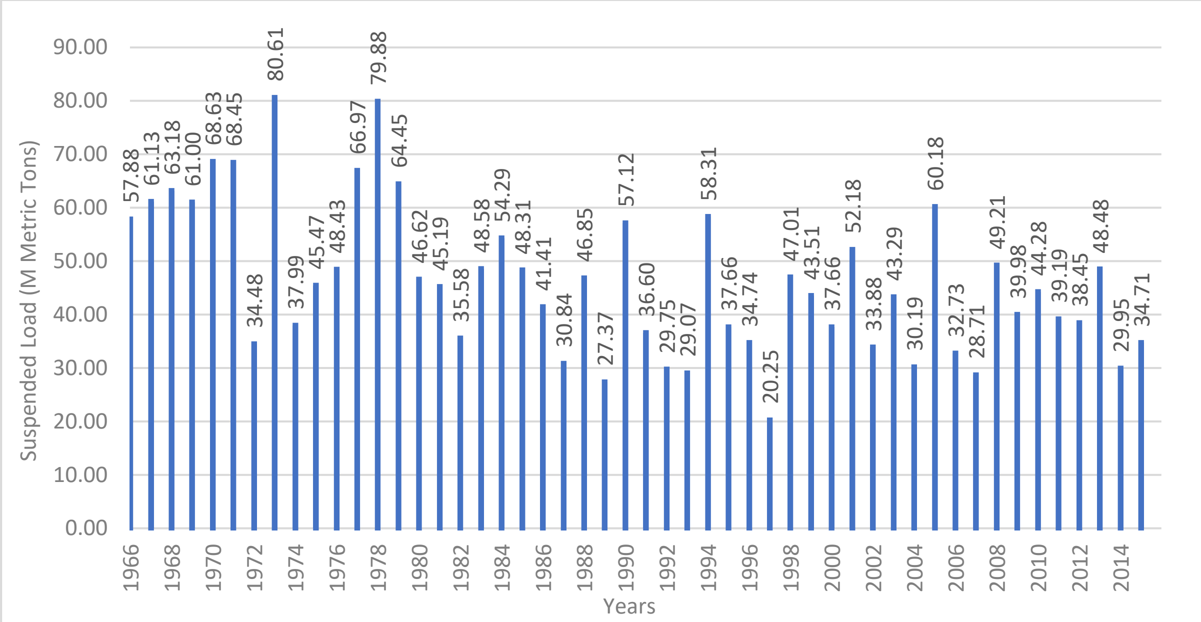


Figure 4-21 Average Annual Suspended Sediment Load at Danyor Gauging Station.

Average value of suspended sediment at Danyor comes out 33.43 MMT with data range 1966-2015 which falls on higher side and also differs from realistic value. To get a realistic value, we used lake capacity from recent hydrographic survey (2020), compared with 2010 capacity and do reverse calculation for sediment load which comes out about 20 MMT/year.

To remain on realistic side, we choose the period of 2011-2015 for the calculation of suspended sediment and the average of suspended sediment comes out 20.06 MMT.

4.13.8 Initial Density of Deposited Sediment and its Consolidation

Total sediment inflow to a reservoir is converted into volume by using the density of deposited sediment. In order to compute the initial density of deposited sediment, main factors are

i. The approach that is adopted to operate the reservoir and

ii. The texture and size of deposited sediment.

In present study, it was considered that reservoir operation is normally moderate to considerable reservoir drawdown. The same concept has also been adopted for the assessment of initial density of deposited sediment in this study. Therefore 561, 1140, and 1550 kg/m3 initial density of deposited sediment have been adopted for clay, silt and sand. The equation derived by Lara and Pemberton (1963) is used to estimate the initial density of deposited sediment which is:

$$\mathbf{Wo = WcPc + WsPs + WsaPsa}$$

Where W0 is the initial density of deposited sediment, Pc, Ps and Psa are the percentages of clay, silt and sand, Wc, Ws, and Wsa are initial densities of clay, silt and sand. Initial density of the deposited sediment is thus computed as 1,122.4 kg/m^3.

The accumulation of sediment deposits changes the density of previously deposited sediments. The consolidation of settled material results in an increase in density with time. Miller's (1953) equation is used for the prediction of consolidation that is:

$$W_t = W_o + 0.434\,(K)\,(t/t-1) * ((\ln t) - 1)$$

Where Wt is the average dry bulk density after t years of consolidation, Wo is initial density and k is the compaction factor based on type of reservoir operation and sediment size analysis.

4.13.9 Mean Annual Sediment Load

Mean annual total sediment load is normally estimated by adding unmeasured sediment bed load to the observed suspended sediment load. The sediment volume is determined from the total sediment load and the unit Wi sediment weight. The average volume of fresh sediment deposits for Attabad Lake HPP is estimated as: (20.06 MMT x 1000 kg/MT) / (1122.4 kg/m3 x 1234 m3 /acre-feet x 106) ~ 14,483 Acre-Feet/ year.

4.13.10 Bed Load

The sediment load of a river is one of the key variables in channel dynamics. Plan form pattern, morphology, erosion, deposition and migration of the channel are in a large part determined by the amount of sediment moved by the flow in relation to the water discharge. A river may transport sediment in two distinct modes. In bed load transport, the sediment particles travel by rolling, sliding or hops of the length of a few grain sizes (known as saltation), and they are thus in frequent contact with the channel bed. On the other hand, in suspended load transport, the weight of the particles is supported by turbulent forces in the water and they can travel considerable distances without coming into contact with the bed. Herein, the dissolved load, which can be substantial, is ignored. Grains with sizes that cannot be found in the shifting parts of the bed in appreciable quantities are known as wash load, which in general is a part of the suspended load. Whether an individual particle is transported as suspended load or as bed load depends on particle size, weight and shape and on the ambient hydraulic conditions. Bed load can be defined as the rate of movement of sediments particles along the river bed in the process of rolling, sliding and / or hopping. It is very difficult to measure bed load by sampling as we do for suspended load. As such, no practical device for measurement of bed load in the field is used by any concerned department. Consequently, estimates of bed loads are not available at any gauging site in Pakistan.

Generally, the amount of bed load transported by a large deep river varies from 5 to 25 % of the suspended sediment load. For computing the bed load, several formulas or relations have been developed by various researchers and departments. Some of the earlier formulas, such as those of Schoklitsch, and Meyer-Peter and Muller, were based purely on experimental results. However, more recent formulae such as those of Einstein have a semi-theoretical background. All these formulas involve huge amount of field data. The application of these formulas is for theoretical consideration, and may not produce satisfactory results. Thus, by using the recommended guidelines, based on experience and observations, are considered acceptable for estimation of bed load.

Two guidelines have been considered. Firstly, a guideline presented by E.W. Lane and W.M. Borland (1951) as shown in **Table 4-15**: according to these guidelines the bed load being transported by the Hunza river based on the Daniyor sediment concentrations may range from 10 to 35 %. Secondly, the USBR guidelines (1987) based on the Modified Einstein Procedure.

In these guidelines, which are reproduced in **Table 4-16**, five conditions are given for defining bed load dependent on suspended sediment concentration and size analysis of river bed material and suspended materials. According to this procedure, Condition 2 is close to the river bed conditions. This gives a recommended range of the bed load in terms of suspended load of 10 to 35 %. In view of these recommendations, a bed load concentration of 20% of the suspended sediment has been adopted. Here to calculate bed load of sedimentation of Attabad Lake HPP, 20% of suspended load has been taken as un-measured sediment load. Therefore, the annual bed load for Attabad Lake HPP site is estimated to be 4 Million Metric Tons.

Table 4-15 Lane and Borland Guidelines for Estimating Bed Load

Condition	Suspended Sediment Concentration (ppm)	Stream Bed Material	Texture of Suspended Material	Bed load in Terms of Suspended Load (%)
1	< 1000	Sand	Similar to bed	25 to 150
		Compacted clay	Small amount of sand	5 to 12
		Gravel, cobbles & boulders	Small amount of sand	5 to 12
2	1000 to 7500	Sand	Similar to bed	10 to 35
		Compacted clay	25% sand or less	5 to 12
		Gravel, cobbles and rocks	25% sand or less	5 to 12
3	> 7500	Sand	Similar to bed	2 to 8
		Compacted clay	25% sand or less	2 to 8
		Gravel, cobbles and rocks	25% sand or less	2 to 8
4	Any Concentration	Clay and silt unconsolidated	Silt and clay	< 2

Table 4-16 USBR Guidelines for Estimating Bed Load

Condition	Suspended Sediment Concentration (ppm)	Stream Bed Material	Texture of Suspended Material	Bed load in Terms of Suspended Load (%)
1	< 1000	Sand	20 to 50% Sand	25 to 150
2	1000 to 7500	Sand	20 to 50% Sand	10 to 35
3	> 7500	Sand	20 to 50% Sand	5
4	Any Concentration	Compacted clay, gravel, cobbles, or boulders	Up to 25% sand	5 to 15
5	Any Concentration	Clay and silt	No sand	< 2

4.13.11 Trap Efficiency

Trap efficiency (TE) is the proportion of the incoming sediment that is deposited, or trapped, in a reservoir or pond:

$$TE = \frac{S_{inflow} - S_{outflow}}{S_{inflow}} = \frac{S_{settled}}{S_{inflow}}$$

Where:

S_{inflow} is the sediment mass entering a reservoir (the sediment yield or delivery);

$S_{outflow}$ is the sediment mass leaving the reservoir with the outflowing water;

$S_{settled}$ is the sediment mass deposited within the reservoir.

The TE of reservoirs and ponds is dependent on several parameters (an overview of the processes taking place in a reservoir is given by Heinemann, 1984). Since TE is dependent on the amount of sediment deposited, parameters controlling the sedimentation process are very important. Therefore, the particle-size distribution of the incoming sediment controls TE in relation to retention time (i.e., the average time the incoming runoff remains in the reservoir or pond). Coarser material will have a higher settling velocity, and less time is required for it to be deposited. Very fine material, on the other hand, will need long retention times to deposit.

