UPPER IRKHUWA HYDROPOWER PROJECT

(14.50 MW)

BHOJPUR

Detailed Project Report (DPR)

VOLUME I – MAIN REPORT

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SUBMITTED TO:

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EXECUTIVE SUMMARY

Upper Irkhuwa Hydropower Project is situated in Bhojpur District, in Province no 1. Project area lies between 27°22′58″ N and 27°24′17″ N latitude and 87°01'33" E and 87°03'51" E longitudes. The Project area is approximately 12 kilometres south east from Dingla, one of the major historical town of Bhojpur. Upper Irkhuwa Khola, within the Project area, lies entirely within Dobhane, Khatama and Kuda kaule Village Development Committees (VDCs)Major structure of project such as Headworks, surge tank and powerhouse lie on left bank of the Irkhuwa Khola. Waterway of the project passes through both bank. Due to topography of waterway, it crosses the Irkhuwa Khola twice. Initial and final stretch of water lie on left bank whereas middle stretch through right bank. The headworks site has been proposed at Irkhuwa Khola at about 400m upstream from the confluence of Irkhuwa Khola and Phedi Khola whereas the proposed powerhouse site is located about 800 m upstream from the confluence of Irkhuwa Khola and Benkhuwa Khola which lies in Kuda Kaule VDC.Powerhouse is proposed about 4.0 km downstream from the headworks on left bank of Irkhuwa Khola.

The two headworks have been proposed for diversion of required water, one at the Irkhuwa khola which is designed for full discharge as main headworks. Other at Phedi Khola which will be operated during dry season.

The proposed main diversion weir axis area is located about 400m upstream from the confluence of Irkhuwa khola and Phedi Khola at Irkhuwa khola to divert the water into waterway. Also, additional headworks is proposed at the Phedi khola to add the additional discharge to Irkhuwa Khola headworks. The catchment area at the intake site at Irkhuwa khola is 74.17 km^2 and at Phedi intake is 63.18 km^2. The powerhouse site of Upper Irkhuwa Hydropower Project is proposed at an elevation of 692 masl. Design discharge of the project at 45.0% exceedance flow is 7.80 m3/s including both Irkhuwa khola and Phedi Khola. Design of headworks has been carried out considering for 100 years return period flood discharge of 373.19 m3/s. Similarly, Power house design has been carried out considering 100 years return period of 383.80 m3/s.

Installed capacity of the Upper Irkhuwa Hydropower Project is 14500 kW. This ROR scheme comprises of 25 m long diversion weir with full reservoir level at 920.90masl will divert the design flow discharge to the intake at left bank. One number of under sluice 2.5 m wide and 2.5m high has been provided. Similarly, three no of intake 2.5m width & 1.5m high have been provided. Immediately after intakes, 7.5m length and 9.30m width gravel trap has been proposed to settle the gravel size of more than 5mm with gravel flushing arrangement. Settling basin is a surface type with two bays having length 55.5.0 m, width 6.50 m and 3.14 to 7.74m height. Settling basin has been designed for 0.20mm sediment particle with 90% trap efficiency of the basin. Also 24 m boulder weir has been proposed to divert water from Phedi khola to Irkhuwa khola with weir height of 3.33 m from river bed level. Crest elevation of Phedi weir is proposed at 924.60 masl. Intake arrangement is done by placing two gate of each 3.0m width and 0.8m height which will draw the diverted flow from Phedi diversion weir.

Penstock pipe is the main water conveyance system of the project which is about 3873.5m length with internal diameter varies from 2m to 1.75m connect the powerhouse. Three Horizontal axis francis turbines each of 4.83 MW capacities each will be installed in a surface powerhouse and tailrace canal of 87.10 m long is provided to discharges water back to the Irkhuwa Khola.

About 10 km long single circuit 132kV Transmission line is required to evacuate power from project's powerhouse up to Sithalpati substation.

This targeted commercial operation date of project is on 5th March 2024, with construction period estimated at 2.0 years. Construction power will be managed by connecting from the nearest distribution line or by using diesel plant.

The net energy generation as per PPA in the dry season will be 30.26 GWh/yr and that in the wet season will be 60.32 GWh/yr, the total energy during a year will be 90.58 GWh/yr including outage.

Cost estimate of Upper Irkhuwa Hydropower Project has been carried out based on 2077/2078 price level. Major cost components are divided into Land and support, Pre- operating expenses, infra-structure works, main civil works, hydro-mechanical works and electromechanical works & transmission line works. Cost of value added tax and contingencies have also been considered in the cost estimate.

Financial cost of the project includes taxes, duties, contingency and interest during construction. Based on the assumed disbursement of the cash flow, the total cost of the project is estimated NRs. 2,639,339,644.00 NRs including IDC.

Financial analysis of the project is carried out to assess the financial viability of the project. PPA is expected to follow the prevailing practice in Nepal i.e. NRs. 8.40/kWh in the dry season) and NRs. 4.80/kWh in wet season with annual escalation of 3% for eight times from the commercial operation date.

Internal rate of return of the project is 18.19%. Likewise, benefit cost ratio is 1.76 and NPV is NRs. 1,722,647,000. The financial parameter indicates the financial viability of the project.

TABLE OF CONTENTS

List of Tables

List of Figures

List of Abbreviations

%	Percentage
`	Minutes
`'	Seconds
masl	Meter Above Sea Level
cm/s	Centimeter per second
DHM	Department of Hydrology and Meteorology
DoS	Department of Survey
DMG	Department of Geology and Mines
f	Angle of repose for the soil
GWh	Giga watt hour
km	Kilometer
kN	Kilo Newton
kV	Kilovolt
kW	Kilowatt
kWh	Kilowatt hour
m	Meter
m^2	Square meter
m^3/s	Cubic meter per second
MIP	Medium Irrigation Project
mm^2	Square millimeter
MW	Megawatt
N	Newton
NEA	Nepal Electricity Authority
o	Degree
º C	Temperature in degree centigrade
US$	United States Dollars
VDC	Village Development Committee
WL	Water Level
Yr.	Year

Salient Features of the Project

1 Project Location

Development Region	:	Eastern Development Region
Zone/Province no.	:	Koshi / Province-1
District	:	Bojpur
Rural Municipality	:	Dobhane, Khatama & Kudakaule VDCs of Bhojpur District
Intake Site	:	Dobhane VDC
Powerhouse Site	:	Kuda Kaule VDC
Geographical Co-ordinates		
Latitude	:	27°22' 58" N to 27° 24' 17" N
Longitude	:	87° 01' 33" E to 87° 03' 51" E

2 General

Name of River	:	Irkhuwa Khola and Phedi Khola
Nearest Town	:	Dobhane, Kundakaule and Khatama
Type of Scheme	:	ROR-Hydropower
Gross Head	:	229.13 m
Net rated Head	:	214.78 m
Installed Capacity	:	14500 kW
Dry Energy	:	31.79 GWh
Wet Energy	:	61.42 GWh
Total Energy	:	93.20 GWh
Average Available flow	:	14.55 m^3/s

3 Hydrology

<u>Catchment Area</u>

Irkhuwa Khola Headworks	:	74.17 km^2
Phedi Khola Headworks	:	63.18 km^2

Combined Catchment Area at the Headworks	:	137.35 km²

Mean Annual Discharge

Irkhuwa Khola	:	7.74 m³/sec
Phedi Khola	:	6.81 m³/sec
Combined Mean Annual Discharge	:	14.55 m³/sec
Design Discharge (at 45.0% PoE)	:	7.8 m^3/s
Riparian Release	:	0.31 m³/sec

100 Yrs. Flood Discharge

Irkhuwa Headworks	:	191.63 m³/sec
Phedi Headworks	:	181.56 m³/sec
Average Annual Precipitation	:	1976 mm

4 Diversion Weir

Irkhuwa Khola

Type of Weir	:	Boulder weir
Length of Weir	:	25.00 m
Crest Elevation	:	920.90 masl
Weir height	:	3.45 m
Width of weir crest	:	2.00 m

Phedi Khola

Type of Weir	:	Boulder weir
Length of Weir	:	24.00 m
Crest Elevation	:	924.60 masl
Weir height	:	3.33 m
Width of weir crest	:	1.50 m
Water Conveyance upto Irkhuwa khola	:	Approach canal of size 2.5m width and 1.80m high,84.50m length

5 Undersluice

Number	:	1
Size of undersluice	:	2.5 x 2.5 m
Slope	:	1 in 20

6 Intake Structure cum Gravel Trap

Irkhuwa Khola

Type of Intake	:	Orifice, Side Intake
Nos of Opening	:	3
Size of Intake (W x H)	:	2.50 m * 1.50 m each
Intake Sill Level	:	918.70 masl
Size of Gravel Trap	:	7.50 m x 9.30 m x 2.05-5.20m (L x B x H)
Particle size to be trapped	:	5 mm
Flushing Duct (W x H)	:	1.0 m x 1.15 m

Phedi Khola

Type of Intake	:	Orifice, Side Intake
Nos of Opening	:	2
Size of Intake (W x H)	:	3.00 m * 0.80 m each
Intake Sill Level	:	923.60 masl

7 Settling Basin

Type	:	Conventional with intermittent flushing
Nos of bay	:	2
Dimension (L x B x H)	:	55.50 m * 6.5 m * (3.14 to 7.74) m
Inlet Transition Length	:	10.00 m
Particle Size to be settled	:	0.20 mm
Trapping Efficiency	:	90%

8 Penstock Pipe

Type	:	Mild steel
Length	:	3873.50 m
Steel headrace pipe diameter	:	Varies from 2000 mm-1750mm diameter, 8mm-25mm Thick
Nos. of Anchor Blocks	:	43 nos of AB and 2 nos of Concrete Casing(at river crossing)
Nos. of Saddle Supports	:	42 (stone Masonry), 13 (R.C.C. Saddle) and 361(saddle Pad)

9 Powerhouse

Type	:	Surface with 3 units of turbine
Size of powerhouse	:	47.5 m * 16.30 * 18m (L x B x H)
Turbine Axis Level	:	506.2 masl

10 Tailrace

Type	:	Concrete, Box canal
Tailrace Length	:	87.10 m
Size (W x D)	:	2.5 m * 2.5 m
Tailrace Water Level	:	691.77 masl

11 Turbine

Type	:	Horizontal Francis
Number	:	3
Rated Output Capacity per unit	:	5,040 kW
Net Head	:	214.68 m
Discharge per Unit	:	2.6 m3/sec
Efficiency	:	92.00 %

12 Governor

Type	:	Digital electronic with PID type
Adjustment for Speed Drop	:	Adjustable to any degree between zero and 10 %

13 Generator

Type	:	Cylindrical pole, synchronous ,3 phase
Rated Output Capacity per Unit	:	5,750 kVA
Power Factor	:	0.85
Voltage	:	11 kV
Frequency	:	50 Hz
No of Units	:	3
Excitation System	:	Brushless Excitation System
Efficiency	:	97.00 %

14 Transformer

At Powerhouse Switchyard

Type	:	Single Phase, Oil Immersed, Outdoor
Rated Capacity	:	5,750 kVA
Voltage Ratio	:	132/11 kV
No of Units	:	3 + 1 Standby
Vector Group	:	Ynd11
Efficiency	:	99.0 %

15 Transmission Line

Voltage Level	:	132 KV single circuit
Length	:	10.0 Km Approx.
Conductor Type	:	ACSR Dog
From	:	Upper Irkhuwa Switchyard
To	:	Sithalpati substation

16 Project Cost Estimate

Total Cost of the Project	:	NRs. 2639.339Million (With IDC)

17 Construction Period : 2.0 years

18 Project Evaluation

Internal Rate of Return (IRR)	:	18.19

BC Ratio	:	1.76
Return on Equity (ROE)	:	29.42%
Interest rate	:	10 %
Net Present Value (Nrs ’000)	:	1,722,647

1 INTRODUCTION

1.1 Background

Nepal is in a phase of sustainable economic development characterized by harnessing its maximum hydroelectric potential. According to the annual report (2019/12/24) of Nepal Electricity Authority (NEA), NEA is supplying 7924 MWh, IPP is 7231 MWh and demand is 22489 MWh. Power demand is gradually increasing at the rate of approximately 100 MW per year but production growth is only 50 MW. In order to meet the increasing power demand in an efficient manner, there is an urgent need to identify and promote small to medium sized hydroelectric projects which can be implemented at the earliest. Thus, NEA and Department of Electricity Development (DoED) are encouraging to develop such project from private sectors for harnessing the water resources potential in a sustainable manner.

Realizing the fact that, efforts from the Government of Nepal only, will not be sufficient an open and free policy has been adopted for expediting hydroelectric development with private sector investment. Necessary laws and regulations including the Hydroelectric Development policy (2001) has been proclaimed to encourage the Independent Power Producers (IPPs) to build, own, operate and transfer Hydroelectric project. In this context, Upper Irkhuwa Hydropower Project (UIHPP) was identified in Bhojpur District of Nepal and now it is in development phase.

Upper Irkhuwa Hydropower Project (UIHPP) is a Run-of-River type project. It is located in Bhojpur District of Eastern Development Region of Nepal (Province no 1). The headworks of the project lie at Irkhuwa khola about 400 m upstream of Irkhuwa Khola and Phedhi Khola confluence at Irkhuwa khola and the additiomal headworks is proposed at the Phedi Khola to divert the additional discharge to the Upper Irkhuwa Hydropower Project. The sub-surface powerhouse lies on the left bank of the Irkhuwa Khola at about 3.8 Km downstream of the proposed weir site. The pressurized steel pipe constitutes the major waterways component. The generated power will be evacuated through approximately 10 km long 132 kV transmission from Upper Irkhuwa HPP Switchyard to Sithalpati substation.

1.2 Objectives

The main objective of the present study is to carry out the review of feasibility study and detailed design of the project component. This study report can be used as a basis for financing of the project as well as for awarding the tender. Following are the general objectives of this study:

- Review the proposed headwork site, headrace alignment, position of surge tank, penstock alignment and power house and further optimize the general arrangement of the project.
- Carryout detail topographic survey and investigation.

- Obtain additional information / data through field surveys, investigation and laboratory tests.
- Prepare necessary maps and sections/ profiles as per the project requirement.
- Finalize the project layout.
- Carry the hydrological and meteorological study.
- Conduct the geological study to determine the overburden condition at the sites of major hydraulic structures and to assess rock conditions and slope stability.
- Update possible energy generation.
- Prepare Bill of Quantity (BOQ) and make cost estimates.
- Prepare tender document, contract document and construction drawings.
- Prepare construction plan and project implementation schedule.
- Carry financial analysis.

1.3 Scope of Works

In order to achieve above-mentioned objectives, the primary task of the Consultant is to prepare the detailed study of the project.

The detailed design is carried out in accordance with the standard practice and guidelines. The study is in line with the requirements mentioned in the Standards for Study of Hydropower Projects published by GoN/ DoED. The study covered all aspects of the project including:

a) Review of previous studies
b) Hydrological, meteorological and sediment studies
c) Update hydrological analysis
d) Project layout
e) Optimal design of project components
f) Update power and energy
g) Construction methods and planning
h) Structural design and working drawing preparation
i) Cost estimate
j) Prepare tender document and drawings, contract document and
k) Financial analyses of the project

1.4 Methodology

Previous studies on the project have been reviewed. A team of experts comprising of senior hydropower engineer, hydrologist, geologist and surveyor visited the site. Recognizing the importance of directly measured flow, flow measurement using current meter was undertaken and arrangement was made to establish a gauging station to continue gauge height recording. Leveling was carried out for the alternative locations of intake and powerhouse sites to create a basis for selection of most promising alternative among the identified alternatives. Based on site-specific information gathered during this initial site visit, a field investigation program for detailed survey, geological investigation and hydrological measurement as well as gauge height recording was prepared.

The topographical survey and geological investigations were carried out and necessary topographical maps were prepared using CAD.

The hydraulic design of structures, drawings and quantity calculation were done. The rate analysis of the items of work was carried out on the basis of district rates and standard norm. Economic and financial evaluation of the project was carried out and the reports were prepared.

1.5 Organization of the Report

The Detailed Project Report has been organized into two volumes as follows:

- Main report (Volume I)
- Drawings (Volume II)

The main report (Volume I) has following twelve chapters.

Chapter 1 Introduction

Chapter 2 Description of Project Area

Chapter 3 Field Investigation and Data Collection

Chapter 4 Hydrology and Sediment study

Chapter 5 Geology and Geotechnical investigation

Chapter 6 Project Description and Design

Chapter 7 Power and Energy

Chapter 8 Cost Estimate

Chapter 9 Project Evaluation

2 DESCRIPTION OF PROJECT AREA

2.1 Location

The project area is located between 917.00 m and 688.00 m above mean sea level in the middle reach of Upper Irkhuwa Khola of Bhojpur District, Province no. 1 of Nepal. Geographically project area lies between latitude 27° 22' 58" & 27° 24' 17" and longitudes 87° 01' 33" & 87° 03' 51". The headworks of the project lie in Irkhuwa Khola at Dobhane VDC and the powerhouse lies on the left bank of the Irkhuwa Khola at Kudakaule VDC. The project area location map is shown in Figure 2-1.

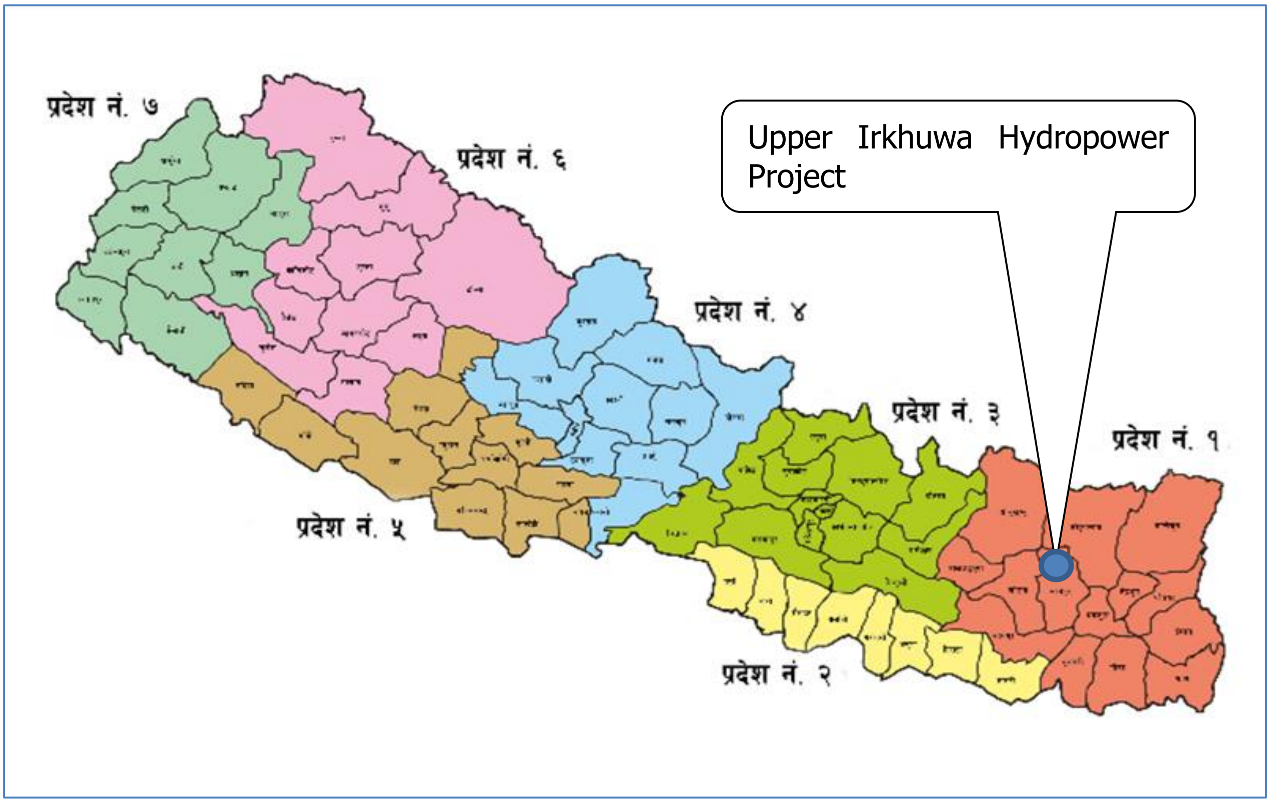


Figure 2-1: Location Map

2.2 Physical Feature

2.2.1 Topography

Project area lies in the Lesser Himalayan region (Figure 2-2). Irkhuwa is a rain fed, Perennial River. The average gradient of the river up to the intake is about 3.571% and in between the intake and powerhouse site is about 4.167 %. Based on the topographical maps, Limited agriculture lands occupy the basin in parts below 3000 m. The areas of the basin from 750 masl to 1500 masl are covered by fairly dense pine forest to mixed forest.