The particle-size distribution of the incoming sediment is dependent on the soils in the catchment that are being eroded and on the sediment delivery processes. The retention time of a reservoir or pond is related to the characteristics of the inflow hydrograph and the geometric characteristics of the reservoir or pond, including storage capacity, shape and outlet typology. A small runoff volume will have a larger retention time for a given pond than a very large runoff event, whilst the distance between the inlet and outlet controls the time it takes the runoff water to leave the reservoir or pond. The shape of the reservoir or pond (e.g., expressed as a stage-area curve) can also govern the retention time. Similarly, the location of the principal spillway can also control the retention time. If located at the bottom, the water will flow out directly while, if it is located at the top of the embankment, the runoff water will, first, have the opportunity.

Two methods are widely being used for the estimation of trap efficiency i.e. the method of Brune (1953), which is based on the capacity-inflow ratio and the method of Churchill (1948), which is based on a sedimentation index obtained by dividing the retention period by the average flow velocity in the reservoir.

US Army Corps of Engineers (1989) developed a regression using Brune's curve to estimate trap efficiency (T.E), which is:

$$T.\ E = 100 \times 0.97^{0.19^{\log (S/I)}}$$

Where S is the storage and I is the inflow rate. Using this equation, initial trap efficiency is to be 58% and its value decreases as the reservoir is silted up progressively

4.13.12 Life Assessment of Attabad HPP Reservoir

According to UNESCO (1985), life of a reservoir is the time from first impoundment till it is filled with sediments to a certain point, where it no longer serves the intended purpose.

For Attabad HPP, initial trap efficiency was estimated to be 58%. In order to do the reservoir sediment empirical modeling, the average sediment inflows have been taken as

24.06 million metric tons. Furthermore, an initial density of 1,122.4 kg/m3 has been used for the conversion of sediment load to sediment volume. By using above sediment flow in Attabad Lake, it will be filled in 10 years. So, reservoir life of the Attabad Lake HPP is about more than 11 years without flushing. **Table 4-18** shows in detail the life of reservoir

Table 4-18 Life of Attabad Reservoir

Sr. No.	Capacity		Inflow	Cap. /Inflow	Trap Efficiency		Annual Sediments		Loss of Capacity	No. of Years in which capacity is lost
	(% age)	(MAF)	(MAF)	Ratio	From Brune	Average	Transported	Trapped		
					Curve	Incremental	(MAF/Year)	(MAF/Year)	(MAF)	(Years)
I	II	III	IV	III / IV	VI	VII	VIII	VII x VIII	X	X / IX
1	100%	0.1	5.3	0.019	58.00%		0.017			0
						56.50%		0.010	0.010	
2	90%	0.09	5.3	0.017	55.00%		0.017			1.0
						53.50%		0.009	0.010	
3	80%	0.08	5.3	0.015	52.00%		0.017			1.1
						50.00%		0.009	0.010	
4	70%	0.07	5.3	0.013	48.00%		0.017			1.2
						46.50%		0.008	0.010	
5	60%	0.06	5.3	0.011	45.00%		0.017			1.2
						42.50%		0.007	0.010	
6	50%	0.05	5.3	0.009	40.00%		0.017			1.4
						39.00%		0.007	0.010	
7	40%	0.04	5.3	0.008	38.00%		0.017			1.5
						34.50%		0.006	0.010	
8	30%	0.03	5.3	0.006	31.00%		0.017			1.7
						25.50%		0.004	0.010	
9	20%	0.02	5.3	0.004	20.00%		0.017			2.3
									Total	**11**

5 GEOLOGY AND GEO TECHINCAL STUDIES

5.1 GENERAL

Geologically, the Project Site is located in Karakorum Block (KB) further to the north of Main Karakorum Thrust (MKT). The Karakorum Block consists of sedimentary, metasedimentary, igneous as well as metamorphic rock, throughout its extension from Karakorum Fault (KF) in the east, Chaman and Herat Fault in west (Zanchi 1993) ranging in age from Precambrian to Cretaceous. The overburden material, consist mainly of Angular Boulder Gravel with sand and appreciable amount of fines (ABGM) and Rounded Boulder Gravels with sand and appreciable amount of fines (RBGM). The talus deposits are main constituents of ABGM and well developed mostly in Shamshal Valley and along Hunza River in upstream reaches. There are many evidences (the deposition of clayey silt along both banks of Hunza River) along the road indicate that river might be chocked many time in recent past. Prior to Attabad slide, the slope failure occurs at Salmanabad in 1958 and chocked the Hunza River.

The topography and geological conditions present in this valley indicate that it is glacial originated valley modified later on by river system. There are many glaciers that feed the Hunza River, from south to north i.e. Hassanabad, Gulmit, Gulkin, Passu, and Batura Glaciers, from right side and Shamshal Valley Glacier from left side. Morphologically the valley is lithological as well as structurally controlled. Weak lithology i,e slates as well as fault system attributed to the development of present shape of the Hunza Valley in upper reaches and near MKT.

This report is mainly based on the annotations observed during geotechnical investigations carried out at Attabad Lake Hydro Power Project (ALHPP). The geological and geotechnical investigations include Surface Geological Mapping, Drilling at weir site, sediment flushing channel/undersluice, head race tunnel and powerhouse area, and identification of borrow area for construction material. Samples collected during geotechnical investigations have been tested to ascertain geotechnical properties at Central Material Testing Laboratory (CMTL), Lahore.

5.2 SCOPE OF WORK

During the Feasibility Study (FS) of ALHPP, Hydro Planning (HP), WAPDA, has identified the deficiencies of geotechnical investigations in pervious Feasibility Study and carried out detailed geotechnical investigation for comprehensive FS at present. The layout plan was completely changed during present FS and investigation were conducted according to new layout. One of most important aspect is Neo-tectonic studies, because this area is affected by Attabad Slide in 2010. It is very important for the development of hydropower Project in this area to develop the understanding the Neo-tectonic setting operating under regional tectonic forces for the stability and planning of the hydropower Project. All the geotechnical data collected during geotechnical investigations have been utilized for foundation evaluation of all structures of ALHPP.

5.3 REGIONAL GEOLOGY

The Project Area lies in the KB bounded in north by Central Pamir through Rushan Pshart Suture, in east by KF, in the west by Herat Fault and in south by Kohistan Island Arc (KIA) through Main Karakorum Thrust (MKT) (Pashkov & Shvol'man, 1979 & 1981). The Karakorum Block have classified as a part of Gondwana Land in pre-collision history. The rocks of KB have stratigraphic association with rocks of Indian Plate as indicated by Paleozoic to Mesozoic sequence of both plates. It is likely to be considered that Karakorum micro plate and Indian Plate were united till Mesozoic Era.

The stratigraphic sequence of the KB is metamorphic equivalent of sedimentary rock in Indian Plate which shows that both plates have pre-collision similarities. Also the KB consists of sedimentary (well exposed is in Chitral Area along Mastuj River), igneous rocks (Karakorum Batholith) and metamorphic rock (slates, schist and marbles).

5.3.1 Stratigraphic Sequence

The area under study mostly includes part of the Northern Karakorum Terrain, which comprises intensively folded and thrusted sedimentary rocks with a very low metamorphic imprint, locally reaching low grade conditions (Zanchi,1993). The Lower Permian to Upper Cretaceous succession of the North Karakorum represents one of the few terrains which escaped strong metamorphism during the Indian-Eurasian collision, thus permitted a detailed reconstruction of its stratigraphic framework **(Vol-2, DWG-1301)**. Plutonic bodies mainly of mid-Cretaceous age intruded the sedimentary cover forming a discontinuous granitic belt developed about 100 km north of the Karakorum Axial Batholith (KB). Four main tectonic units have recognized in the Project Region (Gaetani et all., 1990). These include;

5.3.2 Misgar Unit (MU)

This unit consist mostly of slates, with few intercalations of metacarbonate quartzite and black terrigenous slates, mostly exposed at the Northern part of the Project Area. In some areas, its thickness increases up to thousand meter. It is strongly folded with intensive developed of slaty cleavage. The fold axes generally trend E-W up to the Khunjerab Pass, where they turned to NNW-SSE. The unit has low grade metamorphism indicated by chlorite, biotite, and muscovite. This unit is intruded by granitoide pluton in northern and eastern terrain having western extension up to Sost. This unit belongs to different stratigraphic formations of Paleozoic age.

The southern boundary of Misgar Unit is faulted with south vergent thrust plane, the northern fault stacking the Misgar Slate over Jurassic limestone and sandstones of Sost belt (Gaetani et al. 1990). Large recumbent folds present along the northern flank of the Chapursan Valley suggest southward movement of MUT.

5.3.3 Sost Unit (SU)

It consists of grey to dark grey slates, meta-limestone, and quartzite. At places, it has dolomitic patches (Gojal Formation). Some sandstone beds with slate intercalations overlain by argillaceous limestone are present (Gircha Formation). It comprises thick pile of folded and thrusted sheets forming in the whole antiformal stack, later disrupted by strike-slip faults. The unit is bounded by two major faults, the Upper Hunza Fault (Desio, 1979) to the south-east and the Northern Fault to the north. Complexity of the tectonic pattern often prevented the reconstruction of continuous stratigraphic successions, as in the Middle Late Jurassic sediments. Fold axes and fault striations along the main thrust surface generally indicate a N-S compression. The well-developed schistosity is defined by sericite, muscovite and fine grained biotite with occasional occurrence of epidote and chloritoid. This suggests that low grade condition of metamorphism with an important increase of temperature with respect to other thrust sheets of the SU. These shear zones is still poorly understood and may possibly be related to the eastward prosecution of Hunza Fault (HF) juxtaposing the Gircha Slates of Gojal

Unit to analogues metasediments of Sost. The stratigraphic succession present in the SU spans from Permian to Late Cretaceous.