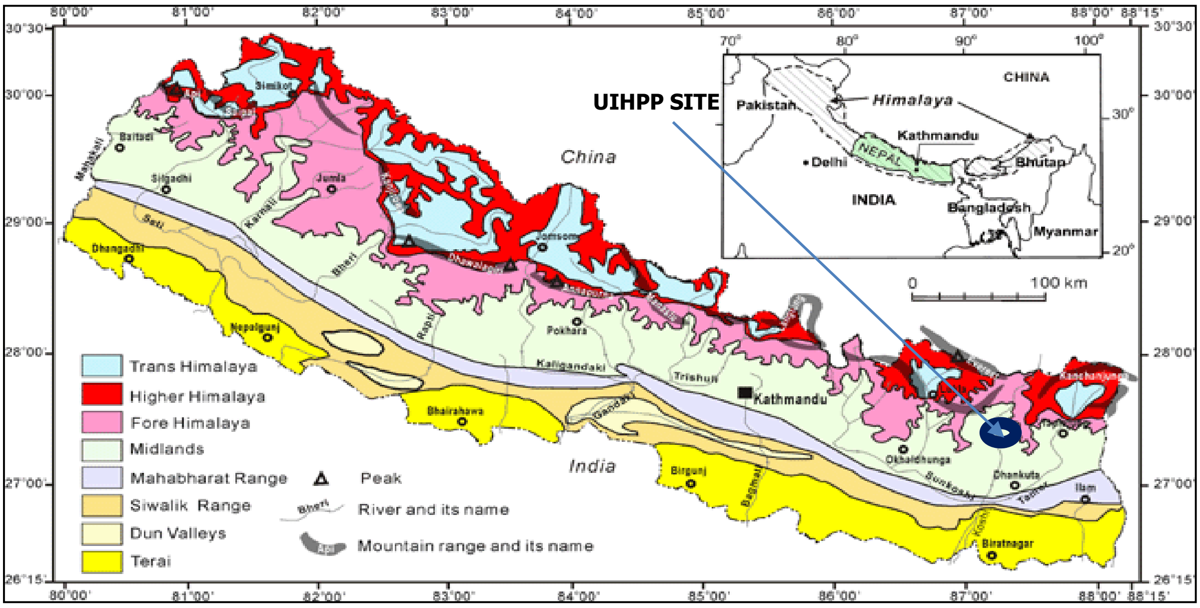


Figure 2-2: Physiography of the Nepal Himalaya (after Dahal and Hasegawa, 2008) and location of the Project site

2.2.2 Climate

Nepal experiences an exceptional climate variation owing to its steep gradient from high Himalayas in north to plains in south. Five different climatic zones i.e. tropical, sub-tropical, temperate, alpine and tundra as shown in Figure 2-3 have been classified from low land in south to snow peaked Himalayas in north. The country as a whole receives most of rainfall due to south-west monsoon, which arises from the Arabian Sea and passes through India before entering Nepal from eastern part during June-July. Difference between the warm humid summer and the cold dry winter becomes more marked with the change in the altitude.

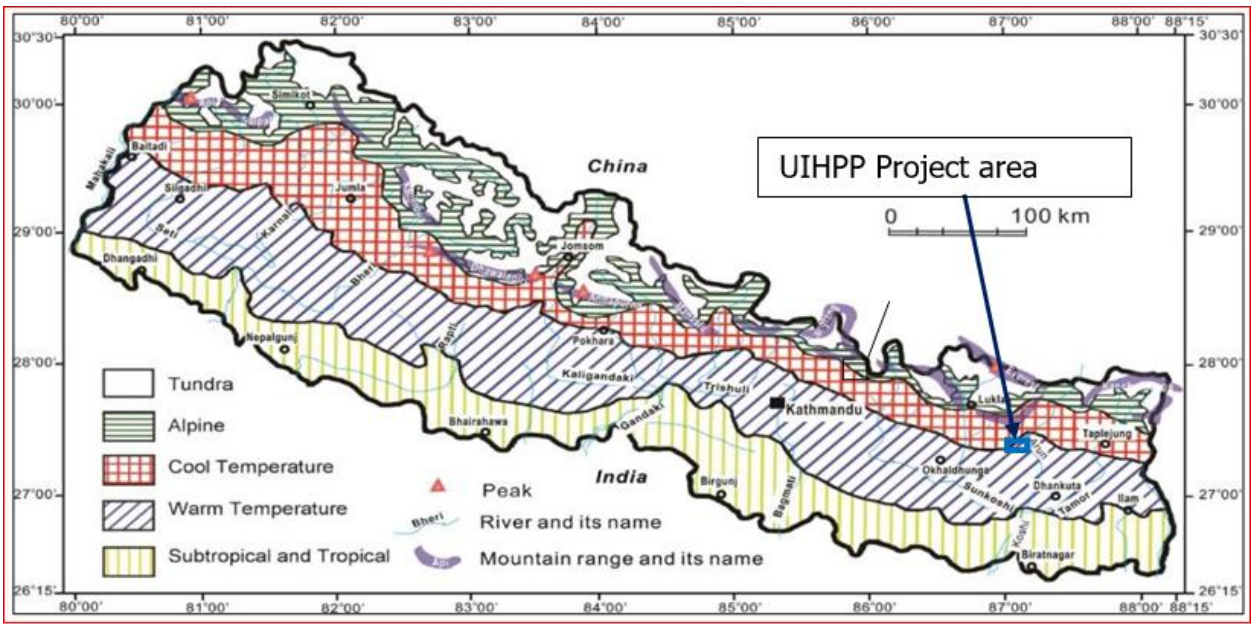


Figure 2-3 Climatological Map of Nepal and Location of Project Area

2.2.3 Geology

Area lies in the Lesser Himalaya of Central Nepal, consisting of Augen gneiss and schist. Structurally, Main Central Thrust (MCT) is located towards North of the project area. Rocks in this area are deformed due to presence of thrusts and folds.

2.3 Accessibility

The proposed project site can be accessed by three different alternatives.

Route 1: Tumlingtar-Satighat-Chirkhuwa-Nepaledanda-Tamutar- Phedi -Headworks site

Route 2: Tumlingtar-Satighat-Chirkhuwa-Gahate-Majuwa beshi – Tintama-Gothe bazaar – Phedi – Headworks site

Route 3: Bhojpur-Dingla-Chirkhuwa-Route1/Route 2

Route 4: Khadbari-Heluwa beshi-Majuwa beshi-Route 2

Tumlingtar in sankhuwasabha district has all-weather motorable roads as well as airport with black topped pitch. For the Route 1, there is bridge underconstruction in Satighat for Arun River. It needs to cross Chirkhuwa to access project all-round the year. The track opening for the Route 1 is ongoing and about 4 km is being built to reach headworks site. Similar is the case for Route 2, there is necessity of track opening about 200m in the right bank of Irkhuwa Khola near the confluence with Sisne Khola. For Route 4, there is public taxi servie up to Heluwa beshi and there is bridge proposed in Arun River. For Route 3, there is public service up to Dingla bazaar and tractor is running from Dingla to Chirkhuwa. From Chirkhuwa it can be extended towards the project site either by Route 1 or Route 2.

2.4 Project description

Upper Irkhuwa Hydropower Project is a run-of-river type project with boulder rip-rap weir of 25m length and crest level at 920.90 masl Proposed at Irkhuwa Khola and along with the discharge from Irkhuwa Khola the additional discharge from Phedi Khola is also added to the project by constructing boulder rip-rap weir and diverting water just upstream of Irkhuwa Khola headworks. A 24m length boulder weir is proposed to divert the water from Phedi Khola to Irkhuwa Khola with weir crest level at 924.60 masl. Powerhouse tail water level at about 691.77 masl respectively. The water from the intake is diverted to the water conveyance system through gravel trap, settling basin and head pond. And then water is feed into powerhouse to generate electricity which is evacuated to national grid through 10 km long 132 kV transmission line.

The diversion weir of 3.45 m high boulder weir is proposed to divert the required water. The project utilizes design discharge and gross head of 7.80 m^3/s and 229.13 m (measured from weir crest) respectively.

The topography of the area is characterized by steep to mild slope. Abundance vegetation can be observed in the project area. There are no any major landslides observed in the project area.

The total length of waterways will be about 3873.50 m before bifurcation. Besides, the major components of the project can be visualized as the combination of the following hydraulic structures:

- Diversion weir, Orifice type side intake
- Intake canal
- Settling basin with flushing arrangement
- Headrace Canal
- Head pond
- Penstock pipe
- Anchor blocks and support piers
- Cross drainage works
- Powerhouse
- Switching substation
- Tailrace canal

The design aspects of the above components are described in Chapter 6 of this report. General Layout, Plan & Profile and design drawings of the project are presented in Volume II.

3 FIELD INVESTIGATION AND DATA COLLECTION

3.1 Topographic Survey and Mapping

Detail topographic survey works for Upper Irkhuwa Hydropower Project were conducted from Poush 7, 2077 to Magh 6, 2077. Upper Irkhuwa Hydropower Project is a run-of-river type project located at Dobhane, Khatama and Kundakaule VDC's of Bhojpur District, Eastern Development Region,Nepal. The site on north east side of Gothebazar is approximately 450 Km far from Kathmandu. The Project area is approximately 12 kilometres south east from Dingla, one of the major historical town of Bhojpur. Geographically project area lies between latitude 27°22' 58" & 27°24' 17" and longitudes 87°01' 33" & 87°03' 51". The headworks site has been proposed at Irkhuwa Khola at an elevation of 920.90 masl and the River Flow of Phedi khola is diverted to Irkhuwa khola whereas the proposed powerhouse site is located at left bank, about 400 m upstream from the confluence of Irkhuwa Khola and Benkhuwa Khola which lies in Kuda Kaule VDC.

3.1.1 Scope of Work

The survey works were carried out with the objective of preparing maps of headworks, intake and powerhouse site area topographical survey and also water way pipe line Survey in appropriate scales to enable working structure layouts to be prepared. The following works were performed:

- All the survey works were under taken using UTM grid co-ordinates and elevations.
- Close traverse survey was carried out from proposed sites covering headworks, waterway and proposed powerhouse site to establish required ground control points at various locations in the project area.
- All the major ground control points were monumented with marked on permanent boulders and Rock with crossing chisel.
- Topographical maps of headworks and powerhouse sites were prepared in appropriate scales.
- Conduct the longitudinal profile survey of the river.
- Conduct river cross section survey of potential weir and powerhouse site showing high flood level and existing water level.
- Conduct strip survey of access road alignment with 5m contour interval (1:5000 scales, 500m interval).
- Conduct leveling survey and traverse survey tying with trigonometric points of national

grid established by Nepal Government.

- Locate approximate potential diversion weir, settling basin sites and to make route alignment for water way.
- Establish horizontal and vertical control points via traverse.
- The topographical Survey of headwork sites, Surge tank, canal alignment, penstock pipe, surge tank, powerhouse sites, tailrace etc.
- Prepare Topographical map of contour interval 1m.
- Submit Detail Survey Report.

3.1.2 Available Information and Data

The available data was the electronic and printed copy of topographical maps provided by Topographical Branch, Department of Survey. The information available for carrying out the final design study of the Upper Irkhuwa Hydropower Project is as follows:

Topographic Maps from the Department of Survey, Topographic Survey Branch.

Scale : 1:25,000

Sheet No : 2787 09 A

Coordinates and elevation of control points set up by the survey department and referring from nearest station.

3.1.3 General

The senior surveyor and his group carried out the detailed topographical survey of the selected schemes. The detail topographical survey was conducted using advanced total station which measures the angle and distance precisely. Total station instruments measures angles by means of electro-optical scanning of extremely precise digital bar-codes etched on rotating glass cylinders or discs within the instrument and measurement of distance is accomplished with the help Electronic Distance Measurement(EDM) devices fitted Inside the telescope to measure the distance accurately. To achieve the required accuracy and standards, the following instruments were used to complete the detail survey of the project:

Table 3-1 List of Survey Instrument

Survey Equipment and Model	Nos.	Angle Accuracy	Distance Accuracy
Topcon ES-105	1	± 5″	± (2mm + 2ppm x D)

Stonex-DL	1	± 2″	± (2mm + 2ppm x D)

3.1.4 Methodology

The methodology used for the entire survey works was developed as per the scope of works, which includes desk study, reconnaissance survey, monumentation of control points, control traversing, horizontal and vertical control points and detailed topographical survey of the project area was carried by the survey team led by senior surveyor.

3.1.5 Desk Study

Prior to the field survey, desk study was carried out by using topographical maps 2787 09 A (Scale 1: 25,000) published by Nepal Government, Survey Department in 1996. Detailed information about the project area for the survey work was noted. Finally, all the available plans, profiles and location maps prepared during the identification study were collected.

3.1.6 Reconnaissance Survey

After finalizing the desk study, a team of multi-disciplinary experts were mobilized for field visit. After finalizing the project site and before the detailed survey work, a brief reconnaissance survey was carried out with flagging at necessary points around the entire project area to be mapped. All the flagging points were marked by red enamel paint.

3.1.7 Monumentation of Control Points

Control Points were established on cross chiseled boulders. Every control points were marked by red enamel paint on the site. Description cards of all the major control points were prepared. The description cards are presented in Annex-B. The description cards of the control points depicted the following information:

- ID of the Control Point
- Location description of the control point
- Monumentation type.
- Dimension to the references of the points.
- Coordinates of the point (E, N and Z) of the points.

3.1.8 Control Traversing

A closed traverse was carried out from BM-1 and BM-3. High accuracy survey instrument (TOPCON ES-105) with a least count of 2″ in angles and ± (2mm + 2ppm x D) in distance were employed to carry out closed traverse and trigonometric leveling.

Closed vertical loops from ΔH reading from the instrument were used for the vertical control. Mean reading of ΔH from face left and face right from both fore station and back station were calculated for the calculation of reduce level. This process of calculation of the reduced level also eliminates the errors due to the earth curvature and also corrects the refraction correction. The errors of the closed vertical loops were evenly distributed on every station.

Closed traverse loops were carried out for the horizontal control to the points. Coordinates of some points were calculated as offset also. Double set of measurement were observed to the points. Horizontal angles and vertical angles were observed with face right and face left as well as distances. Distances were measured from both fore station and back station. The mean of the horizontal and vertical angles and mean distances were carefully calculated prior to the traverse calculation.

Horizontal position of the control points (E, N) were calculated from traverse while reduced level was calculated from vertical loop closure.

The horizontal accuracy of the traverse loop is defined by 1/ (√ (ΔE2+ΔN2)/D) and 1/ (ΔH/D). The horizontal and vertical accuracy of the loops are well above the desired accuracy of 1:5000 for horizontal traverse closures. A total of 1 closed traverse loop for horizontal control and vertical control were conducted throughout the project alignment.

<u>Traverse Calculation Sheet (Grade): Loop – 1</u>

	Name	Easting	Northing	R.L	Remark		
Start Stn	1	506344.7	3031443	696.957	BM-1		
Control Stn	3	506494.9	3031511	687.264	BM-3	Bearing	72.8607
End Station	3	506494.9	3031511	687.264	BM-3		
End Control	1	506344.7	3031443	696.957	BM-1	Bearing	272.8607
Traverse Accuracy Summary							
1	Calculated bearing		272.8587	dE		-0.046	
	Actual Bearing		272.8607	dN		0.146	
	Angular Error		0.002	d		0.153	
	No. of Obs. Stn		11	Error bearing		380.36	
	Ang Error Dist.		0.0002	Traverse length		8312.984	
				Accuracy		54396.64	

Traverse Data

Stn. from	Stn to	IH	Hor. Angle	Ver. Angle	HD	C. HD	Target H.	Code
1.00	500.00	1.432	216.209	94.401	121.623	121.623	1.275	500.00
500.00	501.00	1.499	177.200	94.692	1711.063	1711.063	1.275	501.00
501.00	502.00	1.402	126.035	102.930	340.798	340.798	1.275	502.00
502.00	503.00	1.441	346.330	91.438	437.006	437.006	1.275	503.00
503.00	114.00	1.406	136.633	99.153	1474.014	1474.014	1.275	114.00
114.00	504.00	1.385	399.984	100.857	1474.301	1474.301	1.400	504.00
504.00	505.00	1.388	262.578	110.394	420.313	420.313	1.400	505.00
505.00	506.00	1.528	55.953	95.110	326.303	326.303	1.400	506.00
506.00	507.00	1.464	271.872	104.510	1823.792	1823.792	1.400	507.00
507.00	3.00	1.470	228.722	111.979	183.771	183.771	1.400	3.00
3.00	1.00	1.515	378.483	96.237	165.045	165.045	1.400	1.00

Case - 1					Case - 2				
Station	Bearing	E	N	Z	Station	Adjusted.HA.	Bearing	E	N
500	289.0693	506224.83	3031422.02	707.84	500	216.2088	289.0695	506224.83	3031422.02
501	266.2693	504748.37	3030557.26	851.07	501	177.2002	266.2697	504748.37	3030557.27
502	192.3045	504789.47	3030218.95	835.50	502	126.0354	192.3051	504789.46	3030218.95
503	338.6341	504430.49	3030468.17	894.80	503	346.3298	338.6348	504430.49	3030468.18
114	275.2675	503066.32	3029909.81	914.54	114	136.6336	275.2684	503066.31	3029909.85
504	75.2513	504430.62	3030468.62	894.68	504	399.9840	75.2524	504430.61	3030468.63
505	137.829	504778.88	3030233.31	825.43	505	262.5779	137.8303	504778.87	3030233.31
506	393.7819	504747.06	3030558.06	850.66	506	55.9531	393.7834	504747.06	3030558.06
507	65.6537	506311.80	3031494.97	721.31	507	271.8720	65.6553	506311.83	3031494.93
3	94.3759	506494.86	3031511.18	686.39	3	228.7224	94.3777	506494.88	3031511.14
1	272.8587	506344.58	3031442.93	696.27	1	378.4830	272.8607	506344.61	3031442.89
Case - 3									
Station	Adjusted.HA.	Bearing	E	N	Final Coordinates				
500	216.2088	289.0695	506224.83	3031422.02	Station	Easting(m)	Northing(m)	RL	Code
501	177.2002	266.2697	504748.37	3030557.24	500	506224.83	3031422.02	707.8390	500
502	126.0354	192.3051	504789.46	3030218.93	501	504748.37	3030557.24	851.0702	501
503	346.3298	338.6348	504430.49	3030468.15	502	504789.46	3030218.93	835.5027	502
114	136.6336	275.2684	503066.32	3029909.80	503	504430.49	3030468.15	894.7972	503
504	399.9840	75.2524	504430.63	3030468.56	114	503066.32	3029909.80	914.5429	114
505	262.5779	137.8303	504778.89	3030233.24	504	504430.63	3030468.56	894.6777	504
506	55.9531	393.7834	504747.08	3030557.98	505	504778.89	3030233.24	825.4255	505
507	271.8720	65.6553	506311.85	3031494.83	506	504747.08	3030557.98	850.6648	506
3	228.7224	94.3777	506494.90	3031511.03	507	506311.85	3031494.83	721.3124	507
1	378.4830	272.8607	506344.63	3031442.79					

A closed traverse was carried out from Headworks site to Powerhouse site. Several another required control point were established by conventional traverse survey covering the entire Project area to be mapped from powerhouse site to Headworks site.