5.3.4 Gojal Unit (GU)

This tectonostratigraphic unit was defined by Gaetani et al. (1990) and includes the sediments lying between the KAB and the Upper Hunza Fault (UHF). It is composed by two units, a terrigenous unit (Passu Slates) below and a calcerous-dolomitic unit above. In the lower Shamshal Valley, dolomitic marbles terminate along a sub vertical NS trending fault while southward this unit is intruded by KAB. Contact metapelites generally undeformed or poorly deformed intrusive that grades into biotite, muscovite, and andalusite. Folds within the unit trend from NW-SE to NNW-SSE and are generally NE-facing. Thrust planes show the same trends and are NE-vergent, as in case of UHF.

5.3.5 Karakorum Axial Batholith (KAB):

The KAB crops out along the southern part of the studied area, where two major plutonic complexes were recognized, the Hunza and Batura Units (Debon et al., 1987). The Hunza Unit exists in a huge plutonic unit extending for more than 250 km, made up of medium grained granodioritic in composition, locally recrystallized. They represent a calc-alkaline association. Mafic enclaves of various sizes are abundant and a conspicuous network of Cenozoic leucocratic dykes is locally present.

The Batura Unit (BU) intrusive, spanning in age from Paleocene to Eocene, is mostly new, as well as the findings of plutonic bodies belonging to this unit in upper Chapursan Valley. The BU includes two main intrusive; the Kuk and Sarbzea Plutons.

The Kuk Pluton consists of pinkish, undeformed and unfoliated granitoides of various grain size, locally with porphyritic, microgranular and rapakivi textures. The Sarbzea Pluton mainly differs from the Kuk Pluton by its very coarse to medium grained rocks, and sometimes by the deformation it had under gone.

5.3.6 Ganesh Formation:

This Formation consists of pelite-psammite turbidite unit and overlying calc-pelite marble unit and are intercalated with each other. These units are metamorphosed up to upper amphibolite facies and therefore have well developed sheets of amphibolite. The formation has well developed ruby and spinal. Different mines are also established in this unit, as can be seen along road near Ganesh Bridge.

5.3.7 Hassanabad Granite:

It is well exposed in the Lower Hunza Valley and consists mainly of lower s-type granitoid-migmatite complex with metasedimentary enclaves. These garnet-tourmaline bearing two mica granitoids and migmatites are well exposed in Hasanabad Nullah and in Hunza Valley along Hunza River.

5.3.8 Chalt Formation:

It consists of dark grey quartz biotite schist with subordinate quartz, marble and conglomerate. It is exposed along overturned anticline and faulted against Dumordo Formation. Permo-Carboniferous age is assigned to this Formation.

5.4 REGIONAL TECTONICS

Before the Northward flight of the Indian Plate, small continental pieces (Cimmerids, i.e. KB, Helmand Block, Hasha Block etc.) were broken up from the northern edge of Gondwana Land and welded with the southern edge of Eurasian Plate, consuming the Old Tethey and opening the Neo Tethey, (Tapponnier, 1975, 1977; Molnar, 1977a).

In general, due to the subduction of the oceanic part of the Indian Plate beneath the Eurasian Plate, the Island Arc emerged in Middle Cretaceous age. The Arc Complex consists of calc-alkaline plutonic rocks mainly mafic in nature. The presence of blue schist metamorphism in Swat and Shangla Areas indicate the trench environment.

The collision of the Indian and Asian plates has been described as a “head on” north-south collision (Shackleton and Ries, 1984). This is generally accepted by many workers to have occurred in Eocene times (55-40Ma) (Powell, 1979; Klootwijk et al, 1979; Dewery et al, 1988; Treloar and Coward, 1991; Serrle et al, 1987, 1988). The terminal collision between Indian and Asian Plates is suggested to have occurred between 45-40 Ma (Molnar and Tapponnier, 1975; Klootwijk et al, 1985). It is generally agreed, however, that by 55Ma, the Kohistan Island Arc (KIA) was already sutured to the Asian Plate, probably since the Late Cretaceous, forming the MKT zone. This is confirmed by the presence of 85-80 Ma thermal event at this time (Treloar and Rex, 1990). The collision between the Indian Plate and KIA is recognized as when the Tethyan Ocean disappeared and the continental masses docked. Following features recognized the main arguments for the Eocene age of collision: -

- Sediments deposited on the northern margin of the Indian Plate being of Eocene age.
- Subduction of the oceanic crust stopping, as recognized by the end of calc-alkaline magnetism north of the Indus Suture.
- The blue schist facies are not developed along MKT zone showing the collisional belt.
- Slowing down of the Indian Plate motion, as recognized by magnetic anomalies.
- After collision, continued suturing occurred, associated with a 35˚ anticlockwise rotation of the Indian Plate relative to Eurasia. As a result of collision mighty mountain ranges of Himalayas were developed having Island Arc Sequence in the North.

Anticlock wise rotation of Mega Lhasa followed the Late Triassic docking of the Iranian Spur, using the later as pivot. The rotation was completed during the Middle Jurassic, when SE Pamir, Shaksgam and Karakorum joined the Qiangtang, more closely assembling Mega Lhasa as it approached the Asian margin (Maurizio Gaetani, 2007). The KB bounded in the East by KF, in the North by Rushan- Pshart Suture, in the west by Herat Fault and in south by MKT.

Structurally the KB is characterized by broad asymmetrical to tight, isoclinal folds which are commonly imbricated. A number of large regional scale thrust faults, e, g. the Tirchmir Fault, Reshun Fault, Baltit Fault, UHF, and Chapursan Fault and the MKT extends for a distance up to 100 km or more. The KB has undergone multiple deformations since the Cambrian. Parts of the KB have undergone at least four more deformations since the Kohistan-Karakorum collision from Paleocene to Pliocene.

After the collision, due to further northward subduction of the Indian Plate, still active 2-2.5 mm/yr, the stresses were accommodated by the imbricate thrust faults from north to south (Treloar et al, 1989). The collisional history along with metamorphic events, trapped many clues between these fault systems. These are very useful to delineate the historic events and to reveal the movement of Indian Plate, collision environment and modern deformational style.

5.5 REGIONAL FAULTS

The major regional faults of the region include, from north to south, the MKT, Main Mantle Thrust (MMT), Panjal Thrust (PT), Main Central Thrust (MCT), Main Boundary Thrust (MBT), Kashmir Boundary Thrust (KBT) / Himalayan Frontal Thrust (HFT) and Salt Range Thrust (SRT) **(Vol-2, DWG-1302)**.

Along with these regional faults, many local faults were developed to accommodate the regional stresses, these may be thrust fault or strike slip fault in nature. In most of the area many small scale strike slip faults are associated with the thrust faults to accommodate the deformation.

The general trend of these faults excluding MKT is predominantly east-west with change in trend due to syntaxial bends. The general description of these major faults is as follows: -

5.5.1 Karakorum Fault (KF)

Dextral Strike Slip fault of about 800 Km long bounds western Tibet. The KF represents a much younger terrane boundary, juxtaposing rocks of the Ladakh and Saltoro Blocks to those of Karakorum terrane. U-Pb zircon age of leuco-granites intrusion shows that it must, therefore, be younger than 15Ma old. Movement on the fault displaces the sequence approximately 200-250Km to south eastern Tibet where the regional rock sequence can be regained (Burtman et al. 1963, Srimal 1983). It merges at the confluence defining a triple point and three blocks; the Ladakh block to the south, Saltoro block to the northwest, and the Karakorum block to the northeast.

A number of tele seismic events have occurred along the fault. Interpretation of seismic data from 1975 Kinnaur earthquake confirms right-lateral strike slip motion on this fault. Three events were recorded from KF Zone at the head of the Nubra Valley, since 1980, recorded by portable seismic stations, established by International Karakorum Project (IKP). It is seismically an active fault.

5.5.2 Upper Hunza Fault (UHF)

It is east west trending thrust fault that runs along the depression formed by the Chapursan and Upper Yarkhun Valleys (Zanchi 1973, Kazmi 1979b, Gaetani et al. 1995). In this region it runs parallel to the northern margin of the KAB. Southeast of Morkun (upper Hunza) three tele seismic events of magnitude 5-7 and focal depth of less than 50km have been recorded. These epicenters form a cluster very close to the mapped trace of the UHFt. It means that the northern and western margin of the KAB is characterized by active zone of faulting along Upper Hunza-Reshun Fault zone.

5.5.3 Main Karakorum Thrust (MKT)

The MKT is a low angle mega-shear with strike slip component, which on eastern side passes through Machlu in Hushe Valley, Shigar Valley, Zuhri Brook in Shyok Valley and Chalt in Hunza

Valley extends westward through Ishkuman, Yasin and Shishi Valleys **(Vol-2, DWG-1302)**. Its general trend swings between E and E-NE at low to medium dips towards the north. It is believed that this fault is seismically active.

5.5.4 Main Mantle Thrust (MMT)

The MMT, which is aligned with the Nanga Parbat-Haramosh tectonic line on east, span an area of about 400 km through Diamer, Kohistan, Swat, Dir and Banjaur Areas, before entering Afghanistan **(Vol-2, DWG-1302)**. The general trend of MMT is NE-SW. It is located along the contact of the mafic/calc-alkaline meta igneous rocks and the meta-sediments belonging to the Indo-Pakistan continental mass. Along this megashear near Jijal Village on Indus River (right bank), the igneous rocks have over thrusted the meta-sediments to the south over a 10-15 km wide zone. The thrust also manifests as the broad high topography of Kohistan relative to the Hazara adjacent to the south. In addition, numerous auxiliary fractures are developed and across the thrust frequent brecciation and mylonitization are also present along the contact. It is seismically active fault.

5.6 SITE GEOLOGY

5.6.1 Soil Units

The recent deposits are the most widely spread soil units overlies the bed rocks. The slopes are covered with overburden having variable thickness. Terrace deposits comprise of mixtures of clay, sandy silt, boulders and gravel in various proportions. These units include ABGM, RBGM, Terrace deposit and Moranic deposits. These units are mostly present in Aliabad, Karimabad, Nagar and Gojal Areas **(Vol-2, DWG1305 to 1324)**.

5.6.2 Rock units

The main rock units exposed in Project Area explored during neo-tectonic study are as follows:

IX. Granitic gneiss

X. Granodiorite

5.6.2.1 Granitic Gneiss

It is light grey to grey in color on fresh surface and weathers to light brown, coarse to very coarse grained, moderately to highly jointed, highly sheared up to higher elevation due to faulting, sparsely to moderately weathered, moderately hard to hard. It has well developed foliation with trending value N61ºW and plunging value 79ºNE. It is exposed at the right as well as at the left bank of the Hunza River. Some shear zones are also present with in the unit **(Vol-2, DWG-1305 to 1324)**.

On the basis of petrographic analysis, it is evident that the major constituents' minerals present in granitic gneiss are quartz, oligoclase, biotite while amphibole, chlorite, muscovite, epidote, and tourmaline are present as minor constituent minerals. The high percentage of quartz grains show strong strain extinction, indicating that this unit has Alkali Silica Reaction (ASR) potential. The rock may therefore not be used as a coarse aggregate with Ordinary Portland Cement (OPC) or High Alkali Cement. It may be used with low alkali cement, slag cement or cement with additives likes fly ash, pozzolan. Some chemical additives like lithium nitrate or silica fume can also be used to control this reaction. The Schmidt Hammer values ranges from **35** to **45**

MPa indicating that rock is moderately strong to very strong. But in some shear zone where rock is tectonized locally, this value reduces up to **18-22 MPa**.

5.6.2.2 Granodiorite

It is dark grey to blackish grey in color, weathers to brownish grey, medium to coarse grained, moderately weathered, moderately hard to hard, moderately jointed intruded by pegmatite and granitic gneiss. It is foliated with trend and plunge values of N60ºW/79ºNE. Further downstream it becomes light grey to grey in color, coarse to very coarse grained. It is crushed, mylonized, and sheared at places. It is well exposed at both banks where it is intruded by many pegmatite dykes. Some shear zones are also present in this unit.

On the basis of petrographic analysis, it is evident that granodiorite is quite dominate in the Project Area. The major constituent's minerals present in this unit are plagioclase, quartz, biotite, and amphibole while Iron, muscovite, chlorite, and epidote are minor constituents. The high percentage of Quartz grains show strong strain extinction, indicating that this unit has ASR potential.

5.7 GEOLOGICAL STRUCTURES

As the Project Area has undergone multiple episodes of tectonics events, many regional as well as local faults and their splays have formed. Many thrust fault systems related to regional faults are present in the Project Area. There are many faults present in the vicinity of proposed ALHPP **(Vol-2, DWG 1305-1324)**. These faults are splays of MKT and Karakorum Strike Slip Fault, and lies in between these two fault systems. Some of these faults have been observed during surface geological mapping and marked on geological maps **(Vol-2, DWG-1305 to 1324)**. The brief description of these units are: -

5.7.1.1 Attabad-Hispar Valley Fault

It is thrust fault striking N30°E and dipping 40°SE, and is well exposed at the left side slope near the Project Area **(Vol-2, DWG-1305 to 1324)**. This fault crosses the Hunza River and forming a junction point with Hunza River and Attabad Fault in Attabad Village. The whole rock mostly granitic gneiss along its alignment is sheared / brecciated, forming fault breccia at many places. Due to high degree of shearing, many active slides have been originated along the slope. Rolling down of large boulder is quite common, and can be seen on old KKH. The retaining wall along this slide is fractured/jointed into parts due to operational stresses and downslope load movement. The ABGM along the slope is folded. It is clear indication that this fault has some movement, and is seismically active.

5.7.1.2 Attabad Fault

This thrust fault is striking N60°W and dipping 52°NE, exposed in area at rear side of Attabad Village. It is a small scale fault and terminates along junction point of three faults. A large brecciated and sheared rock is present along this thrust fault. At the junction point of these faults **(Vol-2, DWG-1305 to 1324)**, a large slide originated and destroyed about 2 Km of KKH. Sheared and brecciated rocks can be seen on outcrop at right side slope up to higher elevations in **(Vol-2, DWG-1305 to 1324)**.

5.7.1.3 Attabad River Fault

The exposure of this fault is present at right side slope of Hunza River. The breccia is well exposed at right side, just downstream of Sarat Suspension Bridge. The intensity of brecciation increases towards Salmanabad Village. In fact, Salmanabad Village was founded on this breccia. It may be present up to higher elevation **(Vol-2, DWG-1305 to 1324)**.

5.8 GEOLOGICAL & GEOTECHNICAL INVESTIGATIONS

5.9 SURFACE INVESTIGATIONS

The surface investigations / observations are one of the most important tools to reveal the geological conditions prevailing at the site. The natural processes operating on surface left clues to unfold the environments present in ancient time. During FS, surface geological mapping is carried out to record the geological conditions and to assess the deformation status of rock units exposed in the Project Area

5.9.1 Surface Geological Mapping

The surface geological mapping of the Project Area has been carried out on 16 Nos. topographic sheets prepared by Survey Division Peshawar, HP on scale 1:1000 with contour interval of 2m, with the help of Total Station, Plane Table and Brunton Compass in the field and presented at scale of 1:2000 **(**Photo 5.1**)**. The contacts between different rock units e.g. granitic gneiss and granodiorite as well as between different soil units have been marked. Structural features like joint sets, faults, foliation and shear zones along with dip and strike values have been marked on these sheets **(Vol-2, DWG-1305 to 1324)**. Four Nos. geological cross section were prepared along different alignments including, weir site, power tunnel intake area, and penstock alignment & powerhouse area.

Photo 5-1 Surface Geological Mapping

5.9.2 Neo-tectonics Study

During the FS, the understanding the Neo-tectonic setting operating under regional tectonic forces for the stability and planning of ALHPP has been studied in detail. The area under study has covered by the two Nos of GT sheets 42 L/15 and 42 L/11 at scale of 1:50,000, covering 40 km upstream and 50 km downstream of slided mass. These GT sheets were enlarged and printed at scale of 1:15000 and presented at scale of 1:30000, and used in field for alignment of local as well as regional faults **(Vol-2, DWG-1335 to 1337)**.

5.10 SUBSURFACE INVESTIGATIONS

Sub-surface geological and geotechnical investigation program was prepared to probe the sub-surface foundation conditions at weir site and its appurtenant structures including borehole drilling and test pits excavation. Drilling of exploratory bore holes was executed by Drilling Division, Hydroplaning, and supervised by Directorate of Geology, Hydro Planning WAPDA, Lahore.

5.10.1 Drilling

The main objective of drilling was to determine the nature and engineering characteristics of soil and rock units at Weir site and its appurtenant structures. It was performed to observe the subsurface geological conditions at depth in order to find out nature of the different strata in subsurface, to estimate the behavior and nature of overburden material, the depth of water table encountered. A total 06 bore holes with total drilling of 401m have carried out for subsurface exploration at different structures i,e Weir site, Sediment Flushing Channel (both at intake and outlet), Power tunnel alignment, Power house and tailrace area **(Vol-2, DWG-1330)**. The coordinates, structure, and depths of borehole are given in **Table 5-1**;

Table 5-1 Co-ordinates of Boreholes

Sr. No	Bore hole	Depth (m)	Northing	Easting	Elevation (m)	Location
1	BH-1	90	4018100.45	484075.46	2415.79	Weir site (Left abutment)
2	BH-2	60	4017996.26	484089.59	2452.81	Sediment Flushing Channel (Intake Area)
3	BH-3	61	4018061.58	483541.73	2456.92	Sediment Flushing Channel (outlet Area)
4	BH-4	80	4017721.34	482609.57	2445.37	Power Tunnel Alignment
5	BH-5	50	4017906.94	481690.72	2318.04	Power House area
6	BH-6	60	4017906.55	481605.02	2313.84	Power House area

Photo 5-2 Drilling Rig at BH-02 Sediment Flushing Channel

Permeability tests were performed using constant head method in overburden material at 3m interval whereas water pressure tests (Lugeon tests) in bed rock were performed at interval of 5m or at change of strata. Rock core and soil samples were collected from all the bore holes at various depths for lab testing. All the tests have been conducted at CMTL, WAPDA Lahore. The logs of drilled bore holes were prepared, Permeability values in overburden material and lugeon values in rocks were calculated and discussed structure wise and presented in **Volume 4B.**

The Standard Penetration Test (SPT) has been carried out in boreholes in overburden which mainly consists of Silty Sand with clay intercalations. The Cone Penetration Test (CPT) have been carried out in boreholes in gravelly Silty Sand with clay intercalations. CPT relied upon to provide information about the properties of soils / weak rocks. In foundation designs, SPT in overburden material, blow counts (N Values) are typically used to estimate nature and strength properties of soils to calculate the bearing capacity for foundation. The results are presented in bore hole logs **Volume 4 A**.

5.10.2 Test Pits

Ten test pits (3×3×3) m have been excavated in overburden material at weir site, slope along sediment flushing channel and power house area. Composite samples by con and quarter method from each test pit has been collected. Different tests have been conducted on these samples to estimate the engineering properties of the material.

To identify and proven source for coarse as well as fine aggregate, four test pits have excavated. Samples collected from these pits have been tested at CMTL, WAPDA, Lahore to check their suitability for fine as well as coarse aggregate. The logs of test pits have been prepared and presented in **Volume 4A.**

5.10.3 Laboratory Testing

Different rock core samples, to investigate the engineering properties of rock as well as soil (from test pits) at weir site, sediment flushing channel, power tunnel and powerhouse i have been tested at CMTL, Lahore, to envisage their engineering properties and to check its suitability as construction material.