All traverses formed by the conventional survey were closed loops or closed on existing traverse points. The traverse legs were made as long as possible and a fixed tripod system was used for all reflecting prisms to achieve better accuracy. The traverse network is given in digital Cad Format. The list of main traverse points and their data are given in Table 3-2.

Table 3-2 List of Control Points Co-ordinates

Point ID.	Easting (m)	Northing (m)	RL(m)	Code
1	506344.660	3031442.801	696.957	GPS-1
3	506494.902	3031511.034	687.264	GPS-3
100	506231.394	3031391.780	701.553	BM_100
101	506174.507	3031388.545	702.073	BM_101
102	506072.379	3031314.902	705.006	BM_102
103	505741.864	3031224.767	746.225	BM_103
104	505583.587	3031151.827	746.099	BM_104
105	505461.651	3031006.662	741.777	BM_105
106	505187.582	3030923.605	764.855	BM_106
107	505007.823	3030763.529	769.528	BM_107
108	504780.333	3030474.719	807.908	BM_108
109	504625.798	3030363.517	814.719	BM_109
110	503950.078	3030270.425	851.732	BM_110
111	503813.913	3030248.969	858.848	BM_111
112	503460.038	3030072.440	883.191	BM_112
113	503256.680	3029991.428	900.292	BM_113
115	503016.045	3029845.179	917.236	BM_115
116	502924.415	3029849.736	926.652	BM_116
500	506224.826	3031422.020	707.839	TP-500
501	504748.370	3030557.243	851.070	TP-501
502	504789.464	3030218.928	835.503	TP-502
503	504430.493	3030468.148	894.797	TP-503
114	503066.320	3029909.796	914.543	BM-114
504	504430.626	3030468.564	894.678	TP-504
505	504778.889	3030233.235	825.426	TP-505
506	504747.076	3030557.980	850.665	TP-506
507	506311.847	3031494.828	721.312	TP-507

3.1.9 Horizontal and Vertical Control

High accuracy survey instrument (TOPCON ES-105) with a least count of 2" in angles and ± (2mm + 2ppm x D) in distance were employed to carry out closed traverse and trigonometric leveling.

Closed vertical loops from ΔH reading from the instrument were used for the vertical control. Mean reading of ΔH from face left and face right from both fore station and back station were calculated for the calculation of reduce level. This process of calculation of the reduced level also eliminates the errors due to the earth curvature and also corrects the refraction correction. The errors of the closed vertical loops were evenly distributed on every station.

Closed traverse loops were carried out for the horizontal control to the points. Coordinates of some points were calculated as offset also. Single set of measurement were observed to the points. Horizontal angles and vertical angles were observed with face right and face left as well as distances. Distances were measured from both fore station and back station. The mean of the horizontal and vertical angles and mean distances were carefully calculated prior to the traverse calculation.

Horizontal position of the control points (E, N) were calculated from traverse while reduced level was calculated from vertical loop closure.

The horizontal accuracy of the traverse loop is defined by 1/ (√ (ΔE2+ΔN2)/D) and 1/ (ΔH/D). The horizontal and vertical accuracy of the loops are well above the desired accuracy of 1:5000 for horizontal traverse closures. A total of 1 closed traverse loop for horizontal control and vertical control were conducted throughout the project alignment.

3.1.10 Accuracy

The closing errors were distributed according to common survey standards. Since, in all the survey works, high accuracy survey instruments with a least count of 2" were employed, the accuracy in linear closing error in closed traverse is better than Scale 1:10,000.

3.1.11 Data Processing

All the survey data were computed in the field as well as in the Kathmandu office. Similarly, some field data were evaluated and horizontal distances and elevations were calculated reciprocally. All the co-ordinates and elevations of each station and survey point were then computed with respect to the given UTM co-ordinates and elevation of the control point. Finally, the topographic map was prepared in Auto CAD 2015 format SW DTM software.

3.1.12 Detailed Topographical Survey

Detail topographical survey was carried out from push 7, 2077 to magh 6, 2077. The detail feasibility survey was carried out on key components of the hydropower project (diversion weir, intake, settling basin, powerhouse and tailrace). The detail topographical survey covered a strip of 50-60 meters on the penstock alignment and necessary coverage on the other components of the hydropower project. The list of detail works completed is given in the table below.

The features of terrain have surveyed by means of spot surveying. Spot positions were taken by the total station from different traverse and offset points. The survey adopted the break line method of survey. Points were taken on the original ground surfaces where the break of slop seemed to appear. Sufficient points were surveyed to represent the existing ground surface to the fullest.

The detail topographical survey depicted following information on ground:

- High Flood Level, Water Level, River Center, River Bank, etc.,
- Kulo, Gully, Kholsi etc.,
- Boulders, Rock, Cliff, Land Slides etc.,
- Trees etc.,
- Houses, Shed, Temples, Mane, Gumba etc,
- Tap, Water tank etc.
- Roads, Bridges, Tracks etc.
- Agricultural, Forest, Village boundaries.

3.1.13 Topographical Mapping

The data acquired by the surveyors were plotted in site itself to check for gaps and errors in survey works. The data was then brought to Kathmandu for final plotting and map preparation. The topographical map was prepared in Auto CAD using SW DTM software. All the natural and manmade features like houses, rivers, roads, tracks, kulo etc., were drawn and appropriate symbols were used to show rivers, trees, boulders, cultivated fields, rock, boulders, landslides etc. The map was prepared with a contour interval of 1m and major contour at interval of every 5m. Major contours were annotated in appropriate places with height values. Spot heights were also placed in appropriate places for further height information. Further map information such as place names, river names, direction of flow of rivers, way to places were placed on the map. Legends of the symbols were also prepared. The detailed topographical mapping of headworks, intake, settling basin, penstock pipe alignment,powerhouse and tailrace area were carried out in the required scale as given below.

Proposed Headworks site Plan	Scale 1:1000
Proposed water way pipeline corridor site Plan	Scale 1:1000
Propose Surge Shaft penstock pipe line site plan	Scale 1:1000
Proposed Powerhouse site plan	Scale 1:1000

All the coordinates and elevations of the ground control stations and their description cards (D card) are given in the Appendices and map shown in the general contour map. All the maps prescribed above have been prepared in the scales as mentioned in the scope of work. All the topographical maps are given in digital soft copy.

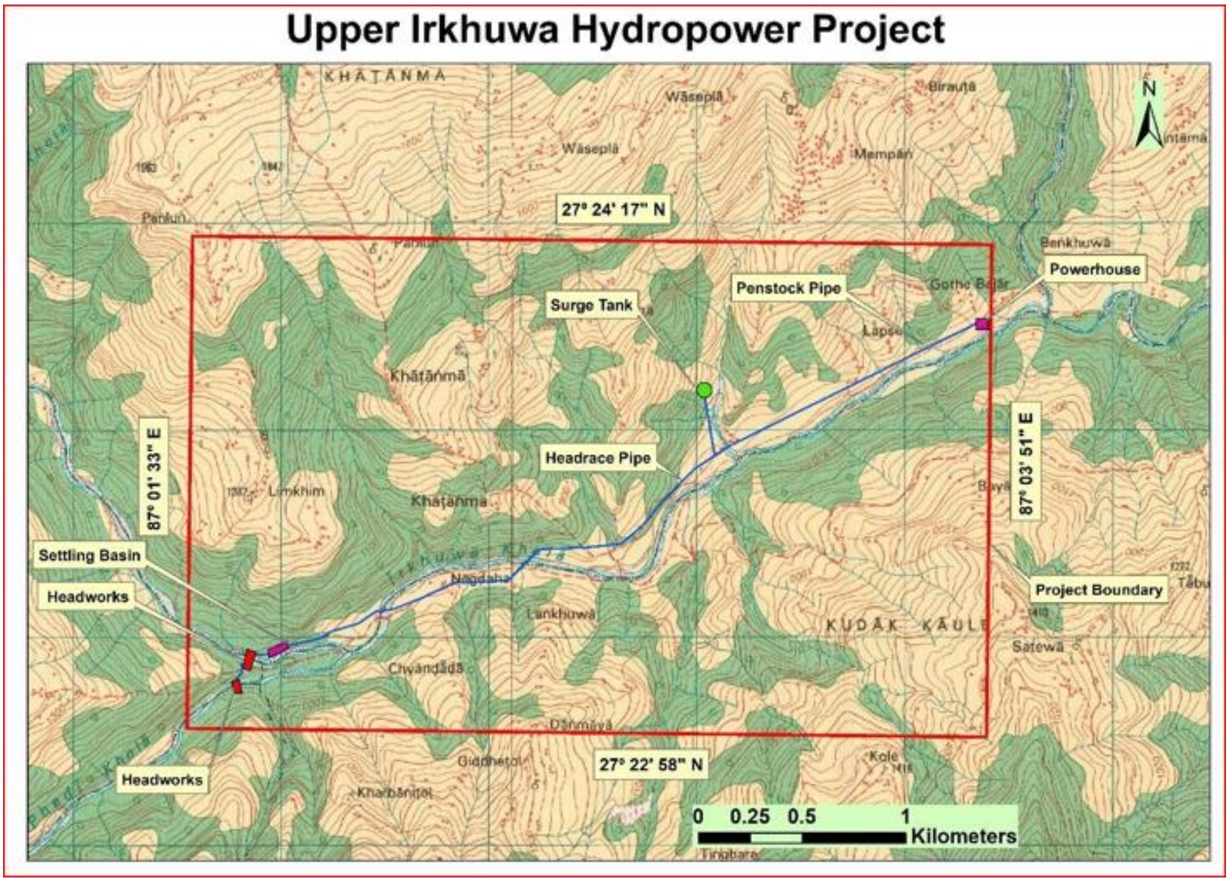


Figure 3-1 Topographic map of Project area with major component

3.1.14 River Cross Section

Cross-sections of the Irkhuwa Khola and small streams were taken to plot the river cross-sections for computing the rating curves for the weir and powerhouse/ tailrace sites of the project area. The sections were taken at interval of 50 m.

3.1.15 Conclusion

As a result of field survey and data computation works, topographical maps in the scale of 1:1000 with 1 m contour intervals have been prepared, permanent Bench Marks are fixed at major structure works in Headworks to Powerhouse site & Waterway Penstock pipe line of Upper Irkhuwa Hydropower Project. The errors are checked and distributed to all the control points. Topographical maps in different scale are prepared. The topographic survey report has been prepared as the outcome of the work.

3.2 Hydrological Investigations

3.2.1 Collection of Available Meteorological and Hydrological Data

Meteorological and Precipitation Data

There are some meteorological stations established by the DHM around the Irkhuwa River basin. Meteorological stations near to the headworks area are given in Table 3-3.

Table 3-3: Meteorological Stations

Index No	Location	Elevation	Latitude	Longitude
1113	Thodung	3120	27°37′	86°21′
1202	Chaurikharka	2619	27°42′	86°43′
1219	Salleri	2378	27°30′	86°35′
1220	Chialsa	2770	27°31′	86°37′
1224	Sirwa	1662	27°33′	86°23′

Climatological Records

Nearest meteorological station for the temperature is located at Chialsa (index no. 1220), Bhojpur district. The elevation of this station is 2770 masl. As per the climatological record, annual maximum temperature in the project area generally occurs in June which ranges from 10.9 C to 18.5 0C. Similarly, minimum temperature generally occurs in January which ranges from -2.0 ^{0}C to 7.6 ^{0}C. Detailed records of temperature data of station at Chialsa are listed in Table 3-4.

Table 3-4: Temperature data of Station no 1220

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Avg
Max Temp ^{0}C	7.6	9.0	12.8	15.6	16.8	18.5	18.7	18.9	17.7	15.1	11.5	9.3	14.3
Min Temp ^{0}C	-2.0	-0.8	2.6	5.8	8.0	10.9	11.9	11.6	10.3	6.4	2.0	-0.9	5.5

3.2.2 Establishment of Gauging Station

A permanent discharge gauging station has to be established in the vicinity of proposed intake site to measure the regular dry and flood flows of Irkhuwa Khola.

3.2.3 Water Level Recording and Flow Measurement

Upper Irkhuwa Khola being an ungauged river, discharge measurements were made at the proposed Project site for the purpose of the present study on various dates. Details of flow measurements at the proposed headworks of Upper Irkhuwa Hydropower Project are presented in Table 3-5. Shows representative field discharge measurements used for further hydrological analysis selected out of numerous field measurements.

Table 3-5: Measured discharge at Upper Irkhuwa Khola Intake Site

S.N.	Date	Discharge m3/sec	Remarks
1	February 14, 2016	2.827	Current Meter
2	March 21, 2016	2.793	Current Meter
3	May 2, 2016	1.852	Current Meter
4	November 23, 2016	6.594	Current Meter
5	December 27, 2016	5.339	Current Meter
6	January 1, 2017	3.625	Current Meter

3.3 Geological and Geotechnical Investigations

Geological studies were carried out to establish the geological setting, determine detailed geological and geotechnical conditions of the project area.

3.3.1 Collection of Available Data and Maps

The main objectives of the geological field investigations is to collect geological and geomorphological information, measurements of discontinuities and shear zones, identification of foundations condition, overburden condition, geo-technical properties of rocks and soils and support types at different hydraulic structures. The findings of these parameters are used in the evaluation of the technical feasibility of the project. The following data and maps are collected to initiate geological and geo-technical investigations:

- Geological map of Nepal (after Upreti and Le Fort, 1999)

- Geological map of western Nepal, scale 1:250000 (Department of Mines and Geology, 1984)
- Physiographic division of Nepal Himalaya
- Seismic risk map of Nepal (National Seismological Center, BCDP,1997)
- Probabilistic Seismic Hazard Assessment Map of Nepal (Department of Mines and Geology)
- Epicenter Map of Nepal (Department of Mines and Geology)

3.3.2 Surface Geological Mapping

Information about regional geological features and structural geological conditions of the project area has been received from the desk study of the existing geological reports and regional geological maps of the Eastern Nepal. Direct Observational Traverse method was adopted for recording geological information of the project area like geological structure, rock type, and rock quality, strength, weathering condition, surface deposit and geomorphological features. The inclination, dip and strike direction of joint sets of the bed rock were also measured in the field.

Selection of the layout of the project components such as diversion weir, settling basin, pipe alignment, surge tank, penstock alignment and powerhouse location was done on the basis of geological and topographical condition of the area.

Slope stability analysis of different structure area of the project was carried out on the basis of aerial photo interpretation, geological observation and geological data analysis. An analysis of the foliation plane to determine the stability of the rock mass at different structure area of the project was done by using Lower Hemisphere Projection of the foliation plane in Schmidt's equal area net. The wedge formed by the planes was analyzed with respect to the hill slope surface and pipe alignment.

3.4 Construction Material Survey

The survey was carried out to find the potential availability of the construction materials to determine the quantity and quality of the construction material in the project area and around the project area. The locally identified materials within the project area and its vicinity are coarse aggregate, fine aggregate and impervious materials.

4 HYDROLOGY AND SEDIMENT STUDY

4.1 Introduction

The proposed Upper Irkhuwa Hydropower Project will utilize the flow available in Irkhuwa khola and Phedi khola, one of the minor tributaries of the Arun River (a major tributary of the Saptkoshi River basin) in the eastern Nepal. The proposed project is located at Bhojpur district.

The hydrological inputs play a very vital role in planning, execution and operation of any water resource development project. The hydrological studies are carried out with a view to assess the quantity of available water and its time variation, estimation of design flood usually required for the hydraulic design as well as for safety of the structure and sedimentation studies.

This chapter describes the hydrological studies carried out for UIHPP with a view to:

- Assess the availability of water for power generation
- Assess design floods.
- Assess sediment exclusion provisions.

4.2 Physiographic Characteristics of Upper Irkhuwa Khola Basin

4.2.1 The Catchment

The Upper Irkhuwa Khola is a minor tributary of the Arun River (a major tributary of the Saptkoshi River basin). The total drainage area at the confluence at headworks location is about 137.35 km2.The catchment area of Irkhuwa Khola basin below 3000 m elevation is about 119.47 km2. The proposed powerhouse site of Irkhuwa Khola is located at around 400m upstream of confluence with Benkhuwa Khola. The total catchment area at proposed powerhouse site is 165 km2.The catchment area at various locations is presented in Figure 4-1 and Figure 4-2.

The proposed intake of Upper Irkhuwa Hydropower Project lies at Latitude 27°23'12"N and Longitude 87°01' 38"E, at an Elevation of about 918.50 masl.

The proposed powerhouse site of Upper Irkhuwa Hydropower Project lies at Latitude 27°23' 55"N and Longitude 87°03'43"E, about Elevation 691.00 masl and located at about 3873.50 m downstream of the proposed intake.

Upper Irkhuwa Khola is a rain-fed perennial river. The average gradient of Irkhuwa Khola in between the headworks site and tailrace site is about 10%. The Irkhuwa Khola basin drains towards east direction. The basin shape is roughly equilateral triangular having average length of 20 km. Irkhuwa Khola basin is mainly covered with moderately dense mixed forest. Agricultural field on terraces and scattered settlements dominate in the catchment area lying below 2’500 masl.

All of the above-mentioned drainage areas have been estimated based on the latest topographical maps compiled from 1:25000 scale aerial photography of 1996 by the Survey Dept. and also with GIS application.

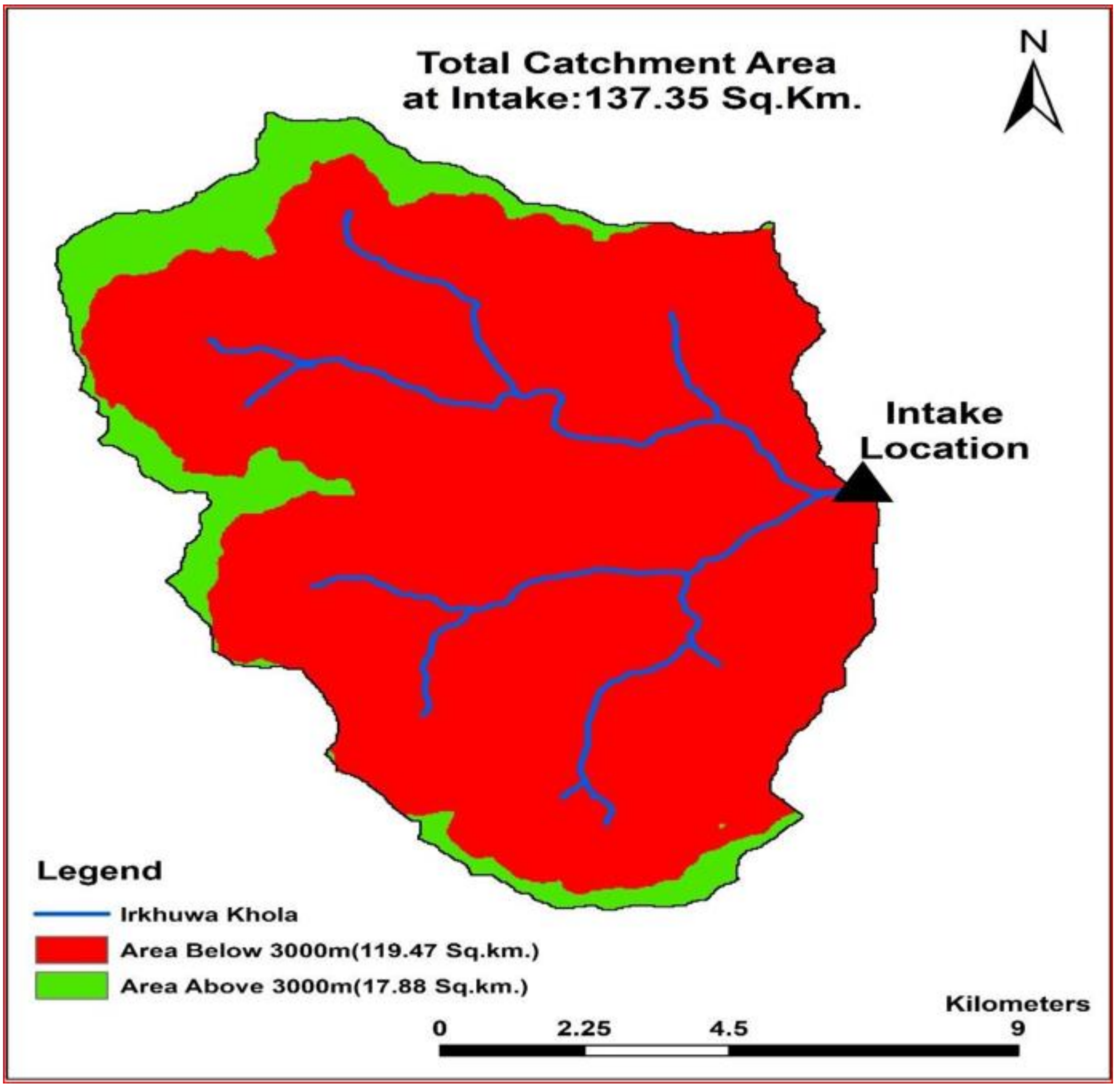


Figure 4-1: Catchment area of UIHPP intake site

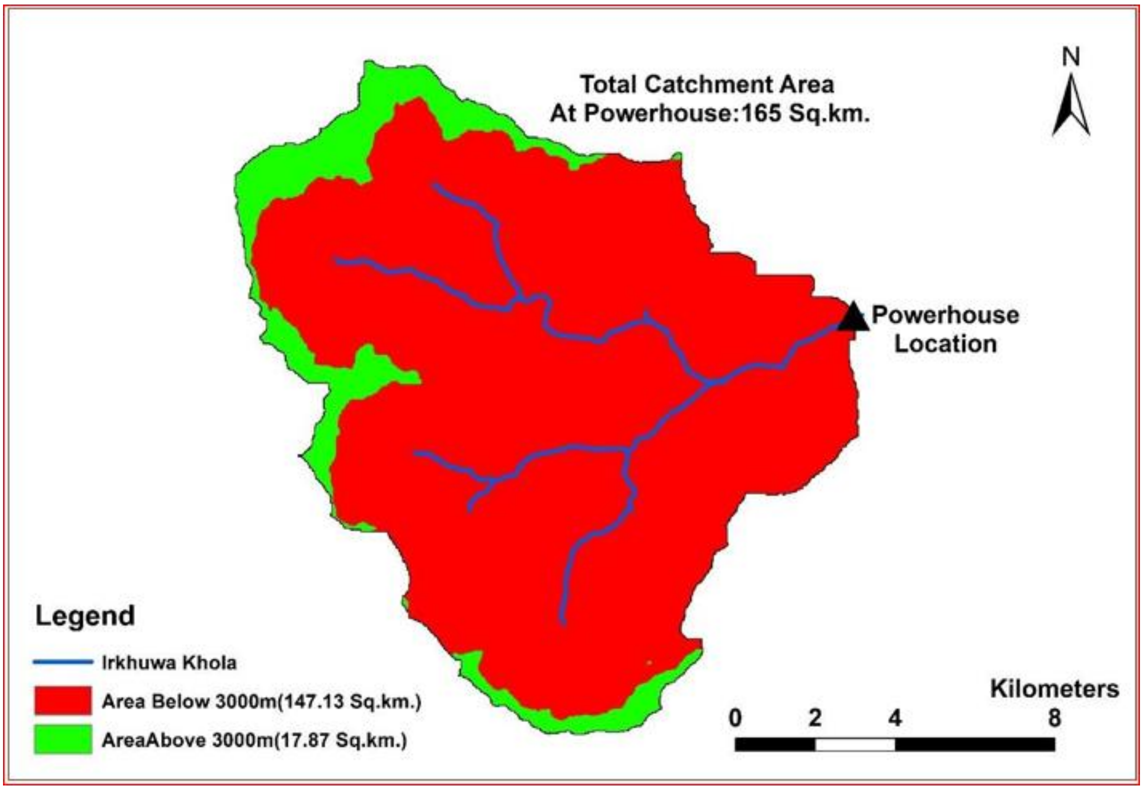


Figure 4-2: Catchment area of UIHPP Powerhouse site

4.2.2 The Climate and Precipitation

Monthly precipitation records published by Department of Hydrology and Meteorology (DHM) are available for different stations which are pertinent for the project study, however there are no meteorological records available within the proposed catchment of Irkhuwa Khola. So, the information of the pertinent precipitation stations were used from the stations near to Sabha Khola which are given in Table 4-1 below.

Table 4-1: Information of Precipitation Stations around Project Basin

Index No	Station Name	Elevation	Latitude/Longitude	Annual Basin Precipitation (mm)
1204	Aiselukhark	1497	27.35 / 86.75	2371
1222	Diktel	721	27.21 / 86.80	1514
1321	Tumlingtar	303	27.28 / 87.22	1424.81
1324	Bhojpur	410	27.18 / 87.05	1283

1325	Dingla	1190	27.37 / 87.15	1907

Table 4-2: Computation of Annual Average Precipitation by Thiessen Polygon

SN	Index No.	Area coverage (km^2)	Average Annual Precipitation (mm)	% Area x Ppt (mm)
1	1204	33	2371	78743
2	1324	6	1283	7698
3	1325	137	1907	261259
		176	**Average Annual ppt (mm) = 1976**	

The locations of the meteorological stations and the mean annual isohyetal map of the project and adjacent basins are shown in the annex. The estimated mean annual basin precipitation for the Upper Irkhuwa Project at the weir site is about 1976mm. The monsoon rains contribute about 80% of the total annual precipitation. The onset of monsoon starts from June to September. The climatological station located at the Tumlingtar is the nearest climate monitoring station from the project location. In term of elevation, the station is located about 303 masl. The temperature at the intake site can be expected to be higher than the temperature recorded at the station by four to five degrees centigrade. Based on the records of the Tumlingtar site, the annual range of average monthly temperature at the intake site can be expected to be within the range of 0oC to 22oC.

Climatological stations in Nepal record relative humidity twice a day: at 08:45 in the morning and at 17:45 in the afternoon. Although relative humidity data were available for the climatological station at Chialsa, it was found to be less reliable. Hence the data obtained for the meteorological station at Okhaldhunga has been used to derive the annual pattern of relative humidity presented in above. Wetness increases with the onset of the monsoon exceeding 80% in the morning and in the evening. Humidity may decrease below this value during afternoon when temperature is at its maximum.

4.2.3 Stream Flow Data

The Department of Hydrology and Meteorology installed gauging station on the Likhu Khola at

Sangutar, Bhojpur; which has the similar catchment characteristics with this project basin. The station no is 660 and gauge reading has been done since 1974. The recorded data of that station are fair with 31(1964 – 2006) years period. The catchment area of Likhhu Khola at Sangutar is about 856.14 Km2.

The long-term mean monthly flow of Likhu Khola at Sangutar is presented in Table 4-3. Based on these data, the mean annual monthly flow recorded is 7.80 m^3/s.

Table 4-3: Mean Monthly Discharge of Likhu Khola at Sangutar

Year	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
1964	-	-	-	10.40	12.30	24.50	90.60	102.00	98.50	48.20	23.90	16.40
1965	12.20	10.70	9.07	11.90	13.00	27.60	116.00	-	-	-	25.60	15.90
1966	12.30	10.50	10.70	11.00	13.20	38.50	142.00	205.00	124.00	42.00	22.90	16.80
1967	13.90	12.10	11.70	12.60	13.50	31.10	94.90	126.00	96.10	46.80	25.80	18.90
1968	14.30	12.40	12.30	13.10	18.00	49.30	142.00	195.00	109.00	82.80	26.00	17.00
1969	15.10	13.90	13.30	12.80	17.20	28.60	107.00	145.00	122.00	51.30	30.80	22.30
1970	17.60	15.30	13.90	14.40	15.50	65.00	181.00	224.00	99.30	58.90	32.90	21.40
1971	17.70	14.70	13.70	17.20	26.30	117.00	159.00	187.00	95.80	74.10	39.00	24.10
1972	17.70	14.20	12.80	12.60	20.10	39.00	130.00	143.00	119.00	57.30	32.80	21.80
1973	17.70	13.90	13.80	14.00	20.70	81.70	114.00	162.00	140.00	88.40	40.90	25.10
1974	19.00	14.80	13.60	17.00	19.90	44.20	155.00	196.00	136.00	65.70	33.20	21.90
1975	16.30	13.20	11.00	11.90	15.80	41.30	138.00	136.00	162.00	76.80	28.30	16.90
1976	12.70	10.60	8.57	7.84	12.60	63.50	138.00	158.00	118.00	45.90	23.40	14.90
1977	11.50	9.72	8.26	10.30	13.90	27.40	113.00	167.00	97.50	51.30	25.40	15.90
1978	12.20	10.20	9.97	11.50	24.50	77.20	174.00	188.00	108.00	63.80	31.60	20.60
1979	15.60	13.30	10.30	10.10	12.50	39.10	129.00	150.00	92.40	42.30	25.40	18.90
1980	13.80	11.60	10.90	11.40	13.10	42.00	126.00	160.00	114.00	49.00	27.30	18.90
1981	12.00	10.10	9.63	13.40	17.10	46.90	-	-	94.10	40.50	25.00	14.70
1982	10.50	11.00	9.98	13.70	14.60	43.90	115.00	110.00	80.60	37.90	24.00	17.40
1983	13.30	10.40	9.66	12.60	31.50	31.80	123.00	116.00	105.00	54.50	28.40	19.90
1984	15.00	10.70	9.47	10.10	17.00	65.50	194.00	106.00	162.00	47.20	26.60	18.80
1985	13.60	11.50	10.10	10.10	13.80	36.50	171.00	183.00	153.00	75.70	37.80	23.50
1986	17.90	11.20	10.50	12.00	14.00	47.60	135.00	114.00	91.30	53.90	27.40	18.60
1987	9.78	7.36	7.45	19.60	14.40	58.50	163.00	164.00	-	-	-	-
1988	-	-	-	-	-	39.50	126.00	163.00	90.20	35.30	24.00	19.50
1989	14.00	-	-	-	17.40	47.30	166.00	148.00	117.00	54.60	27.10	18.80
1991	12.40	11.00	11.30	11.10	14.60	38.30	111.00	177.00	97.70	37.30	21.20	16.60
1994	18.90	15.10	15.40	13.80	18.70	62.80	112.00	204.00	124.00	42.20	24.90	22.80
1995	18.20	15.30	12.30	11.80	34.70	93.70	203.00	187.00	83.30	63.70	38.10	30.00
1996	17.20	11.10	8.27	6.19	13.90	84.50	269.00	275.00	167.00	66.10	51.00	36.90
1997	10.70	7.76	6.99	8.42	13.40	26.60	205.00	210.00	134.00	84.50	39.20	27.60

1998	13.10	14.90	17.90	-	-	59.50	235.00	271.00	207.00	89.50	34.20	19.50
1999	11.90	-	-	8.50	26.40	59.60	200.00	246.00	221.00	132.00	62.50	26.50
2001	-	-	-	-	-	52.80	180.00	277.00	144.00	84.60	37.10	15.50
2003	12.40	8.84	7.08	13.30	11.80	34.40	75.60	62.10	111.00	41.00	12.60	8.71
2005	20.60	17.20	18.80	17.50	21.50	33.10	75.30	136.00	112.00	82.40	44.90	16.50
2006	14.10	13.10	13.90	16.00	23.20	56.60	143.00	107.00	-	-	-	-
Ave	**14.56**	**12.12**	**11.33**	**12.37**	**17.65**	**50.17**	**145.87**	**168.57**	**121.35**	**60.81**	**30.89**	**19.99**

Four different methods are used to carry out the hydrological analysis. They are

- Catchment area correlation method
- MIP (medium irrigation project) method
- Regional hydrology method
- WECS-DHM method

4.2.4 Monthly flow

4.2.4.1 Catchment correlation method

There are four key stream gauging stations in the vicinity of the Project area, Hinwa Khola at Pipletar (Index No. 602.5), Sabhaya Khola at Tumlingtar (Index No. 602), Likhu Khola at Sangutar(Index No. 660) and Khimti Khola at Rasnalu Village (Index No. 650). These station's data have been analyzed for the stream flow analysis of Irkhuwa Khola. Because of the non-availability of long-term discharge data for Irkhuwa Khola, an attempt has been made to derive the reference hydrology from the gauging station at these four reference stations.

Considering the physiographic conditions and geographical proximity of Upper Irkhuwa Khola from the gauging stations, it is appropriate to use the discharge data from Hinwa Khola at Pipletar (watershed area: 148.4 sq.km), Sabhaya Khola at Tumlingtar (watershed area: 393.66 sq.km), Likhu Khola at Sangutar (watershed area: 856.14 sq.km) and Khimti Khola at Rasnalu Village (watershed area: 313.00 sq.km), for deriving the stream flow at the headworks site of the Project.Hence the gauge data of the Likhu Khola is correlated to the headworks of this project and average of the co-related discharge is used for the further study of the project. In both area correlations the precipitation ratio adopted is one. The results from CAR method are presented below in Table 4-4

$$Q_1 = \frac{P_1}{P_2} \times \frac{A_1}{A_2} \times Q_2$$

Where,

P = Average Annual Precipitation (mm)

A = Basin Area (km^2)

Q = River Discharge (m^3/s)

Table 4-4: Mean Monthly Discharge at Headworks Site by CAR

Month	Design(m3/s)			
	CAR-Hinwa	CAR-Sabhaya	CAR-Likhu	CAR-Khimti
January	2.44	3.12	3.87	3.30
February	2.07	2.63	3.20	2.86
March	1.80	2.42	2.99	2.57
April	2.63	3.24	3.30	2.67
May	5.64	7.98	4.87	4.81
June	10.91	16.69	13.41	19.47
July	16.45	25.25	38.16	50.25
August	17.92	26.29	43.54	51.11
September	14.85	23.91	31.81	31.28
October	9.64	12.80	15.95	14.34
November	5.58	6.44	8.19	7.01
December	3.60	4.12	5.36	4.76
Average	**7.79**	**11.24**	**14.55**	**16.20**

4.2.4.2 Mean Monthly Flow by MIP Method

MIP method is based on regional regression analysis that separates the whole country into 7 geographic regions. This method presents the monthly flows as a ratio of the flow in April. The project area lies in region 1 of the MIP Hydrological region. The monthly flows have been derived based on measured discharge different 3 seasons and flow ratio for this region. The MIP method, as is based in regional hydrograph of the locality, trends to deliver traditional results yielding an absolute minimum flow during the month of April. The field discharge measurements and interviews with local people show the driest period to take place somewhere in April with gradual reduction in discharge between the months November to April. With the onset of monsoon in June/July, once the spring sources are recharged, the discharge of Irkhuwa Khola goes up smoothly till the month of September, with an instantaneous peak during the monsoon month of August. The mean monthly discharge at head works are shown in the Table 4-5.

Table 4-5: Predicted Monthly Mean Flow (m^3/s) by MIP Method

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Avg.
MIP-14 Feb,2021	3.87	2.84	2.05	1.83	3.69	8.44	22.01	34.75	27.49	14.59	7.47	5.20	**11.19**
MIP -21 March,2021	5.59	4.10	2.96	2.64	5.32	12.19	31.80	50.20	39.72	21.08	10.80	7.52	**16.16**
MIP-2 May,2016	2.77	2.03	1.47	1.31	2.64	6.05	15.77	24.90	19.70	10.46	5.36	3.73	**8.02**
MIP- 23 Nov,2016	3.95	2.90	2.10	1.87	3.77	8.63	22.51	35.54	28.11	14.92	7.64	5.32	**11.44**
MIP- 27 Dec,2016	4.41	3.23	2.34	2.08	4.20	9.62	25.08	39.60	31.33	16.63	8.52	5.93	**12.75**
MIP- 1 Jan,2017	3.98	2.91	2.11	1.88	3.79	8.68	22.62	35.72	28.26	15.00	7.68	5.35	**11.50**

4.2.4.3 MSHP METHOD

Nepal Electricity Authority (NEA) in 1997 developed a method to predict long-term flows, flood flows and flow duration curves at ungauged sites through regional regression technique. This approach uses both monsoon wetness index and average precipitation of the area along with catchment area of the river. With all other input parameters as previously adopted in WECS/DHM method and average precipitation obtained at Upper Irkhuwa Khola as 1976 mm, the results from MHSP method are presented Nepal Electricity Authority (NEA) in 1997 developed a method to predict long-term flows, flood flows and flow duration curves at ungauged sites through regional regression technique. This approach uses both monsoon wetness index and average precipitation of the area along with catchment area of the river. With all other input parameters as previously adopted in WECS/DHM method and average precipitation obtained at Upper Irkhuwa Khola as 1976 mm, the results from MHSP method are presented in Table 4-6

Table 4-6: Long-Term Mean Monthly Flow by MSHP Method

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Avg.
Q (m^3/s)	2.2	1.8	1.6	1.97	2.24	7.45	22.5	26.86	21	9.9	4.73	3.1	8.78

4.2.4.4 Mean Monthly Flow by WECS/DHM Method

A study on methodologies for Engineering Hydrologic Characteristics of ungauged locations in Nepal was published out by WECS and DHM in July 1990. This study uses the approach of multiple regression equations relating the physiographic and climatologic characteristics of the selected basins to the average monthly flow values. Altogether twelve individual monthly regression equations are developed.

Catchment area of Irkhuwa Khola at the proposed headworks site is 137.35 km2 with the catchment area lying below 3000m elevation being 119.48 km2. Monsoon wetness index at the catchment centroid has been adopted from the published data of Aiselukharka (St.1204), Bhojpur (St.1324) and Dingla (St. 1325) rain gauge stations which comes out to be 1534 mm, total rainfall during four monsoon months from June to September.