A total ten rock core samples from BH-04 (Power tunnel alignment) selected for evaluation of geotechnical engineering parameters for design purpose. The table below shows the testing program proposed in BH-04 at different depths.

Fifteen samples, i.e. 3 Block Samples and 3 samples from borrow area and 9 test pit samples have been selected for investigation. Samples from all tests pits have been selected by cone and quarter method and different test have been proposed to check their engineering properties and confirm their suitability as aggregate material.

All the laboratory tests on rock core samples were conducted in CMTL, WAPDA, Lahore. The detailed results are presented in laboratory testing **Volume 4B**.

5.11 GEOLOGY AND FOUNDATION EVALUATION

On the basis of surface geological mapping, geological x-sections, borehole logs, test pits excavation and laboratory test results, the foundation evaluation of various engineering structures proposed for ALHHPP have been made and described in the following sections: -

5.12 WEIR SITE

The surface geological mapping of the main weir area has been carried out at scale of 1:1000 with the help of Total Station, Plane Table and Brunton compass and presented at 1:2000. A geological X-section along line AA` has been developed and presented as drawing **(Vol-2, DWG-1326)**. The main purpose of geological x-section is to estimate condition prevailing in subsurface i.e. overburden thickness, extension / alignment of faults, extension / trend of rock units in the subsurface strata.

Photo 5-3 View of Weir Site.

An overtopping concrete weir founded on slided mass is proposed after foundation treatment. Geological rock units with which weir has to be abut, includes granodiorite, intruded by pegmatite veins at right side. On left side weir has to be abut with ABGM formed by slided mass **(Vol-2, DWG-1309 & 1310)**. Some treatment / engineering solution have to be implemented for stability of the weir. A borehole BH-1, has been drilled at left side slope to investigate the subsurface geological conditions.

Table 5-2 Permeability Values in Soil and Rock

PERMEABILITY TEST IN OVERBURDEN		PERMEABILITY TEST (Lugeon) IN ROCK	
$<10^{-6}$	Impervious	0 to 5	Low Permeable
10^{-6} to 10^{-4}	Semi-pervious	5 to 15	Slightly Permeable
$>10^{-4}$	Pervious	15 to 25	Permeable
		>25	High Permeable

No rock has been encountered in this borehole up to 90m. The core recoveries CR (%) are graphically presented in **Figure 5-1.** The permeability test was conducted after every 3 meters, in most of test head could not be maintained due to cavities encounter in subsurface strata.

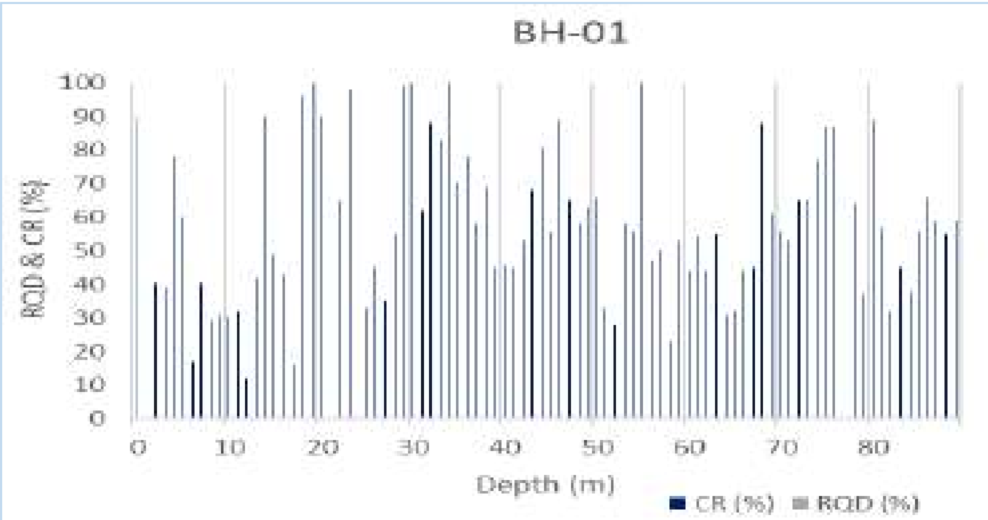


Figure 5-1 Graphical Representation of CR Vs Depth of BH-01.

It is noticed that head could not be maintained throughout the drilling of borehole. 100 % water loss has been observed throughout drilling activity. It indicates that slided mass is highly permeable with large cavities and open works as also testified by cementing job to stabilize the bore holes during drilling.

5.13 INTAKE AREA

The surface geological mapping of the intake area has been carried out at scale of 1:1000 and presented at 1:2000. A geological X-section along line BB` has been developed and presented as drawing **(Vol-2, DWG-1327)**

Photo 5-4 Proposed Intake Area for Power Tunnel

The main purpose to develop geological x-section is to estimate condition prevailing in subsurface strata i.e. overburden thickness, extension/alignment of faults, and extension/trend of rock units. The intake area is proposed at the left side of the Hunza River. Granodiorite rock is exposed at steep angle where rock is hard, massive, strong to moderately strong with Schmidt hammer values ranges from 40 to 58 MPa **(Vol-2, DWG-1307&1310)**. The rock in foliated where platy minerals are aligned in specific orientation with trending at N42°W and plunging at 52°NE. Granodiorite is hard, strong to moderately strong, and sparsely to moderately jointed **(Photograph 5-4)**. But at higher elevation the rock is highly jointed and sheared, having vertical open joints which must be treated for stability and safety purpose.

5.14 POWER TUNNEL

It is observed during surface geological mapping that a fault is running obliquely across the alignment of power tunnel alignment **(Vol-2, DWG-1308,1309,1312,1315,1316 &1319).** A geological X-Section CC` has been developed to estimate the subsurface conditions and presented as **(Vol-2, DWG-1315).** The power tunnel has to be excavated mostly through the granodiorite with subordinate granitic gneiss at the left side slope of Hunza River. The strength of rock reduces downstream and near the termination point of slided mass, brecciated/ gaugic rock is present/exposed **(Vol-2, DWG-1315).** Rolling down of large boulders are quite common at this point. The rock units are quite crushed, sheared and brecciated forming active slides throughout its alignment.

A borehole BH-04 has been drilled to estimate the rock conditions in the subsurface strata. Lugeon test has been conducted in the field to check the permeability condition of the rock mass at every 5m interval. On the basis of data collected during borehole logging, a graph has been developed between depth Vs Rock Quality Designation (RQD) and Core Recovery(CR) and presented as **(Figure 5-2)**.

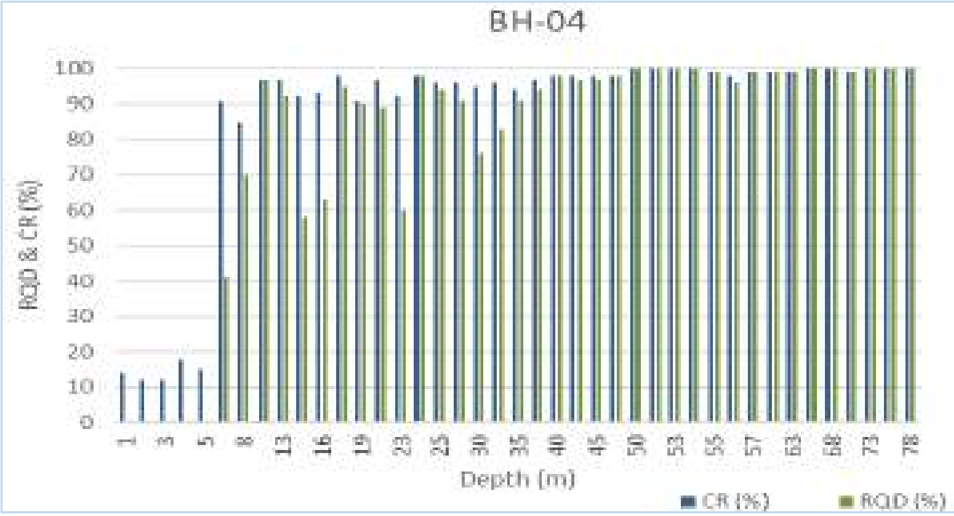


Figure 5-2 Graphical Representation of RQD&CR Vs Depth of BH-04.

During drilling work, it is estimated that the RQD values in upper 23m is moderately low after that the value increases/improved up to 100%. The lugeon values calculated after every 5m interval indicate that rock is low permeable. It shows that rock in sparsely jointed in subsurface. The lab test results indicate that RQD is quite high in lower portion but the strength index is moderate. The value of all test indicates that the rock in BH-04 is moderately hard and moderately strong with low cohesion "C" and low angle of internal friction "Ø". While excavating through this portion, some treatment is required to enhance the stability of structure.

5.15 UNDER SLUICE SECTION/SEDIMENT FLUSHING CHANNEL

The surface geological mapping of the power tunnel alignment has been prepared at scale of 1:1000 in the field and presented at 1:2000. It is proposed at the left side of Hunza River **(Photograph 5-5)**. It is observed during surface geological mapping that the sediment flushing channel has to be excavated through ABGM of slided mass **(Vol-2, DWG-1309&1310)**.

Slided mass covers an area of about 1 Km and consists of huge volume of ABGM. One of the difficult and critical task is to stabilize the both side slopes along the sediment flushing channel. The large boulders of more than 25 m in length are present in slided mass. Benching in one of the best solution for such type of slope to stabilize. At some place, mashing or gabion may be helpful for slope stabilization/protection.

Photo 5-5 Intake Area of Sediment Flushing Channel.

To investigate the nature of material exposed at left side slope, borehole BH-2 and BH-3 have been drilled at outlet and intake of sediment flushing channel respectively.

Permeability tests were performed at every 3m interval. It is noticed that throughout the borehole drilling, head could not be maintained and 100% water loss is observed during drilling.