Alternately, modified HYDEST method has been used as a comparative approach for estimation of mean monthly discharge at the headworks site of Irkhuwa Khola. Average altitude of the Upper Irkhuwa Khola catchment at proposed intake site has been taken to be 2510 m for this study. The following Table 4-7 shows the results from WECS/DHM and modified HYDEST.

Table 4-7 Mean monthly flow (m3/s) at headworks site by WECS/DHM & modified HYDEST Methods

Month	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Avg.**
WECS/DHM	1.76	1.5	1.35	1.37	1.82	6.37	19.57	23.65	18.18	7.98	3.5	2.29	7.445
Modified HYDEST	3.73	3.17	2.1	1.96	2.54	11.88	28.77	41.91	28.81	13.73	6.55	4.53	12.47

4.2.5 Adopted Mean Monthly Flow

The results derived for long-term mean monthly flows at the proposed intake site from various methods for comparative study is Presented below in Table 4-8

Table 4-8 Mean Monthly Flow (m3/s) at Headworks by Various Methods

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Avg.
MIP- 14 Feb	3.87	2.84	2.05	1.83	3.69	8.44	22.01	34.75	27.49	14.59	7.47	5.20	11.19
MIP -21 March	5.59	4.10	2.96	2.64	5.32	12.19	31.80	50.20	39.72	21.08	10.80	7.52	16.16
MIP- 2 May	2.77	2.03	1.47	1.31	2.64	6.05	15.77	24.90	19.70	10.46	5.36	3.73	8.01
MIP- 23 Nov	3.95	2.90	2.10	1.87	3.77	8.63	22.51	35.54	28.11	14.92	7.64	5.32	11.44
MIP- 27 Dec	4.41	3.23	2.34	2.08	4.20	9.62	25.08	39.60	31.33	16.63	8.52	5.93	12.75
MIP- 25 Jan	3.98	2.91	2.11	1.88	3.79	8.68	22.62	35.72	28.26	15.00	7.68	5.35	11.50
Hydest	1.76	1.50	1.35	1.37	1.82	6.37	19.57	23.65	18.18	7.98	3.50	2.29	7.45
Modified MSHP	3.73 2.20	3.17 1.80	2.10 1.64	1.96 1.97	2.54 2.24	11.88 7.45	28.77 22.53	41.91 26.86	28.81 21.01	13.73 9.85	6.55 4.73	4.53 3.05	12.47 8.78
CAR-Hinwa	2.44	2.07	1.80	2.63	5.64	10.91	16.45	17.92	14.85	9.64	5.58	3.60	7.79
CAR-Sabaya	3.12	2.63	2.42	3.24	7.98	16.69	25.25	26.29	23.91	12.80	6.44	4.12	11.24
CAR-Likhu	3.87	3.20	2.99	3.30	4.87	13.41	38.16	43.54	31.81	15.95	8.19	5.36	14.55
CAR-Khimti	3.30	2.86	2.57	2.67	4.81	19.47	50.25	51.11	31.28	14.34	7.01	4.76	16.20

The table shows that the derived long-term mean monthly flows at the intake site from various methods are quite comparable. There is not a proven statistical tool to interpret the river specific annual discharge variation pattern of Irkhuwa Khola. The best method to analyze the Upper Irkhuwa Khola hydrology is to establish a permanent gauging station and get a long-term daily discharge data for sufficiently long period.

The MIP method, as is based in regional hydrograph of the locality, trends to deliver traditional results yielding an absolute minimum flow during the month of April. The field discharge measurements and interviews with local people show the driest period to take place somewhere in March with gradual reduction in discharge between the months November to March. With the onset of monsoon in June/July, once the spring sources are recharged, the discharge of Irkhuwa

Khola goes up smoothly till the month of September, with an instantaneous peak during the monsoon month of August. WECS/DHM method and MHSP methods give reliable estimates of monthly flows compared to the measured values, though they give comparatively lower values. Similarly, CAR method generates the data on the higher side in all of the cases except for Hinwa.

Hence, a cognitive approach has been applied in deriving the long-term average monthly flows of Irkhuwa Khola by considering the measured discharge values during the dry season as the reference values and comparing the results with other methods. The MIP method based on measurement done in the dry month of March gives the higher average monthly flow values. The results obtained from the WECS/DHM, MHSP are on lower sides whereas Modified HYDEST method gives relatively higher values of discharge giving overestimated design discharge value. After due consideration to the results from various methods, the results obtained from CAR method for Likhu Khola has been adopted to compute the long-term mean monthly flows of Irkhuwa Khola used for the purpose of this feasibility study. This is done as the flow pattern has similarity to the discharge values noted at the intake site at various dry months and since this analysis uses the mean monthly discharges of the stations which are similar to our site. The adopted long-term mean monthly flows used for the design purpose are presented below in Table 4-9.

Table 4-9 Adopted Long-term mean monthly flow (m3/s) at Irkhuwa Headworks Site

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	**Avg.**
Irkhuwa khola Discharge (m3/s)	2.06	1.70	1.59	1.76	2.59	7.13	20.30	23.17	16.92	8.49	4.36	2.85	**7.74**
Phedi Khola Discharge(m3/s)	1.81	1.50	1.40	1.55	2.28	6.27	17.86	20.38	14.88	7.47	3.83	2.51	**6.81**
Total Discharge(m3/s)	3.87	3.20	2.99	3.31	4.87	13.40	38.16	43.55	31.80	15.96	8.19	5.36	**14.56**

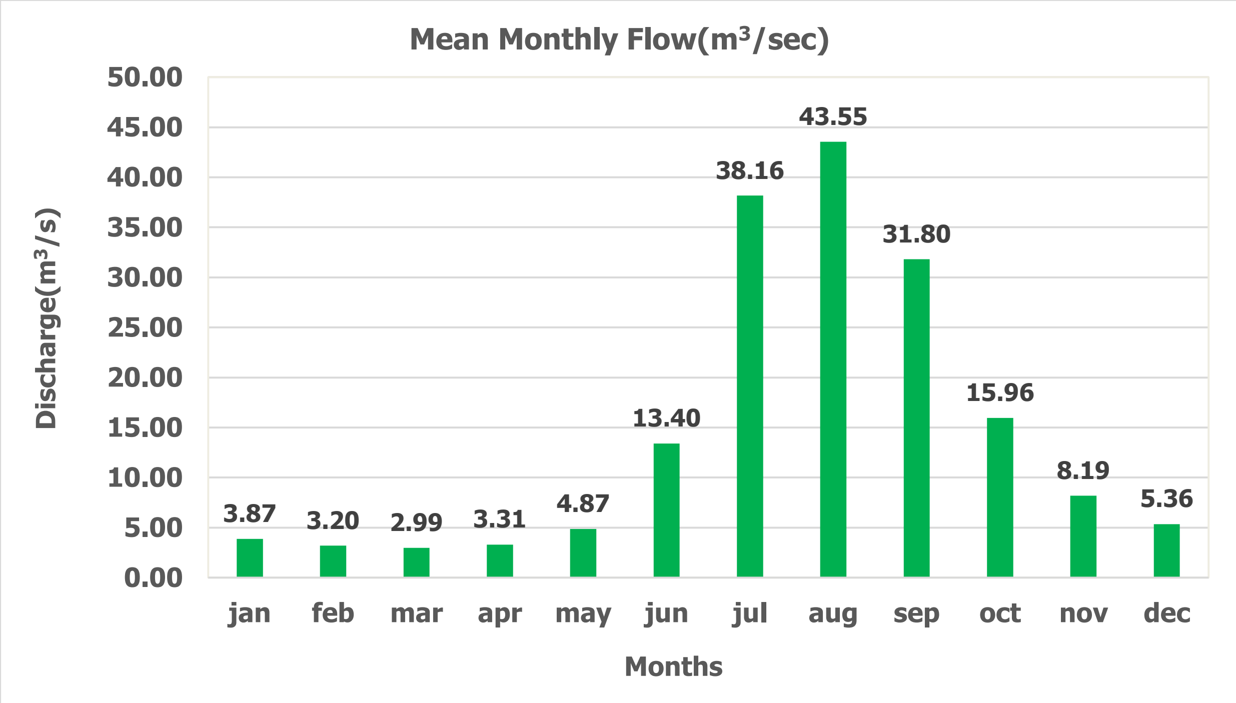


Figure 4-3 Mean Monthly Flow at Upper Irkhuwa Intake

4.3 Flow Duration Curve

The flow duration curve (FDC) is a probability discharge curve that shows the percentage of time a particular flow is equaled or exceeded. As discussed above, the long-term flow series at Upper Irkhuwa Khola HPP intake has been generated from catchment correlation with Likhu Khola at Sanghutar station (St no 660). The flow duration curve has been derived based on the monthly average discharge computed using catchment area ratio method.

The value from correlation with Likhu Khola has been adopted for further analysis and these values are presented in Table 4-10 and the flow duration curve is presented in Figure 4-4. Based on the flow duration curve, design discharge (45.0 percentile flow) at the proposed intake is 7.80 m^3/s.

Table 4-10: Probability of Exceedance of Flows at Intake site based on adopted flow

Probability of exceedance (%)	Discharge (m3/sec)	No. of days	Remarks
5	44.05	18	
10	41.48	37	
15	36.08	55	
20	31.66	73	

25	24.27	91	
30	17.96	110	
35	13.13	128	
40	9.83	146	
45	7.80	164	**Q45.0%**
50	6.44	183	
55	5.62	201	
60	5.09	219	
65	4.19	237	
70	3.88	256	
75	3.55	274	
80	3.33	292	
85	3.19	310	
90	3.08	329	
95	2.97	347	
100	2.89	364	

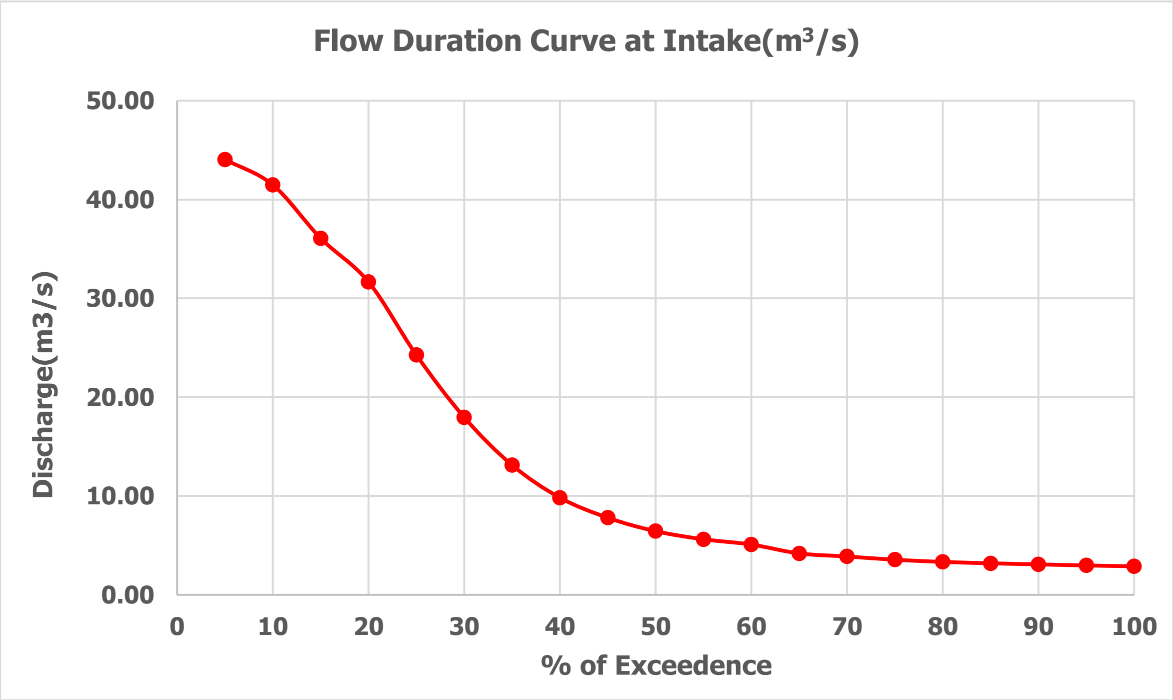


Figure 4-4: Flow Duration Curve at Intake Site

4.4 Low Flow Analysis

The low flow information is generally used to assess the reliability and the economics of the proposed project. If the occurrence of inadequate flow is too much frequent, a particular project might prove to be uneconomic and unreliable. Knowledge of minimum stream flow is therefore essential in the planning of any hydropower project.

For such type of ungauged rivers, HYDEST method was used for low flow computation. For the purpose, different durations viz: 1-day, 7-day, 30 days and monthly were adopted to compute the low flow for different return periods. The estimated low flows from the HYDEST method are presented in Table 4-11.

Q=[Cd,T+Fd,T×√(A≤5k)]^2; Where A<5k =Basin area below 3000 masl

& Cd,T = Constant, Fd, T = Coefficients

Table 4-11: Low Flow Frequency Analysis.

Return Period (Years)	Low Flow (m^3/s)					
	Irkhuwa			Phedi		
	Daily	Weekly	Monthly	Daily	Weekly	Monthly
2	0.54	0.57	0.80	0.46	0.49	0.70
10	0.26	0.31	0.53	0.20	0.25	0.45
20	0.19	0.26	0.47	0.15	0.21	0.40

4.5 Riparian Release

The long-term mean monthly flow at the proposed intake site of Upper Irkhuwa Khola for the driest month March as per Table 4-9 is 2.99 m3/sec. A flow equivalent to 10% of the driest flow, i.e.0.31 m3/sec will be released downstream at all the times as the riparian release for downstream riverine habitants for fulfilling environmental protection requirements.

4.6 Flood Flows

4.6.1 General

Design flood assessment involves the computation of a set of values of various return periods of say 2, 5, 10, 20, 50 and 100 years, through frequency analysis of flood series or through hydro-meteorological approach with the help of inputs of rainfall storm parameters provided by the

Meteorologist and flood data provided by the river gauging units. These peak floods are required to be computed for designing the headworks structures as well as the powerhouse complex. It has been a common practice to analyse the flood events that might occur during the driest periods for the purpose of the construction of diversion headworks structures. Flood hydrology has been analysed in two parts - design high floods for the design of headworks, powerhouse, and other hydraulic structures; and dry season floods for the construction of river diversion structures.

The availability of limited discharge measurement data, daily water gauge readings and the uncertainties involved in the raw and historic-reconstituted data series necessitated the application of flood frequency analysis. This formed a basis for daily project inflow time series at intake site and a regional flood frequency analysis.

The techniques used are:

- Flood Frequency Analysis
- Regional Flood Frequency Analysis (Hydro Regional)
- HYDEST Method

4.6.2 Flood Frequency Analysis

The annual monsoon in the project area basin occurs between June and October which causes sustained high flow condition and floods. This reaches its maximum between July and September. Prior to initiating the flood frequency analysis, the maximum instantaneous discharges were extracted from the observed historical flood data between 1974 and 2006 at Sabha khola, Tumlingtar gauging station using CAR method. Sabha khola gauging station drains an area of 375 km^2. Generation of the extreme instantaneous maximum discharge was done at the intake sites of the Upper Irkhuwa Hydropower Project. In addition, this was done for the powerhouse site.

Flood frequency analysis was performed using a customized Excel spreadsheet. Following types of frequency distribution functions were used in the flood frequency analysis from the generated annual maximum flood series data between 1974 and 2006. Analyses were done separately for both Intake and powerhouse. Analyses were done using different methods given below.

- Gumbel's Analytical method
- Gumbel's graphical
- Log-Pearson Type III
- Log Lognormal distribution

A comparative study of the distribution based on the fitting of observed and computed values shows that the Log Pearson distribution shows better fitting. Others distributions are also acceptable since there are very little differences between the various distributions. The resulting flood discharges of the Upper Irkhuwa Hydropower Project at intake and powerhouse sites by different methods, with the return periods are analyzed.

4.6.3 Design Flood

Design flood with a return period of 100 years were evaluated using different methods and the outcomes are tabulated in Table 4-12 for Upper Irkhuwa intake and Table 4-13 for Powerhouse respectively. However, the recommended design flood values are chosen using values obtained from Gumbel's Method. So, the recommended value is 373.19m^3/s for Irkhuwa intake. Similarly, using the same method for the powerhouse site, the value obtained is 383.80 m^3/s

Table 4-12: Summary of flood (m^3/s) analysis by different methods for Irkhuwa intake

Return Period (Years)	FlOOD FREQUENCY AT IRKHUWA INTAKE							
	WCS/DHM		Gumbels Methods		Log Pearson Type III		Log Normal Distribtion	
	At Irkhuwa	At Phedi	At Irkhuwa	At Phedi	At Irkhuwa	At Phedi	At Irkhuwa	At Phedi
2	71.16	67.13	52.07	49.34	46.46	44.02	48.96	46.39
5	120.6	114.16	89.44	84.73	76.88	72.84	78.6	74.46
10	158.87	150.66	114.18	108.17	103.18	97.76	100.65	95.36
20	199.43	189.41	145.43	137.78	144.78	137.17	131.01	124.12
50	257.68	245.13	168.62	159.75	182.64	173.04	155.33	147.17
100	305.54	291	**191.63**	**181.56**	227.23	215.29	180.99	171.48
200	357.34	340.68	214.57	203.28	279.64	264.95	208.3	197.35
1000	493.09	471.09	267.69	253.61	440.65	417.49	278.08	263.46

Table 4-13: Summary of flood (m^3/s) analysis by different methods for Powerhouse

Return Period (Years)	FLOOD FREQUENCY AT POWERHOUSE			
	WCS/DHM	Gumbels Methods	Log Pearson Type III	Log Normal Distribtion
2	151.30	104.29	93.05	98.06
5	245.20	179.12	153.99	157.42
10	315.50	228.67	206.66	201.59

20	388.50	291.26	289.97	262.39
50	491.20	337.70	365.81	311.11
100	574.00	**383.80**	455.11	362.51
200	662.50	429.73	560.09	417.20
1000	889.50	536.11	882.57	556.95

4.7 Diversion Flood

The value of the diversion flood for weir may be relatively lower as a higher than the designed value could be passed safely over the partly constructed weir. The following criteria would help in deciding the value of diversion flood.

a) Maximum non-monsoon flow observed at the weir site.

Or

b) 20 years return period flow, calculated on the basis of non-monsoon yearly peaks.

The floods of various return periods are estimated on the basis of analysis of the transposed non-monsoon flood peaks at Irkhuwa Diversion site, assuming that June to October is affected by monsoon. Non–monsoon flood peaks (November to May peak values) were used to estimate the 20-year return period diversion flood using Gumbel's Analytical method, Gumbel's graphical, Log-Pearson Type III and Log -normal distribution.

Different types of frequency distribution functions were fitted to the sample flood data. There were very little real differences among the results from various distributions. The results of non-monsoon flood peak corresponding to the Gumbel distribution of Sabhaya River were adopted and are given below in Table 4-14 below.

Table 4-14: Estimated Floods for River Diversion

Return Period (Years)	Diversion Flood (m3/sec)
2	16.85
5	29.95
10	38.61
20	46.94

From the above table, the 20-year return period flood works out to be 46.94 m^3/s. Therefore, for present study, the diversion flood has been adopted as 46.94 m^3/s.

4.8 Sediment Study

4.8.1 General

Sediment transport in Himalayan Rivers is a natural and complex phenomenon and Irkhuwa Khola is no exception. Particle size may range from fine sand to big boulders. Prior to this study, there were no data on suspended sediment load of Upper Irkhuwa Khola. However, it is expected to follow certain characteristics which are common to Himalayan Rivers.

Sediment load in the river may vary from year to year. Therefore, for design purpose a long-term data base is required. Fluctuations in the annual sediment load are usually much larger than flow variations. Larger seasonal variations are usually seen in the sediment load. Most of the sediment transport takes place during the monsoon season (usually assumed to be 80% to 90%). High sediment concentrations can, however, is expected during relatively small pre-monsoon floods.

Removal of sediments from the diverted water is very important for any hydropower plant. Suspended sediment particles cause severe abrasion to the runner and other mechanical parts of a turbine and thus drastically decrease its life and efficiency. The abrasion of hydro-mechanical components due to suspended sediment largely depends upon factors like the hardness, shape and size of mineral, hardness of substrate material, impingement angle and relative velocity with which the particle strikes the substrate material. To estimate the amount of wear, collection, study and analysis of these aspects is therefore imperative.

4.8.2 Source of Sediment

The basin area of Upper Irkhuwa Khola is mainly covered with sub-tropical forest. Sediment generation in forest area is relatively small. Landslides of significant scale are not available within the catchment area of the project. Debris flow is also not so frequent. It is a comparatively stable river with little meandering. So there is not vulnerable sediment problem in the river. But due to the steepness of the river, the river scours its side and bed which is the main source of sediment.

4.8.3 Estimation of Sediment Yield

Sediment measurement and sampling was not carried out in Irkhuwa Khola. Thus, indirect method of sediment yield was adopted to compute sediment volume and sediment concentration. During the identification visit river deposits are observed and found the possibility of transporting up to 500 mm diameter sediment particle in yearly flood. Cobble, pebble, gravel, sand and silt are predominant sediment of the river. Quartz, feldspar, mica is the predominant mineral of the sediment.

The sediment yield equation adopted in Nepal for catchment area below 150 km2:

$$Y=0.395/A^{0.311}$$

And sediment concentration by mass

$$C = T_m/Q_m$$

Where,

Y = Sediment Yield ($Mm^3/100\ km^2$ / year)

A = Catchment area (km^2)

C= Sediment concentration ($tons/m^3$)

T_m = Mass of sediment carried in three months (tons)

Q_m = Water volume during three months (m^3)

The sediment concentration is worked out as 2000 mg/litre assuming the density of sediment 2 tons/m3, mean monsoon discharge 1.00 m3/s and 60 % sediment is transported within three months' period. This is an average sediment concentration in river during monsoon season. Peak sediment concentration can be more than three times of the above values but all the sediment at the river may not enter into the intake. Some of the sediment can be excluded from gravel trap, some from settling basin. For the purpose of settling basin design about 1.5 times of the average sediment concentration (3000 ppm approximately) is assumed for sediment storage volume calculation and flushing frequency computation.

4.9 Conclusion and Recommendation

- The design discharge for the project is 7.80 m^3/s which is 45.00 percentile exceedance flow.
- The 100-year design flood is 191.63 m^3/s at Irkhuwa intake site.
- The 100-year design flood is 181.56 m^3/s at Phedi intake site
- The 100-year design flood is 383.80 m^3/s at powerhouse site.
- The 20-year construction flood at intake site is 46.94 m^3/s.
- The 20-year 1-day low flow estimate is 0.34 m^3/s at the intake site.

- The recommended mean annual sediment concentration at the intake site is 3000ppm

It is recommended that daily staff gauge readings of the river at the intake will be continued. River discharge measurements should also be taken at various gauge height so as to develop reliable rating curves at both the sites.

It is also strongly recommended that the measurements of suspended sediment be carried out in the future on a daily basis covering the principal months of the monsoon period and including discharge measurements so that a sufficient data base is available for a reliable and representative assessment of suspended sediment transport in the Upper Irkhuwa Khola at the proposed weir site.

5 GEOLOGICAL AND GEOTECHNICAL STUDIES

5.1 Introduction

Geological and engineering geological study of the project area is one of the basic requirements for the development of hydropower projects. Such study provides information on the surface and sub-surface condition of rock and soil and their engineering properties.

The proposed Upper Irkhuwa Hydropower Project is located in Bhojpur district of Eastern Nepal (Province no 1). The proposed project utilizes water from the Irkhuwa and Phedi khola that flows southwest to north east direction. The project covers the area between Gothe Bazaar village just upstream from the confluence between the Irkhuwa Khola and Benkhuwa Khola at Dobhan village and about 400 m upstream from the confluence between Irkhuwa and Phedi Khola. The entire project components follow Irkhuwa Khola passing through Dobhane, Khatama & Kudakaule VDCs. The Irkhuwa Khola is one of the minor tributaries of the Arun River originates from the Makalu Himalayan Region of the Higher Himalaya.

This report summarizes a brief description of regional geology, a detailed geological, engineering geological study in the project area.

5.2 Objective and Scope of Work

The main objective of the study is to carry out engineering geological survey and mapping of the proposed project site. The work is to assess the surface geological and geotechnical condition of the site. The results obtained from geological survey and mapping works will be used to assess the technical viability of the project during the next study phase.

The scope of work includes,

- Regional geology as well as seismicity study of the project area;
- Assessment of general geological condition of the project area;
- Discontinuity survey, slope stability analysis and presentation of the result in graphical format.
- Assessment of availability of construction material deposit.
- Recommendation for further investigations.

5.3 Previous Studies

Department of Mines and Geology (DMG), Nepal Government has published Geological Map of Eastern Nepal in scale 1:250,000. It is a regional geological map and also includes the project area.

5.4 Methodology

The methodology adopted consists of desk study and field investigation works. The initial desk study consists of collection and interpretation of available geological reports, geological maps, aerial photographs, and topographical maps of the project area. This was followed by field visit by a team comprising of an engineering geologist and engineers.

In field investigation works, a field reconnaissance survey was carried out to get information regarding the general layout of the project components. Geological route traverse in the project area and adjoining regions was conducted to assess the soil & rock types and orientation of discontinuities.

The engineering geological mapping was carried out in 1:1000 scale topographical maps. Finally, this geological report was prepared after the analysis and compilation of existing and field data.

5.4.1 Desk study and site reconnaissance

Prior to the mobilization for the site investigation a detail desk study was carried out about the project site. The desk study was limited with the detailed review of available maps, documents and research reports. The topographical maps, regional geological maps, aerial photographs were studied and planning for the detail survey and mapping of the site was made.

5.5 General Geology

Broadly, Nepal has been divided into five lithologic units, from north to south they are Tibetan Tethys unit, Higher Himalayan unit, Lesser Himalayan unit, Siwalik unit and Terai plain. The Tibetan Tethys Unit exposes only occasionally within the territory of Nepal, while the other four units are distributed from east to west throughout the country. The Tibetan-Tethys Zone begins at the top of the Higher Himalayan Zone and extends to the north in Tibet. This zone is composed of sedimentary rocks such as shale, limestone and sandstone ranging in age from Lower Paleozoic to Paleogene.

The Higher Himalayan Unit include the rocks lying north of the MCT and below the fossiliferous Tibetan-Tethys Zone. This zone consists of an approximately 10km thick succession of crystalline rocks also known as the Tebetan Slab. The crystalline unit of the higher Himalaya extends continuously along the entire length of the country and its width varies from place to place. The high-grade kyanite-sillimanite bearing gneisses, schists and marbles of the zone form the basement of the Tibetan Tethys zone. Granites are found in the upper part of the unit.

The Lesser Himalayan Zone is bordered in the south by the MBT and in the north by the Main Central Thrust (MCT). The Lesser Himalayan rocks throughout the Himalayas consist of two sequences: allochthonus and autochthonus. The MBT itself is a fault zone that has brought older

Lesser Himalayan rocks over the Siwalik. The Lesser Himalayas are mostly comprised of unfossiliferous, sedimentary and meta-sedimentary rocks such as slate, phyllite, schist, quartzite, limestone, dolomite etc. ranging in age from Precambrian to Eocene. There are also some granitic intrusions in this zone.

The Siwalik is bounded in the north by the Main Boundary Thrust (MBT) and in the south by the Main Frontal Thrust (MFT). It consists basically of fluvial deposits of the Neogene age. The Lower Siwalik consists of finely laminated sandstone, siltstone and mudstone. The middle Siwalik are comprised of medium to coarse grained salt and pepper type sandstones. The Upper Siwalik is comprised of conglomerates and boulder beds. The dun valleys within the Siwalik consist of Quaternary fluvial sediments.

The Terai zone represents the northern edge of the Indo-Gangetic alluvial plain and is the southernmost tectonic division of Nepal. Though physiographically this zone does not belong to the main part of the Himalayas, it is a foreland basin and owes its origin to the rise of the Himalayas, it is thus genetically related. To the north, this zone is often delineated by an active fault, the main Frontal Thrust (MFT). The Siwalik rocks are found to rest over the sediments of the Terai in many places along this thrust. The Terai is covered by Pleistocene to recent alluvium. The average thickness of the alluvium is about 1500m. The basement topography of the Terai is not uniform. The Terai region contributes significant quantity of good quality construction material and groundwater in Nepal.

The geological division of the Nepal Himalaya is presented in Table 5-1 and Figure 5-1.

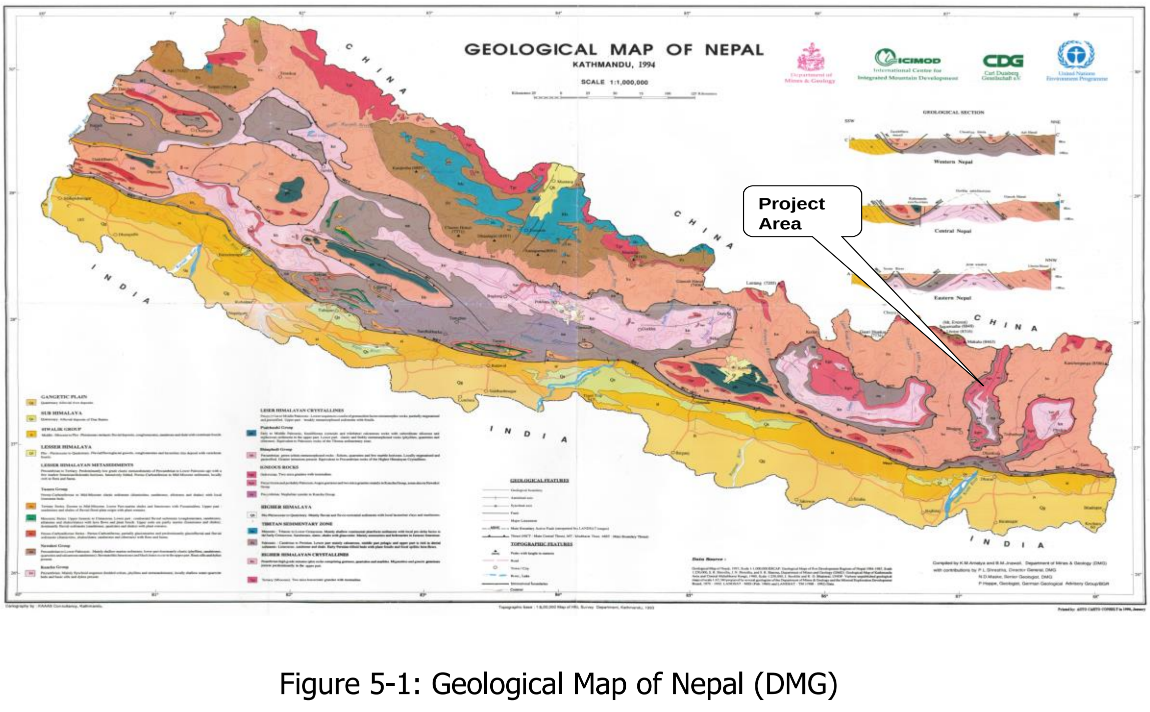


Figure 5-1: Geological Map of Nepal (DMG)

Table 5-1: Geological sub-division of Nepal Himalaya

Topographic Division	**Geological Sub-division**	**Geological Age**
Tethys Himalays	Tibetan Tethys Sedimentary Zone	Cambrian to Cretaceous (570 – 65 my.)
STDS (South Tibetal Detachment System)		***Tertiary***
Higher Himalaya	Higher Himalayan Crystalline Zone	Pre-Cambrian (> 570 my.)
MCT (Main Central Thrust)		***Miocene***
Lesser Himalaya	Kathmandu Complex	Pre-Cambrian to Paleozoic (570 – 250 my.)
	MT (Mahabharat Thrust)	*Miocene*
	Nawakot Complex	Pre-Cambrian (> 570 my.)
MBT (Main Boundary Thrust)		***Pliocene***
Sub-Himalaya	Siwalik Zone	Middle Miocene to Early Pleistocene (23 – 1.6 my.)
MFT (Main Frontal Thrust)		***Pleistocene***
Gangetic Plain (Terai)	Gangetic Alluvium	Quaternary (1.6my–Recent)

Source: Geological Map of Nepal compiled by Department of Mines & Geology, 1994.

5.6 Regional Geology

The project area lies within the Lesser Himalaya of the Eastern Nepal. It lies on Sarung Khola Formation of Kathmandu Group. The rocks such as dark grey to greenish white quartz biotite schist and gneiss are the predominant rock type in the project area. The general trend of the rock varies from ESE -WNW with gentle dip angle varying from 300 to 450 towards SW.

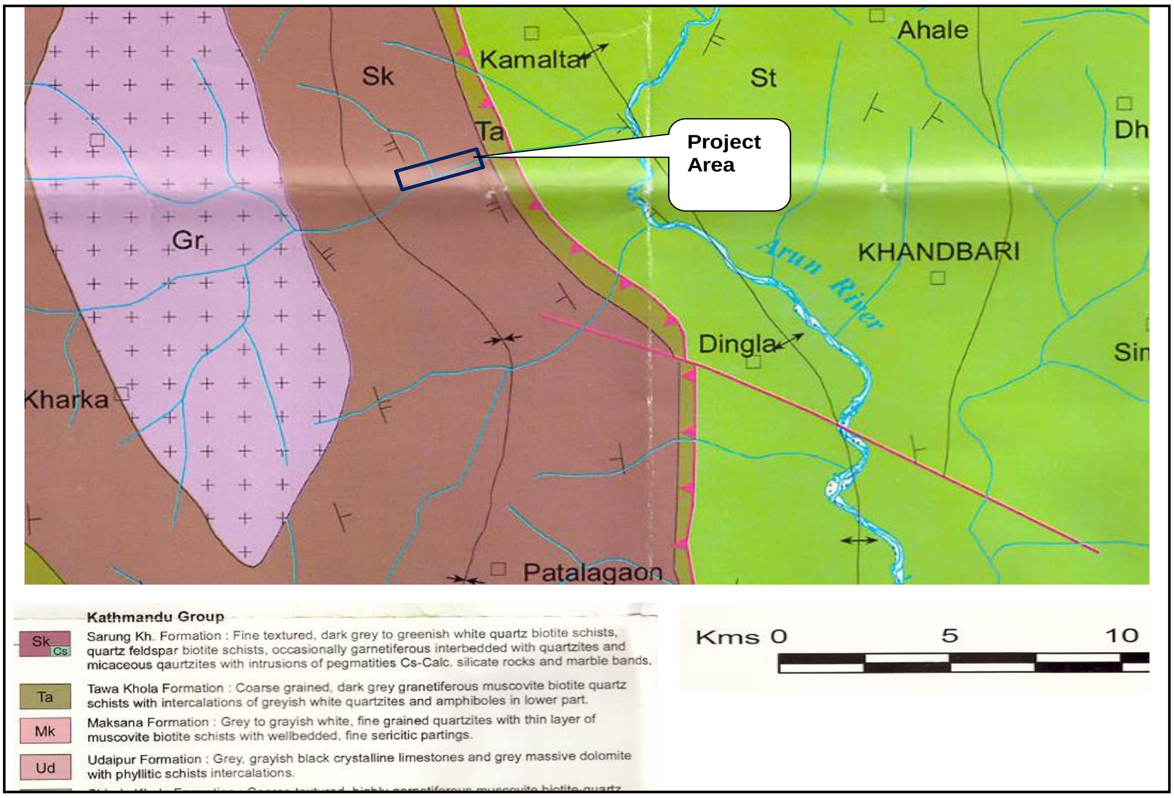


Figure 5-2: Location of project area in regional geological map (DMG)

5.7 Seismicity

The Himalaya seismicity, in general owes its origin to the continued northward movement of Indian plate after continental collision between Indiana plate and Eurasian plate. The magnitude, recurrence and the mechanism of continental collision depend upon the geometry and plate velocity of Indian plate in relation to southern Tibet (Eurasian Plate). Recent results suggest that the convergence rate is 20mm per year and the Indian plate is sub-horizontal below the Sub-Himalaya and the Lesser Himalaya. Nepal Himalaya occupies the central one-third portion of Himalayan arc. Inter-seismic monitoring of deformation indicates that the Main Himalayan Thrust (MHT) is locked along the Himalaya of Nepal and that stress build up at the tip of the locked zone is responsible for the belt of microseismicity activity that runs along the front of the high range (Pandey et. al., 1999; Cattin and Avouac, 2000). The interface between the Indian basements along a sub-horizontal decollement is known as Main Himalaya Thrust. Motion along the MHT is thus probably strike-slip and must produce recurring large earthquakes similar to the 1934 Bihar-Nepal event. The moderate magnitude earthquake is generated from thrust faults which originate within the microseismic belt in the front of high Himalayan in the ramp and ramp flat transition vicinity. The result of micro-seismic investigation, geodetic monitoring and morphotectonic study of the Central Nepal has depicted that more frequent medium sized earthquake of 6 to 7 magnitude are confined either to flat decollement beneath the Lesser Himalaya or the upper part of the middle crustal ramp. The ramp is occurring at about 15 Km depth below the foothills of the Higher Himalaya in the south of MCT surface exposure. An earthquake is characterized by an unique magnitude but it can give rise to a range of intensity. The highest intensity is generally observed in the epicenter area. It decreases rapidly beyond the rupture area as we move away from the epicenter.

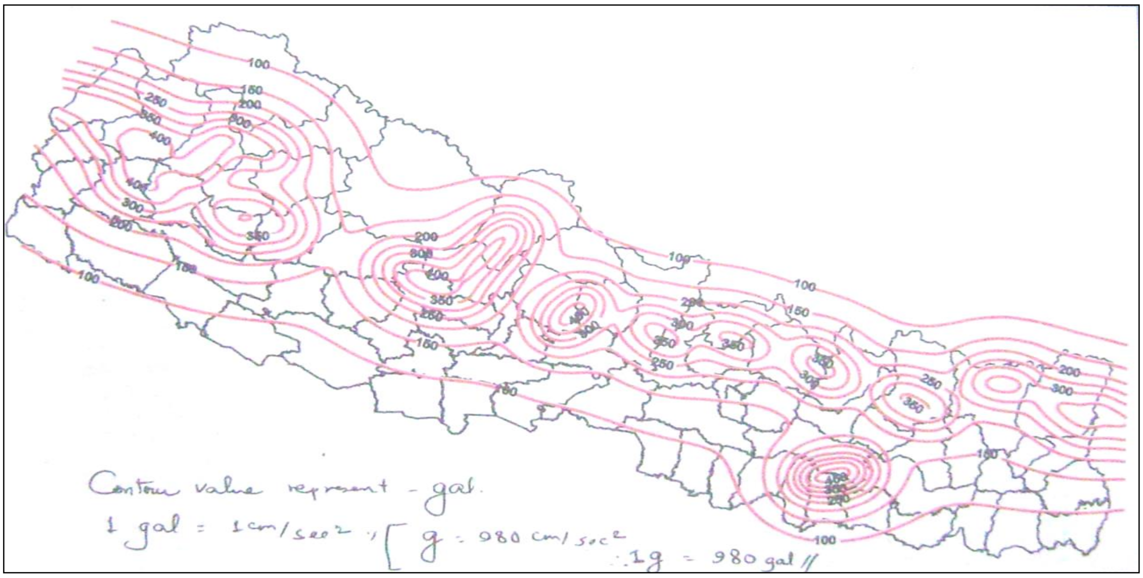


Figure 5-3: Location of Project area in Seismicity map of Nepal

The project specific seismic studies were not carried out for this project. The records of seismic activities are limited in Nepal Himalayas and hence correlation of seismic events with adjacent Himalayan Region would be useful source of information for designing hydraulic structures reference to response to seismicity events. Several seismicity studies have been carried out by Seismicity Department, Department of Mines and Geology (DMG), Nepal. The DMG has produced a very useful map "Seismicity map of Nepal" showing level of seismicity contours within the country. The study of map reveals that the project area is located at contour with horizontal seismicity coefficient of 300 gal which is equivalent to 0.30g. Considering the ratio of horizontal to vertical seismic coefficient to be 1.5, the vertical seismic coefficient will be 0.20. Since an earthquake can oscillate in any direction, the worst case scenario should be considered.