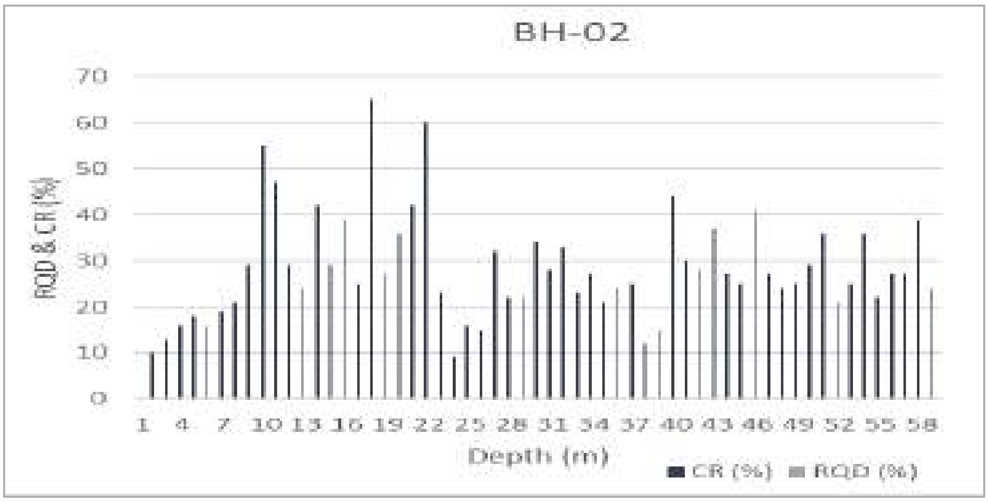


Figure 5-3 Graphical Representation of CR Vs Depth of BH-02.

On the basis of data collected during borehole logging, a graphs have been developed between depth Vs RQD and Core and presented as **Figure 5-3 & 5-4**.

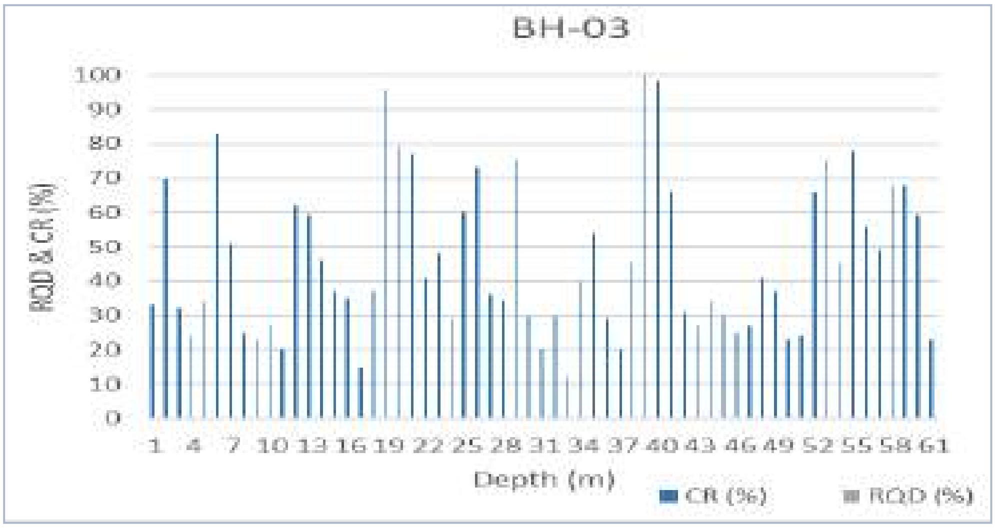


Figure 5-4 Graphical Representation of CR Vs Depth of BH-03.

Permeability tests have been performed at every 3m interval. These values indicate that the material is highly pervious.

It is clear from the drilling logs that rock is not encountered upto 60.0m in both boreholes. The drilling data and lab test results show that the boulders of overburden material ABGM) are hard and moderatly strong. The slope can be stablized by benching, but the permeability in BH-02 is quite high as head could not be maintained throughout drilling while in BH-03 is value shows that strata is pervious.

5.16 SURGE TANK AND PENSTOCK ALIGNMENT

It is proposed at the left side of Hunza River **(Photograph 5-6)**. It is observed during surface geological mapping that the granodiorite rock with granitic gneiss is exposed in surge tank area. It is moderately hard, sheared and highly jointed **(Vol-2, DWG-1319)**.

Photo 5-6 Proposed Area for Surge Tank.

From surge tank 450m long penstock with diameter of 3.6m is proposed up to power house. Piers will support penstock alignment. The foundation of piers will be laid on overburden material **(Vol-2, DWG-1318 & 1321)**. The presence of clayey silt may create problem and might be removed prior to establish foundation for piers **(Photo 5-7)**.

Photo 5-7 Proposed Alignment of Penstock

5.17 POWER HOUSE

The surface geological mapping of the power tunnel alignment has been carried out at scale of

1:1000 and presented at 1:2000. It is proposed at the left side of Hunza River on a flat area **(Photo 5-8)**.

Photo 5-8 Proposed Power House Aarea.

It is observed during surface geological mapping that thick clayey silt has been deposited having depth of about 30 m as confirmed by drilling (BH-5 & BH-6). It is interbedded in upper layers by RBGM while pure clayey silt is found in depth. It is deposited due to choking of Hunza River due to Salamanabad Slide **(Vol-2, DWG-1321).** A geological X-section DD` has been established to estimate the sub surface conditions and presented as **(Vol-2, DWG-1329).**

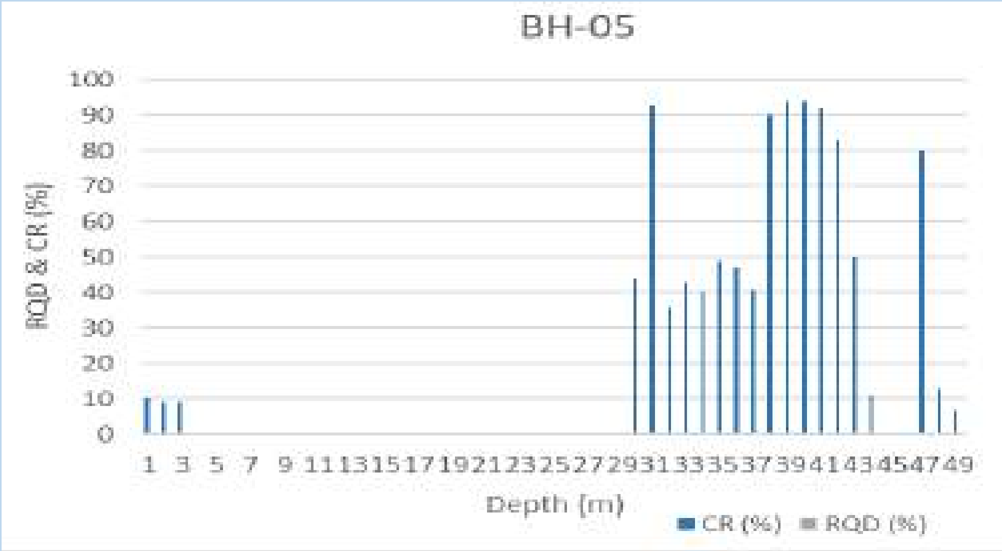


Figure 5-5 Graphical Representation of CR Vs Depth of BH-05.

To explore the nature of material present in subsurface, two boreholes, BH-05 and BH-06 with drilled depth of 50 m and 60 m respectively, have been drilled at powerhouse area. The summary of these boreholes is given in Figure 5-5 and 5-6.

On the basis of data collected during borehole logging, a graph has been developed between depth Vs CR and presented as **Figure 5-5**. Permeability tests have been performed. On the basis of data collected during borehole logging, a graph has been developed between depth Vs CR and presented as **Figure 5-6**. Permeability tests have been performed at every 3m interval

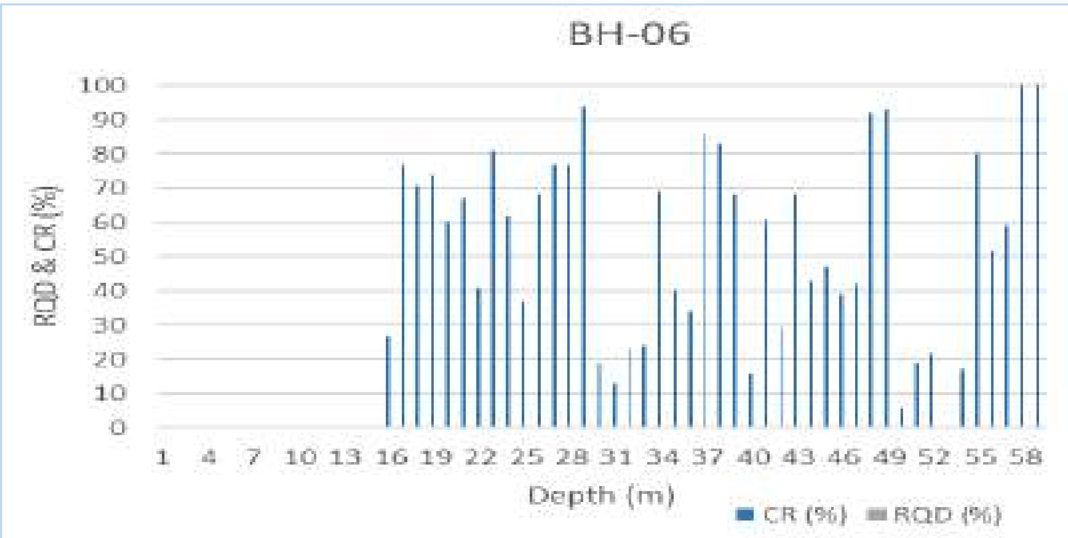


Figure 5-6 Graphical Representation of Depth Vs CR of BH-06.