Recommendation

The seismic coefficients based on deterministic approach and probabilistic approaches for different hydropower projects in Nepal Himalaya are shown in following table.

Table 5-2 Seismic coefficients adopted by different hydropower projects in Nepal Himalaya

Project Name	Study Conducted By	Recommended Seismic Coefficient
Arun-3	JICA	0.12g for all components for design
Upper Arun	MKE, Lahmeyer, TEPSCO and NEPECON	0.12g for dam
Tamur-Mewa	MHSP, CIWEC	MDE = 0.25g-0.24g OBE =0.16g-0.15g
Chameliya HEP (30MW)	KOICA, Hyundai Engineering Co., Korea Water Resources Co.	0.15g
Middle Marshyangdi	Lahmeyer Intl., METCON CONSULTANTA, NEPCONSULT, SHAH CONSULT	0.1g to 0.16g
Lower Modi	WRC	0.25g
Kabeli -A	NEPCONSULT, Hydro Engineering Services	0.25g

Thus from the above discussion and the case histories, the seismic coefficient for the project is recommended as 0.20g.

5.8 GENERAL GEOLOGICAL AND GEMORPHOLOGY STUDY OF PROJECT AREA

Geomorphology

Irkhuwa Khola is one of the minor tributaries of the Arun River (a major tributary of the Saptkoshi River basin) in the eastern Nepal and originates from the Makalu Himalayan Range. The catchment area of the river is characterized by very rugged topography, which was resulted by the upliftment of the Himalayan range. It is mainly composed of sharp crested ridges, medium to very steep slopes and very little spaces are left for gently sloping lowlands in the valley. Majority of catchment lies in the slopes (90%), lowlands less than 10 % and ridge areas are less than here are a number of old as well as active landslides, within their catchments because of thrust activities. The main landforms observed in the project area are following:

River Terraces

Two levels of terraces can be well distinguished in the project area. The height of lower level terrace is 2m in average from the river bed in the project area whereas the upper level terrace is more than 3 m high. The lower terrace is varying in width from almost few meters to more than 30 m in the project area. At some reaches, only the lower terrace is present.

Recent Riverbeds

Recent riverbeds are seen in the Irkhuwa Khola. Some tributaries are reworking the gravels of the older terrace deposits and smaller fan deposits can be clearly seen at the mouth of tributaries. Some meandering belts of Irkhuwa Khola consist of small patches of fine material deposits.

Geology

The project area consists of interbedding sequence of schistose gneiss with few quartzite. In most of the areas, schist is undulated, thin to medium bedded, wavy continuous, fractured and jointed, slightly to moderately weathered grey, light grey to greenish grey in colour. Quartz veins are present in most of the exposure which are randomly folded and discontinuous. The rocks are dipping, in general, with dip angles varying from 30o to 45o towards south west.

5.9 Engineering Geology of the Project Area

The engineering geological study was carried out at the proposed headworks, powerhouse sites as well as along the proposed pipe alignment. The engineering geological investigation included the study of rock mass, discontinuity, and engineering geological mapping of project area.

5.9.1 Headworks Site

The proposed Diversion Weir Axis area is located about 400m upstream from the confluence between the Irkhuwa and Phedi Khola at Dobhan Village to divert the water towards left bank. Width of river bed at proposed headworks site is about 40 m. The area belongs to geologically the rocks of the Irkhuwa Crystalline Nappe, Lesser Himalaya. The rock unit is composed of thick bedded, grey, coarse-grained, two mica bearing gneiss and contents of partings of highly foliated schist. The bedrocks are well exposed on the right bank (vertical cliff) of the Irkhuwa Khola. But, the left bank comprises old and recent alluvial deposits. Exposed bed rock on the right bank is moderately weathered, thin to thickly foliated, medium strong gneiss with schist. Foundation of diversion weir lies on recent alluvium deposit. Estimated thickness of this deposit is about 20-30m. There is a boulder size up to 10m.

Intake, gravel trap and approach canal lie on alluvium deposit. Alluvium deposit consists of boulder of gneiss, schist and quartzite. The material is sandy gravel. Stereographic projection on the right bank of diversion weir shows that dipping of foliation plane lies in oblique to hill slope which is stable similarly wedge formed by the J1 and J2 is high angle which is also stable in terms of wedge failure. Therefore, the area is relatively stable.

Figure 5-4 Diversion Weir Location

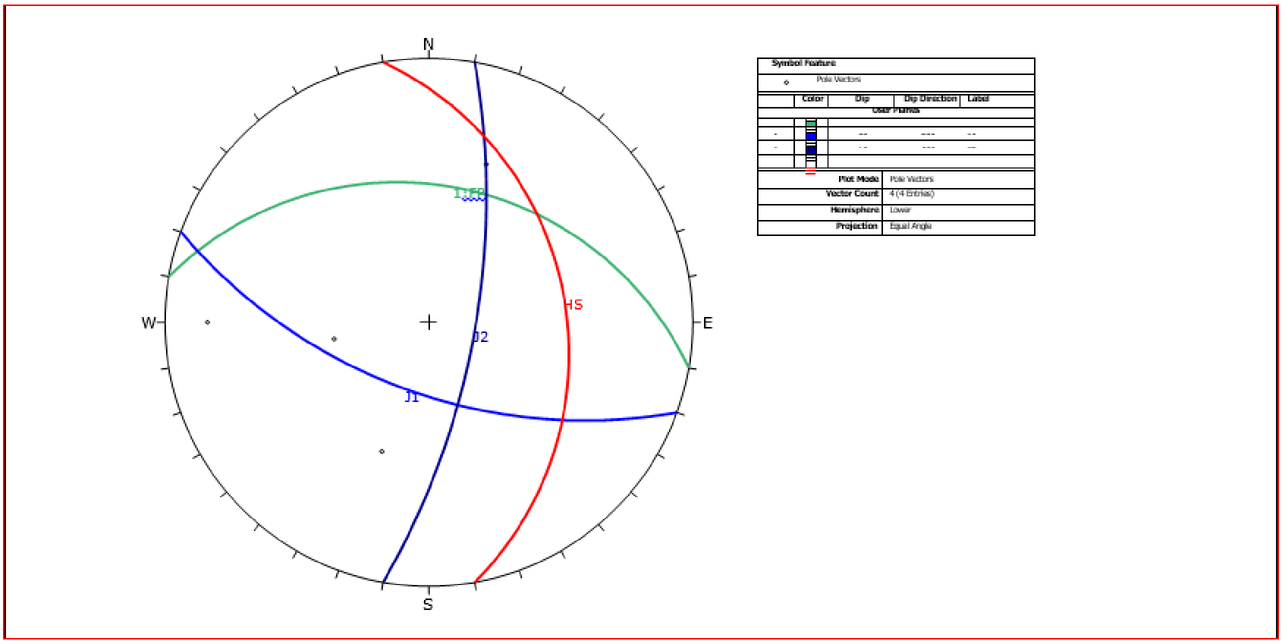


Figure 5-5 Stereographic Projection of Major Joints Headworks area.

5.9.2 Settling Basin

Surface settling basin lies on the alluvial deposit on left bank. The proposed settling basin and approach waterway alignment follow the left bank of Irkhuwa Khola, located at Dobhan village downstream from proposed headworks area. Geologically, the proposed area belongs to the rocks of the Irkhuwa Crystalline Nappe. But, superficially the area is covered by thick residual soil and alluvial deposits. Thickness of the boulder mixed soil is considered as more than 10 m. Uphill side of the proposed settling basin is covered by colluvial deposits on the bedrocks of gneiss. Hill slope is less than 30 degrees. Uphill side is covered by forest and barren land.

The approach waterway alignment which connects the settling basin and the intake or headworks area passes through the boulder mixed soil of the recent alluvial deposits as well as bedrocks of the gneiss. The rocks of the Irkhuwa Crystalline Nappe are exposed on the hill slope along the approach waterway alignment. The exposed rocks are characterized by thick bedded, coarse-grained, two mica bearing gneiss with thinly foliated schist. Bedrocks are well exposed on the left bank hill slope of the Irkhuwa Khola. Thickness of individual beds of the gneiss ranges from 2 to 5m.

Figure 5-6 Settling Basin area

5.9.3 Waterway Alignment

Penstock pipe is the main water conveyance system of the project. The entire alignment passes through the thick alluvial soil and some nominal portion crosses through the bed rocks and colluviums deposits. However, limited rock outcrops are observed along the alignment. The expected thickness of alluvial l deposit is more than 10m in general. Land use of this alignment is both forest and cultivated land. Slope of the alignment is mostly moderate; no major instability was observed along the alignment. The chainage wise description of the pipe alignment is given as follows:

Chainage 0+250m to 0+580m

The chainage of pipe alignment starts from outlet of settling basin. This portion of the pipe alignment runs through the colluvial and alluvial terrace deposits on left bank. The terrace is flat widely and composed of boulders, pebble s, cobbles on matrix of sand and silt. At present this stretch is used for cultivation. Around chainage 0+580m it crosses the Irkhuwa river and runs from right bank. This river brings the significant debris during monsoon, therefore buried structure is recommended.

Figure 5-7 Irkhuwa Khola Crossing at Chainage 0+580

Chainage 0+580 to 1+340

In this chainage alignment passes through alluvail deposits on right bank comprised of sub angular pebble, cobble to boulder sized clasts embedded on light reddish brown coloured cohesive soil. Around chainage 1+340m it again crosses the Irkhuwa River and runs from left bank. This river brings the significant debris during monsoon, therefore buried structure is recommended.

Chainage 1+340 to 1+800

This portion of the pipe runs through the mostly colluvial deposits. The expected thickness of the colluvial deposits is 2-5 m. colluvial soil consists silt and of loose fragments of gneiss and schist.

This area is covered with forest. There is kholsi crossing around 1+740m. This kholsi brings the debris during monsoon therefore buried structure is recommended

Chainage 1+800 to 2+800

The cultivated land of this section is composed of alluvial terrace deposit. The hill slope is very gentle and stable. The material is silty gravel. The expected thickness of this deposit is more than 5 m. Around chainage 2+360m bed rock of gneiss with schist rock is well exposed and classified as good rock.

Chainage 2+800 m to 3+225m

This portion of the pipe runs through the colluvial deposits. The expected thickness of the colluvial deposits is 2-5 m. colluvial soil consists silt and of loose fragments of gneiss and schist. This area is covered with forest.

Figure 5-8 Pipe Alignment from Chainage 1+800 to Surge tank looking downstream.

Chainage 3+225 m to 3+875 m

This penstock pipe alignment is located in the southeastern facing slope of the hill. Initially this alignment passes through the thick cover of colluvial and residual soil than after it passes through the colluvial deposit comprised of sub angular pebble, cobble to boulder sized clasts embedded on light reddish brown colored cohesive soil. Slope of the hill vary from 30^0 to 40^0. Bedrock can be expected at about 3 to 10 m depth along the penstock alignment. Saddle supports and anchor blocks would be founded mostly on colluvial deposit. No major geological instabilities were observed at this section during the present study. Proper retaining structures should be constructed with bio-engineering works for the slope stability at this zone.

5.9.4 Powerhouse site

The powerhouse site of the project is proposed on the left bank of the Irkhuwa Khola. The powerhouse site is located on the alluvial terrace deposit. The deposit consists of pebble bearing light grey sandy soil followed by very thick sequence of well rounded, loose to semi consolidated sand and boulder bearing gravels. Size of boulder is up to 7m. Bank protection work is required.

Gneiss with schist rock is exposed in uphill side of powerhouse site. Exposed rock is moderately to highly weathered with three sets of joints. The joints are mostly tight occasionally open, rough, irregular and moderately spaced with moderate persistence. The rock is classified as fair to good. The stereographic projection of the discontinuities indicates that the hill slope is steeper and the discontinuity planes are across, oblique and opposite to the hill slope dipping at relatively steeper angle. Such relationship between the natural hill slope and discontinuity planes represents a stable slope condition at this locality.

Figure 5-9 Powerhouse Area

5.10 Availability of Construction Materials

Construction material sites are observed mostly along the both banks of Irkhuwa Khola within the stretch of project area. Construction material like gravel are found on the headworks and powerhouse site near the river banks. Coarse aggregates can be obtained by sorting of gravels and crushing of pebbles and cobbles. If the volume of coarse aggregates cannot be sufficient from gravel, pebble and cobble, selective hard boulders should be crushed to fulfill the required volume.

Figure 5-10 Major Potential Source of Construction Materials at Headworks Site

Figure 5-11 Major Potential Source of Construction Materials at D/s of Powerhouse Site

5.11 Conclusion and Recommendations

Head works constitute a diversion weir, intake and settling basin. The right abutment of diversion weir lies on bed rock and other structure will be founded on alluvial deposit.

Total length of headrace pipe alignment is about 3997.83 m. Mostly pipe alignment passes through colluvial and residual soil deposits. Some nominal portion crosses through the bed rocks.

The powerhouse will be founded on alluvial deposit on left bank of Irkhuwa Khola. Depth to bed rock is expected to be about more than 10m below the power house foundation.

The following recommendations are made for the project.

- ❖ Head works constitute a diversion weir, intake and settling basin. The right abutment of diversion weir lies on bed rock and other structure will be founded on alluvial deposit.
- ❖ Mostly pipe alignment passes through alluvial and colluvail deposits. Some nominal portion crosses through the bed rocks.
- ❖ The powerhouse will be founded on alluvial deposit on left bank of Irkhuwa Khola. Depth to bed rock is expected to be about more than 10m below the power house foundation.

The following recommendations are made for the project.

- ❖ Standard Penetration Test (SPT) and Cone Penetration Test (CPT) should be performed to find out the allowable bearing capacity and tolerable settlement in the alluvial deposit of power house area.
- ❖ Construction at loose materials (like alluvial and colluvial deposit) should be properly treated.
- ❖ Medium and small scales landslide should be treated by using bioengineering techniques and maintain the slopes.
- ❖ Precautions should be taken in the headrace pipe alignment during the cutting of slope because probability of slope failure is maximum in different locations.
- ❖ Geophysical survey is recommended in head works, pipe alignment and powerhouse area.

6 PROJECT DESCRIPTION AND DESIGN

6.1 Design Basis

A brief summary of site condition, design criteria and concept for the major components of Upper Irkhuwa Hydropower Project are discussed in this chapter. The major components of the project are: Intake canal, Diversion weir, side intake, settling basin, penstock pipe, powerhouse and tailrace, electro-mechanical equipment, and hydro-mechanical works and switchyard. The headworks components are proposed on the left bank of the river. The water ways follow the left bank of the river and the powerhouse is also proposed on the left bank. The project's civil structures have been broadly classified into three groups, namely, headworks, water conveyance system and powerhouse complex.

6.2 General Arrangement of Project Components

The overall layout of the project is prepared for the installed capacity of 14500 kW with the design discharge of 7.80 m3/s. The main civil components of the project are: diversion weir, side intake, gravel trap cum settling basin, collecting chamber, steel penstock pipe, powerhouse and tailrace structure respectively.

A 25m long boulder diversion weir with a sluice on the left bank shall divert design discharge of 7.80 m3/s. A side intake having three orifices 2.50m x 1.5m is proposed. Gravel trap is proposed immediately after the intake. Gravel trap directly delivers water to the settling basin. Two bay settling basin is proposed with 55.50m length (excluding transition), 6.50m width and (3.14-7.74) m average depth which is aligned on the left bank of Irkhuwa Khola immediate to the gravel trap. About 3873.50m long headrace and penstock pipe (upto bifurcation) of diameter varies from 2.0 to 1.75m proposed between the submergence pond and the powerhouse follows two river crossing at the chainage at about 0+600.00m to 0+700.00m (i.e from left bank to right bank) and another crossing at the chainage of 1+420.00 to 1+460.00m (i.e from right to left bank) of Irkhuwa Khola. A 24.00 m long free overflow boulder diversion weir has also been proposed at Phedi Khola to meet discharge requirement during dry season. The diverted discharge from Phedi khola is conveyed through 84.50 m long of size 2.5m width to 1.80 m height canal to the intake at Irkhuwa Khola.

The powerhouse and the tailrace structures are placed on the left bank of the Irkhuwa Khola. A powerhouse of 47.50m x 16.3m size will be constructed in the plain area at an elevation of 690.00 masl from the mean sea level. Three units of horizontal axis Francis Turbine is proposed in the powerhouse. The tailrace water level after turbine is fixed at 691.77 masl.

6.3 Civil Works

6.3.1 Diversion during construction

The river diversion shall be done in two stages. In the first stage diversion, the river will be diverted from the right bank. A temporary cofferdam shall be constructed upstream of the weir axis to divert the river flow into the channel. During this stage, construction of sluice, intake and partial weir shall be done. In the next diversion stage, the river will be allowed to flow from the sluice ways, thus construction works on the remaining portion of the weir can be undertaken.

6.3.2 Headworks

Headworks consist of intake canal, weir and sluiceways, settling basin, collecting chamber and headrace pipe. The components are described below.

6.3.3 Weir

The weir is located about 400m u/s from the confluence between the Irkhuwa khola and Phedi Khola on the straight portion to divert the water towards left bank. A boulder weir is proposed as the suitable diversion structure for this purpose.

Weir and Undersluice are designed to pass design flood discharge of 191.63 m3/s safely corresponding to 1 in 100 return periods without affecting the headworks structures. Design parameters considered for the diversion weir is as following:

Design parameters:

- Design flood is 191.63 m3/s (1 in 100 years return at Irkhuwa Khola)
- Flood through weir is 191.63 m3/s
- Flood through Undersluice is 19.16 m3/s
- Weir type is broad crested weir with a discharge coefficient of 1.80
- Weir and undersluice are designed for optimum creep length and hydraulic stability

Geologically, the foundation of diversion weir lies on recent alluvium deposit.

Weir and undersluice will impound the flow for diversion through a side intake to be constructed on the left bank. Main features of the weir are described below:

- Boulder weir at Irkhuwa khola has been designed as an uncontrolled overflow spillway to safely pass a flood of 191.63 m3/s corresponding to return period of 100 years. The water head over the weir is 2.60m.
- Weir has been designed with a floating foundation as the bedrock below the riverbed is anticipated at higher depths only. More detailed investigations on seepage through weir

are required during the construction.