It is clear from the drilling data that about 15 m and 30 m clayey silt have been encountered in BH-06 and BH-05 respectively. SPT have been conducted in the clayey silt for 18 inches' penetration in these boreholes. It is estimated from this data that firm to stiff clayey silt is present. The permeability test conducted in this strata show that they have relatively high hydraulic conductivity. The lab test results indicate that the clayey silt has swelling potential.

Foundation of the powerhouse will be laying on overburden material. The whole thickness of clayey silt layer has to be removed/excavated prior to establish the foundation for power house.

5.18 TAILRACE CHANNEL

The surface geological mapping of tailrace channel has been carried out at scale of 1:2000. It is proposed at the left side of Hunza River. It is observed during surface geological mapping that the whole channel has to be excavated through the overburden material **(Vol-2, DWG-1321)**. Water after generating electricity will again fall into Hunza River near Sarat Village suspension bridge.

5.19 CONSTRUCTION MATERIAL

The rocks granodiorite and grantic Gneiss are exposed in/near the Project Area. Both are acidic rocks and cannot be used as coarse aggregate with Ordinary Portland Cement (OPC) due to Alkali Silica Reaction (ASR). Both rocks show deleterious quartz more than 5%. However, a huge outcrop of marble is exposed in/near Passu Village. More over ten test pits have been excavated for the study of aggregate material and foundation condition. These were excavated in river bed, slided mass and fine deposits near old Chinese Camp in power house area. Samples of marble has been collected from Passu Area to conduct laboratory testing in CMTL WAPDA, Lahore.

5.20 FINE AGGREGATE

Two types of fine aggregate sand and clayey silt have been selected for testing and proven source for fine aggregate. Samples were collected from 0 to 3 m depth (by coning and quartering method) for laboratory testing at CMTL, WAPDA, Lahore.

5.20.1 Sand Quarry

To fulfil the quantity of sand material during construction of ALHPP, ample quantity of this material is deposited in the tail area of Attabad Lake near Shishkat Bridge **(Photograph 5-9)**. A test pit TP-1 has been excavated, for sampling for lab testing. Log of test pit is given in **(Volume 4A)**. Gradation test indicates that 99% sand with only 1% silt and clay is present. The results of Accelerated Mortar Bar indicate minimum average expansion (0.039) for 28 days. Specific gravity and water absorption values also fall in permissible limits. The results of lab testing is provided in **Volume 4B.**

Photo 5-9 Quarry Area Selected for Sand Near Shishkat Bridge.

The lab. test results show that it can favorably be used as sand quarry site during construction of ALHPP.

5.20.2 Silt and Clay Quarry

For fine aggregate (Clayey silt) three test pits 3x3x3m have been excavated to analyze the nature of material present in river bed. Two test pits TP-2 & TP-3 in Helipad/power house area and TP-10 near Klin area, near Ganesh Bridge, have been excavated to asertain the subsurface geological conditions prevailing in the area **(Photograph 5-10 & 11)**. Both composite as well as block samples from each test pit have been collected for lab testing.

Photo 5-10 TP-3, Excavated for Clayey Silt in P/H area.

Photo 5-11 View of Clayey Silt in P/H area.

Lab test results indicate that the material consists of clayey silt with clay index ranges from 40-to 45%. Atterberg Limits and Swell Potential shows that some treatment may be needed prior to their use. Results of Modified Proctor Test on block and composite samples indicate that Max Dry Density (MDD) 1.7 to 1.8 mg/m^3 for clayey silt can be attained in range of 10 to 13% Optimum Moisture Contents (OMC). The laboratory test results can be seen in **Volume 4B**.

Another huge source of borrow area for silt and clay is present at brick kiln near Ganesh Bridge along KKH. It lies in economic haulage. A test pit TP-10 has been excavated in clayey silt and two block samples have been collected from this pit and sent to CMTL to conduct different tests. The log of test pit is presented in **Volume 4A.**

It indicates from lab test results that, clayey silt is present and can be used as fine aggregate material i.e. blanket material to minimize the seepage. The ratio of silt and clay naturally present in 60 and 40% respectively. It is present in adequate quantity in P/H area and near Ganesh Bridge.

5.21 COARSE AGGREGATE

The rock units exposed in the Project Area are acidic in nature on the basis of silica contents i.e. granodiorite and granitic gneiss. Due to sliding of huge mass down slope, large material is deposited in foothills which chocked the Hunza River. For coarse aggregate, three sites have been selected. Samples from slided mass, powerhouse area/river bed and Passu Area has been tested at CMTL, WAPDA, Lahore.

5.21.1 Passu Area

It is located about 35 km upstream of Attabad Lake along KKH near Passu Village **(Photo 5-12)**. Bulk samples have been tested at CMTL, WAPDA, Lahore. Petrographic analysis shows that marble is exposed. It consists of 97% of calcite, with specific gravity 2.84 and 0.37 water absorption, Los Angeles Abrasion has uniformity of wear 0.20, Crushing Value 24, with Flakiness Index of 22. Sulphate Soundness Test result has weight percent loss 0.89 **(Volume 4B)**.

Photo 5-12 Exposure of Marble in Passu Village Area.

The laboratory test results indicate that the rock mostly consists of calcite with no ASR and no Alkali Carbonate Reaction (ACR). This material has no deleterious quartz, therefore it can be use with OPC. The values of tests results fall in permissible limit, therefore, it can be used as coarse aggregate for concrete with OPC.

5.21.2 Power House Area

Large quantity of RBGM is deposited near old Chinese Camp along old KKH route. Bulk sample from TP-2 has been tested at CMTL, WAPDA, Lahore. **(Photo 5-13)**.

Photo 5-13 View of RBGM in TP-2 at P/H Area.

It consists of marble, granite, granitic gneiss, with some slate pieces. As per lab. test results, material has specific gravity 2.78 with 0.33% water absorption. Los Angeles Abrasion value with uniformity of wear is 0.20, Crushing Value is 27, Flakiness Index is 21. Sulphate Soundness value is 0.81 and average expansion for 28 days in Accelerated Mortar Bar is 0.099, and Point Load Index is 4.15 MPa **(Volume 4B)**.

Petrographic analysis indicates that the rock is mostly granitic in composition and has more than 20% deleterious quartz, therefore, it cannot be used with OPC. To minimize the ASR, low alkali cement, cement with some additives like slag, fly ash, pozzolan can be used. Some chemical additives like lithium nitrate or silica fume can also be used. The finalization of the additive material depends upon the other strength and expansion tests during concrete mix design. Moreover, all the values of other tests fall in permissible limit, therefore, it can be used as coarse aggregate material for concrete with OPC by abiding the exceptions as described above.

5.21.3 Slided Mass

Sample from TP-7 have been collected to conduct different lab tests **(Photo 5-14)**.

Petrographic analysis shows that rock is granodiorite and has more than 20% deleterious quartz and cannot be used with OPC. Point Load Strength test result is 5.94 with diametrically failure, Specific Gravity 2.72 and Water Absorption 1.04%. Los Angeles Abrasion Test show 0.41 uniformity of wear, Crushing value 22 with Flakiness Index of 21. The value of Sulphate Soundness Test for this material is 1.87 **(Volume 4B)**.

Photo 5-14 View of Slided Mass in TP-6 at Left Side Slope of Hunza River.

Higher Los Angeles Abrasion, Sulphate Soundness and presence of deleterious quartz values, shows that this rock cannot be favored to be used as coarse aggregate material when compared with other two quarry sites. Thus this material is not recommended as coarse aggregate for concrete works.

5.22 BUILDING STONE

The granodiorite and granitic gneiss rocks are available in the Project periphery, for masonry works in sufficient quantities. Moreover, the large boulders, present in slided material can be used as rip rap material. To control the erosion/ wave action of water, this material has high strength UCS value ranges up to 72 MPa in TP-8. Similarly, the values of Property Index Test, Los Angeles Abrasion Test fall in permissible limits. The slided mass may therefore be used as rip rap material.

5.23 FILL MATERIAL

For protection works along slopes and structures, shoulder fill, construction of coffer dams, fill material of heterogeneous nature e.g. silty sand, sandy silt, gravelly sand etc. is available in river bed as well as in slided mass (**Photo 5-15**). This material is present in ample quantities in the economic haulage of the Project Area.

Photo 5-15 Fill Material (Boulder and Gravels) in Slided Mass.

The test pits excavated in the powerhouse area / river beds shows that large quantities of gravels and cobbles with subordinate sands are present. This material satisfy the quality test , therefore it can be used as fill material.

5.24 CEMENT AND STEEL

Cement and steel is required in adequate quantity for the construction of ALHH. The cement should be supplied from nearby cement factory. The most nearer unit of cement is situated in Haripur/WAH areas includes Askari Cement, Wah cantt unit with capacity of 3500 Ton/day; Fauji cement near Fateh Jang has two units one with 3500 ton/day and other with 6700 ton/day. It can be considered for the supply of cement

The steel has to be transported from Rawalpindi to fulfil the requirement of the Project. It is suggested that laboratory tests on representative samples should be carried out to determine the engineering characteristic of cement and steel prior to their use.

6 NEO TECTONICS AND SEISMIC HAZARD ANALSIS

6.1 GENERAL

A large slided mass move down and chock the Hunza River and KKH for more than 2km in January 2010 from right side near Attabad Village. This large slide causes a 25km long lake to develop upto Khyber Village in Gojal. Due to excavation and development of channel through this slided mass, the level of lake decreases down and extension reduces upto Shishkat Bridge. This large mass slided down due to some regional stress operating in this region. To understand these regional forces and their effect and vulnerability of expected slope material to slide, a Neo-tectonic study was conducted.

During the Feasibility Study, the colossal slide and as a result damping of Hunza River in 2010 has made the Neo-tectonic studies as core point. It is therefore, very important for the development of hydropower project in this area that understanding of Neo-tectonic setting should be explore to know the regional tectonic forces. Regional tectonic forces responsible for the massive slide, affecting project area severely as indicated by diverse features.

6.2 OBJECTIVES

Main objectives are:

- Evaluation of the regional tectonic setting of the area and recognition of fault (regional or local) which may act as a seismic source.
- Detailed investigation of the fault geometry, alignment, and structural deformations associated with these fault. These may include shear zones, fault bend folds, active slides and fault breccias.
- Recognition of active fault zones and their distinction from older, dormant fault zones.
- Assessment of the vulnerability of neo-tectonic activity along the fault/slides around the project area so that the movement along the affected area may be predicted.
- Identification of deformation/displacement in recent deposits to evaluate the activity of area.

6.3 METHODOLOGY

An array of activities including literature review, image analysis, field studies and data compilation is involved in Neo tectonic evaluation as per standard practices in Industry. These include:

- Collection of previous research on regional as well as on local geology, geomorphology and tectonics of project area.
- In-depth studies on satellite image analysis using GIS techniques by applying various image-enhancing techniques e.g. Digital Elevation Model (DEM) have studied, the lineaments and faults on regional as well as on local scale were recognized.

- Detailed geological map of the project site, regional and local faults within the vicinity covering the upstream and downstream of the project area have been marked on GT sheets at scale of 1:15000 in the field area to understand the trend of regional tectonic forces.

- During field visit keen concentration has been given to characterize the kinematics of fault where possible e.g. sense of fault (Strike and Dip), alignment and type of fault, through and heave, dip direction and other associated characteristics.

- Development of fault-source map indicating various regional scale faults that may contribute seismic affect in the project area.

- The relationship of older tectonic features to the recent ones.

- Field evidences of Neo-tectonic features have captured in photographs including active slides, tiltness in recent deposits, folding, faulting, step fault, fault associated folding in recent deposits, topographic features including drainage pattern at slopes and abrupt shifting of river/stream course.

6.4 FIELD OBSERVATIONS

This study covers the 30 km upstream and 30km downstream of the project site covering the both banks of the Hunza River. Different features related to Neo-tectonics activity have been observed during site visit. In this study the focus was given to the recent deposits, at the both bank of river.

The main objective of the Neo-tectonic study was to identify/observe the feature of active tectonic events occurred in recent past about 0.1Million years ago. There are many field observations regarding the Neo-tectonic activity. Some of the Neotectonics features/observation are as under: -

- The tiltness in recent deposition, i.e. to study the slopes of gravels, clays, and sand layers w.r.t slope of the stream beds.

- Intersection of faults in recent deposits i.e. lacustrine deposits, terraces/ alluvial deposits or in any cultural features (houses, roads). The amount of displacement, Heave as well as Throw measurement, dip and strike of the fault.

- The presence of active slide zones.

- The displacement /uplift in fluvial as well as lacustrine deposits on each side of the lake/stream and magnitude of its displacement.

- Identify the zones of brittle as well as ductile deformation.

- To observe the movements along slicken sides / fault / joints blocks.

- The presence of hanging valley along the main streams

- The presence of escarpment slope along the plainer area

- The presence of hanging valleys /cirques along main stream, in series and presence of waterfalls along it.

- Folding/bending in the recent deposits (alluvium, morainic, lacustrine).

The Neo-tectonic features at the right as well as left bank of Hunza River in different village from upstream to downstream **(Vol-2, DWG-1335 to 1337)** is described below: -

6.4.1 Passu Village:

Passu is one of the largest village in Gojal valley situated at the right bank of Hunza River along KKH about 35km from Attabad site. The great Passu Glacier, 56km in length is present near the village. Many deformational evidences were observed in recent deposits along the road.

- 2-3km Upstream of Passu village

N	4038610.325m
E	489292.583m
Ele.	2470.03m a s l

The coordinates measured by mobile topographer application.

A large deposit of RBGM material is present along the right side slope of the river along KKH. This material consists mostly of gravel, cobble, and pebbles with subordinate sandy material. Some inclinations in these deposits have been observed along roof and sole beds. This inclination varies from 15° to 35° layer-by-layer **(Photo 6-1).**

Photo 6-1 Inclined Gravel Layer under Effect of Shearing.

Some shearing effect has been chronicled along these planes in numeral layers. This shows that the area is tectonically active.

The clay deposit is overlain by morainic material of Batura Glacier. The clay deposits are tilted upward at an angle ranging from 10° - 15°. The area has undergone compressional regime, which uplifted the clay beds **(Photo 6-2)**

Photo 6-2 Recumbent Fold Strata with Crenulation in Limbs in Clay Strata.

The clayey strata is folded with straight horizontal limbs and horizontal hingline. This shows that the horizontal compressional stress is applied on this material that turned this unit into folded strata **(Photo 6-3).** Many micro folds (crenulations) in both limbs of fold are present. The Hinge area toward outer layers are point out, that intense compressional stress is applied to the strata.

Photo 6-3 Stylolite/Pressure Solutions in Clay Strata.

The strata show some stylolite structures that are formed by expulsion of water through pressure solutioning. Alignment of wavelength and geometry of Hinge area indicates that the compressional stress is applied horizontally **(Photo 6-4)**. This shows that the recent stresses are functioning in this area.

Many joints are developed in the clay beds showing that there are relative movement in blocks along the plane, which might be act as micro faults **(Photo 6-5)**. The relative movement of hanging wall block moves down relative to the footwall block, signposted the development of Normal Fault.

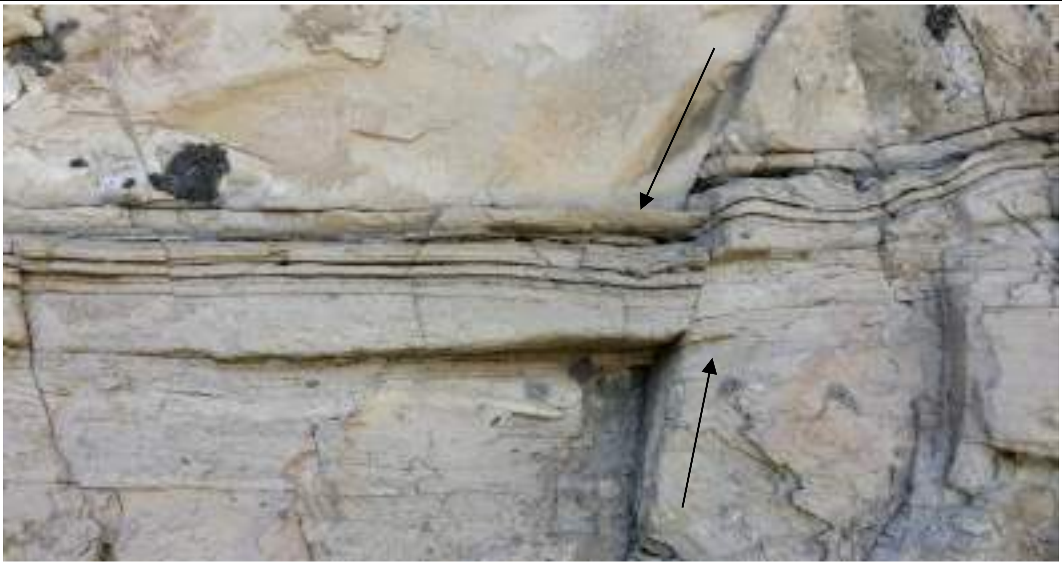


Photo 6-4 Micro Fault in Clay Beds.

At the same location there are cross cutting faults, dipping towards each other in clay beds. The block between two micro faults moves downward forming Graben structure while the block, that cannot move forming Horst structure **(Photo 6-5)**.

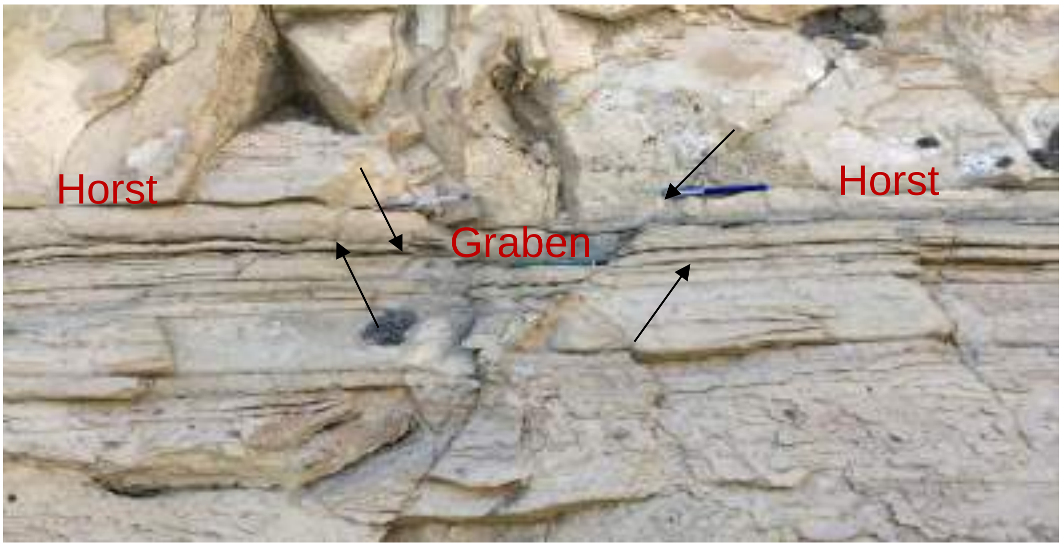


Photo 6-5 Horst and Graben Structure along Micro Fault in Clay Beds.

The formation of these structures in clay bed shows that there is relative movement along the micro faults in recent deposits.

The development of these Normal Faulting system in such compressional regime indicates that these deposits are under such environment where two thrust faults dipping toward each other are present. The upthrown block between these two faults undergone extensional regime where normal faults are developed. This indicates that this area is under active tectonics regime.