- With crest level fixed at El. 920.90 m and height of the weir from the river bed level is 3.45m. The weir is 25m wide.

The stability of the weir has been checked with the water elevation of the design flood. The weir cutoff shall be constructed completely with concrete (C25). Similarly, the d/s slope of the weir is proposed to have high strength concrete of at least C25 to protect from scour.

6.3.4 Sluice

On the left side of the weir, an undersluice will be constructed to channelize flow towards the side intake. The sluice is designed to pass about 19.16m3/sec flow during monsoon with water elevation at the weir crest. The purpose of the sluice is only to flush the bed load deposited in front of the intake. To allow for easy flushing the bed of the sluice is proposed with the slope of 1 in 20. The sill elevation of the sluice gate is proposed at 916.20 masl. An electrically operated vertical gate and stop-log of 2.50m width and 3.50m high stop-log are proposed for the regulation of the flow.

Main features of the undersluice are listed below:

- The sluice opening is arranged on the main course so that the bed load along with the discharge is directed towards the undersluice structure.
- Total opening of the undersluice is 2.5m wide, which can pass 39.77m3/s during high flood. Vertical gates have been provided to control the flow through the undersluice. Gate will be protected by a breast wall provided upstream of the undersluice. Stop log guides will be provided upstream of the breast wall to allow maintenance of the undersluice gate and embedded parts.
- Size of stoplogs is 2.50m (W) x 2.50m (H).
- Sill level of the undersluice is at El. 916.20m, 4.70m lower than the main diversion weir to create a pondage near the intake.
- Deck level of the undersluice gate operating level is at El. 624.80 m 1.00m higher than the high flood level.
- Bed slope of channel upstream of the undersluice has been kept at 1 in 20 in order to ease the flushing of the undersluice portion.
- Hard stone lining shall be provided on the top layer to protect abrasion from sediment.

6.3.5 Intake

Side intake with three orifices is proposed. The dimensions of the orifice are of 2.5 m width and

1.5 m height. The orifices are designed to have flow velocity of 1m/s at the design flow. Coarse trash rack is proposed in front of the intake orifices to avoid trashes during the high flows.

Location of the side intake has been kept immediately upstream and adjacent to the undersluice to facilitate the safe withdrawal of the design discharge of 10.14m3/s (including 30% of flushing discharge). Invert level of the intake will be kept at a higher elevation than the invert level of the undersluice to prevent intrusion of the bed load into the intake. Intake deck has been designed for the high flood level corresponding to the 1:100-year flood.

Design parameters:

- Design discharge is 7.80 m^3/s
- Velocity through intake is 1.0 m/s
- Intake deck level is above the high flood level
- Single layer of course trash rack
- Hydraulic stability of intake

Main features of the side intake are listed below:

- Foundation of intake is on the river bed material
- Intake has been designed to pass a discharge of 10.14 m^3/s, which includes 30% extra for flushing discharge.
- Orifice type intake has been proposed to avoid excess flow into canal during the high flood period.
- Intake on the left bank of Irkhuwa River consists of 3 gated bays of 2.5m wide and 1.5m high. The bays are separated by 0.9m wide concrete pier.
- Operating level of the intake gate is at El. 924.80 m and that of the sill level of intake is at El. 918.70m.

6.3.6 Gravel Trap

A conventional gravel trap is proposed immediately after the intake to settle particle size greater than 5mm. The dimensions of the gravel trap are 7.50 m length, 9.30 m width and average depth of (2.04-5.20) m.

The flushing gate is proposed at the end of the gravel trap. The opening of the gravel trap flushing is 1m width and 1.0m height. The flushing canal is a cut and covered canal having length 46.80m,width 1m and height 1.15m. The longitudinal slope is provided at 1:40 (V: H), the floor of the canal is to be lined with steel for protection against abrasion.

Design Parameters:

- ❖ Design discharge is 10.14 m^3/s (including Flushing Discharge)
- ❖ Sediment to be trapped or settled is 5mm
- ❖ Flushing channel size (1m*1m single)

6.3.7 Flood Spillway

A sharp crested spillway is provided on the right wall of the gravel trap to discharge excess water during high flow back into the Irkhuwa Khola. The length of the spillway is 7.50m with crest level at 920.84 masl.

6.3.8 Settling Basin

The settling basin is designed to remove suspended sediments of particle size greater than 0.20mm in diameter. The efficiency is estimated to be 90% removal of the above-mentioned particle size. Two basins are provided so that the power plant can be operated partially during the flushing of one basin.

Dimensions of the settling basin depend on the characteristics of the river, design discharge, and particle size to be removed.

Design parameters:

- ❖ Design discharge is 8.97 m^3/s (including 15% additional flushing discharge)
- ❖ Sediment removal size is 0.20 mm
- ❖ Fall velocity 0.021 m/s at water temperature 15 ^0C
- ❖ Velocity of flow 0.20 m/s
- ❖ Number of bays in settling basin is 2

Main features of the settling basin are listed below:

- ❖ Effective length and size of the settling basin is 55.50m, width 6.5m (for each bay) and height (3.14-7.74) m founded on left bank of Irkhuwa Khola.
- ❖ Depth of flow at the beginning of settling basin is 4.20m and varies to 7.15m at the end.
- ❖ Full supply level at settling basin is at El. 920.604m whereas the top level of the wall is at El. 621.604 m. Wall thickness of settling basin is 0.3m at the top and at the bottom wall thickness varies from 0.6m to 0.80m.
- ❖ An orifice outlet is provided at the end of settling basin for control of flow through the settling basin. 2 orifice outlets of for each bay with dimensions of 1.85m (W) x 1.3m (H)

are provided at the end of the settling basin to maintain water level in the settling basin and the intake of pipe.

- Flushing canal of size 1.0m x 1.0m are provisioned to flush the deposited sediments back to Irkhuwa Khola.
- A conventional headpond is proposed at the end of the settling basin with dimensions 13.82m length, width varies from 13.50m to 5.80m. Foundation preparation of the settling basin is the critical element. The basin will be founded on a topsoil and hence good compaction with the selected material is required for the foundation. The compaction shall be done in layers of 15cm with selected cohesion less materials.

Foundation preparation of the settling basin is the critical element. The basin will be founded on a topsoil and hence good compaction with the selected material is required for the foundation. The compaction shall be done in layers of 15cm with selected cohesion less materials.

6.3.9 Phedi Diversion

Along with the discharge from Irkhuwa Khola the additional discharge from Phedi Khola is also added to the project by constructing small dam and diverting water just upstream of Irkhuwa Khola Diversion weir. A 24m length boulder weir is proposed to divert the water from Phedi Khola to Irkhuwa Khola. The height of weir is 3.33 m from river bed level. Crest elevation of the weir is 924.60 masl. Intake arrangement is done by placing two gate of each 3.0m width and 0.8m height. The diverted discharge from Phedi khola is conveyed from Phedi intake to Irkhuwa intake through 84.50 m long of size 2.5m width to 1.80 m height canal to the intake at Irkhuwa Khola.

6.3.10 Water Conveyance System

About 3873.50m long headrace and penstock pipe of diameter varies from 2.0 to 1.75m proposed between the submergence pond and the powerhouse follows two river crossing at the chainage at about 0+600.00m to 0+700.00m (i.e. from left bank to right bank) and another crossing at the chainage of 1+420.00 to 1+460.00m (i.e. from right to left bank) of Irkhuwa Khola.The thickness of the pipe varies from 8mm to 25mm. The alignment will be exposed and buried, mostly being the later.

6.3.11 Steel Penstock Pipe

A mild steel penstock pipe is suitable for this hydropower project.

6.3.11.1 Optimization of the penstock diameter

The optimization study of the penstock diameter considered the following input parameters:

- Length of the pipe: 3873.50 m

- Yield strength: 250 N/mm²
- Ultimate tensile strength: 410 N/mm²
- Allowable design stress: 136.6 N/mm²
- Life period: 25 years
- Corrosion allowance: 2mm
- Welding efficiency: 90%
- Cost of pipe (all complete): NRs. 160/kg

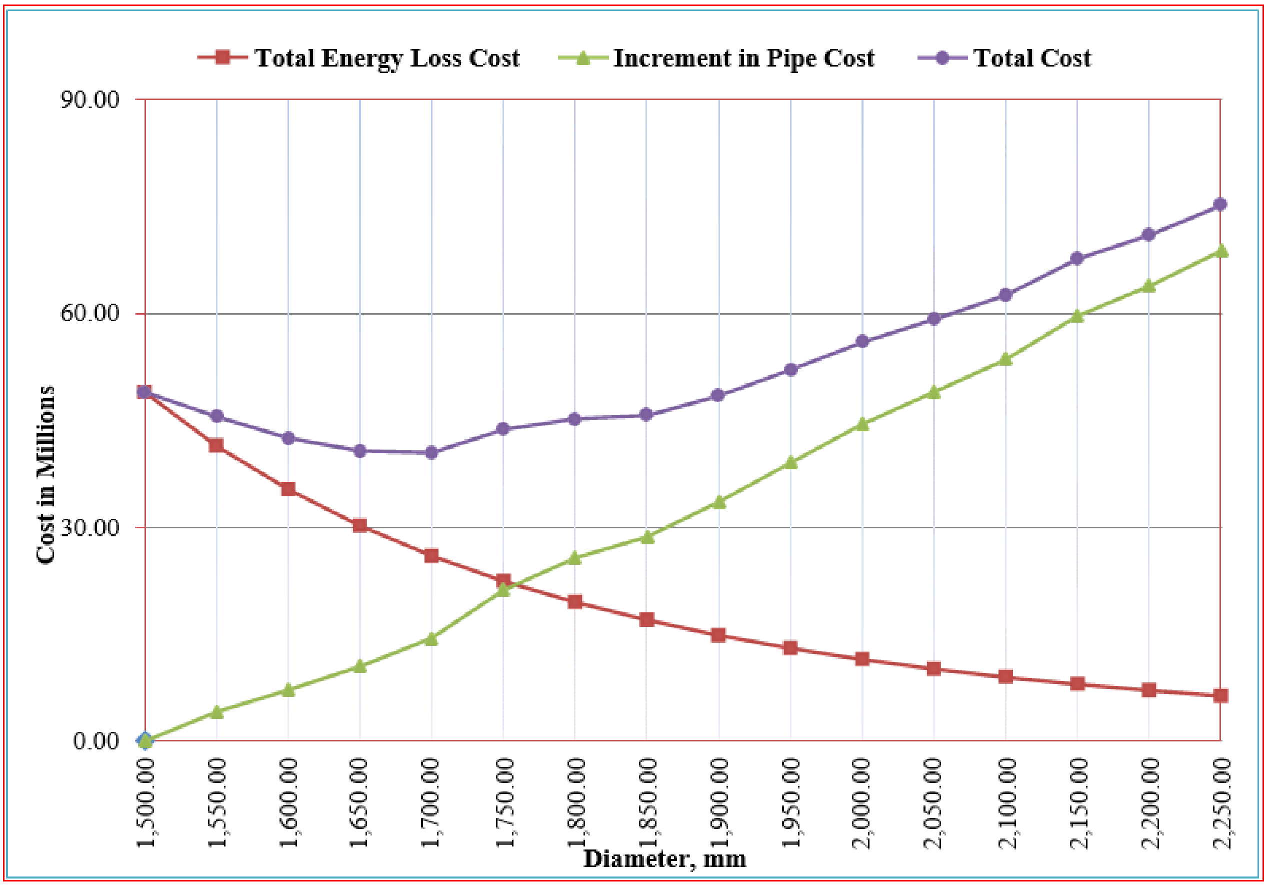


Figure 6-1: Penstock pipe optimization results

The result of the optimization with the above input parameters provides the optimum diameter as 1.7 m.

6.3.11.2 Selected pipe diameter and thickness

The total pipe length of 3873.50 m (up to bifurcation) penstock pipe with diameter varies from 2.0 to 1.75 is provided with thicknesses of the pipe vary from 10mm at the beginning to 25mm at the end of the penstock before the bifurcation.

Due to transportation of pipe, varies diameter of 2.0m,1.95m,1.85m and 1.75m is provided .

6.3.12 Anchor blocks in penstock alignment and saddle

The penstock alignment is both buried and exposed as dictated by the topography. The pipe is supported by anchor blocks at the bends and by saddle supports in between the anchor blocks. Along the pipe alignment river two river crossing is proposed at the chainage about 0+600.00m to 0+700.00m (i.e. from left bank to right bank) and another crossing at the chainage of 1+420.00 to 1+460.00m (i.e. from right to left bank) of Irkhuwa Khola.

Anchor blocks are designed to stabilize the hydraulic forces at the pipe bends. There are altogether 43 number of anchor blocks including bifurcation blocks and 5 nos. of concrete casing (2 at the river crossing and 3 number at powerhouse) throughout penstock alignment. Also Anchor block in a straight section is provided to resist axial forces in the long straight section.

The anchor block foundation soil will be well compacted and well covered by backfill.

The shape of the blocks has been governed by the topography and the bend angle. All the blocks will be constructed of plum concrete with C15 grade. Anchorage bars will be provided around the bend and temperature and shrinkage bars will be provided on the surface of the blocks.

All the blocks will be stable regarding sliding, overturning and bearing of the foundation.

6.3.13 Saddle supports in penstock alignment

Saddle support piers will be provided along the straight sections of exposed penstock between anchor blocks to avoid overstressing in the pipe. The spacing of the piers will be 8.0m and 12m along its true length as specified in Dwg (section water way). The piers will be constructed of stone masonry with concrete cap of 30cm thickness. The stone masonry is tied with10 cm thick RCC band at each 1m height of the pier.

All the saddle support will be stable regarding sliding, overturning and bearing of the foundation.

6.3.14 Powerhouse and Tailrace Canal

Powerhouse is designed to house the turbine, generator and other electro-mechanical equipment. Powerhouse complex is also provided with service and maintenance bay, room for mounting control panel, transformer and high voltage panel. Generally, to lift the heavy installations in the powerhouse, an overhead travelling crane or a suitable mechanism having chain pulley is equipped. Powerhouse is made safe from a possible hazardous flood that can happen in the river basin.

The surface powerhouse is proposed to be constructed on the terrace of the left bank of the Irkhuwa Khola. The size of the powerhouse is 40.0m x 16.3m x 18.0 m. Three generating units will be accommodated in the powerhouse. Normal tail water level is fixed at 691.77 masl. There will be provision for the auxiliary plants and service area. A concrete raft foundation is provided for the machine foundation in the powerhouse.

A rectangular cut and covered concrete box canal of 2.5 m width × 2.5 m height has been proposed to convey water from powerhouse to Irkhuwa Khola. The length of this tailrace conduit is 87.10 m and the maximum tail water level is 691.77 masl.

6.4 Hydro-mechanical works

6.4.1 General

The purpose of the study pertaining to hydraulic steel structures is to identify and dimension the principal components of the hydraulic steel structures for safe and economic plant operation of Upper Irkhuwa Hydropower Project.

Gates, stoplogs, trash rack , hoist, sealing arrangement, controls, steel support with handling tool, and appurtenant parts complete with necessary accessories are required at different areas of the weir, intake, settling basin, powerhouse and tailrace for isolating other equipment for flow regulation, closure, inspection and maintenance purposes of the intake, settling basin, water ways, etc. and also be used for water filling operation into the low pressure and high pressure penstock etc. after they have been dewatered.

General arrangement of the gates, stoplogs, trashrack and hoist will conform to civil drawings. However, the hoist features given on the drawings will not be considered as defining the detailed design of the equipment, but are illustrative; and the intent is to show the general layout of the equipment, its purposed functions and locations.

6.4.2 Design Criteria

Hydro-mechanical equipment will be designed to function properly at all water levels, under normal, unusual and extreme conditions and will be easy to operate and maintain. All relevant factors that have a bearing on the calculations and design, e.g. thermal stresses, reaction and concreting procedures, static and dynamic forces during operation and maintenance will be considered.

Design Water Levels

High flood level of Irkhuwa Khola (1 in 100 years)	El. 623.50 m
High flood level of Phedi Khola (1 in 100 years)	El. 627.15 m
Normal operating level at Irkhuwa Khola Intake	El. 920.90 m
Normal operating level at Phedi Khola Intake	El. 624.60 m
NWL at Headpond	El. 620.51 m

Basic Load criteria for hydraulic steel structures will be carried out in accordance with the following standards and codes of practice:

DIN 19704: Basis of calculation for Hydraulic Steel Structure Equipment;

IS: 9349 -1986: Indian Standard for Structural Design of Slide Gates;

IS: 11388 – 1995: Indian Standard for Design of Trashracks;

IS: 6938 – 1989: Indian Standard for Rope Hoist Design;

IS: 4623 – 1967: Indian Standard for Design of Fix Wheel Gates;

IS: 11228 – 1989: Indian Standard for Screw Hoist Design;

Technical Standards for Gates and Penstock of Hydraulic Gate and Penstock association of Japan

Design of Hydraulic Gates by Paulo C.F. Erbisti

A water resources technical publication :Engineering Monograph No.3 “Welded Steel Penstock”

Steel Penstocks: ASCE Manuals and Reports on Engineering Practice No. 79

AWWA Manual M-11

6.4.3 Gates

For controlling the water flow, numbers of vertical gates are provided in different locations of head-works. Gate will consist of skin plate, girders, stiffeners, seals, guide shoes, wheel and all other necessary components. During structural designing of gates, stoplogs, trashracks and their component parts, following loads and effect will be considered;

Normal Loading Conditions

Full hydrostatic pressure, both external and due to seepage behind embedded parts.

Maximum hydrodynamic forces, which may occur during operation of the gates.

Dead load of the respective gate, trash racks, etc., including concrete ballast.

All possible lifting and friction forces occurring separately and in combination with forces listed above.

Wind forces, especially when gate dogged at open position.

Fatigue due to vibration caused by flowing water or operation of equipment.

Extreme Loading Conditions

Combination of the forces stated above plus seismic loading

Combination of the forces stated above and loading due to a 100-year flood.

All gates will also be designed for the case where gate jams while being raised and the hoist subjects the gate to the full pull developed by the maximum pull force of the power unit.

Gates will have adequate rigidity and guidance for being raised from one side by one hoist operating only.

The gates and stoplogs will have skin plate at upstream and vertical girders and beams at downstream side. Deflection of the beams will be kept within 1/800 of gate span under the design hydrostatic load. Gate frames will be designed to transfer the hydrostatic forces to the concrete structure, exerted on the skin plate, through wheels/ guide shoes. Partial opening of the gate and stoplog is normally not allowed. However, the bottom seal and steel structure will be shaped to wedge type so that vibrations during partial openings is minimum. When closed, the gates rest upon the bottom sill.

Rubber seals of musical note type at side & top and flat rubber seals at the bottom of adequate sizes will be designed to prevent leakage from the gates and stoplogs. According to Indian Standard, maximum permissible eater leakage for the gate and stoplog is five litre/meter/ minute. Seals will be durable, adjustable and replaceable.

6.4.3.1 Intake Gate at Irkhuwa Khola Headworks

Intake canal gate is normally kept in the fully open position and only need to close during the flash flood in river and maintenance at gravel trap or settling basin. Intake structure will be equipped with three (3) vertical fixed wheel gates for closures and can be used to control the water flow, if necessary.

Gate will be closed under balanced pressure and open partially with full differential pressure across the gate for filling of downstream conveyance system. Gates will be designed to open against high flood level when downstream conveyance system is empty. Gate is to be designed to be lowered under flowing water condition.

Basic design parameter of the Irkhuwa Intake Gate is as follows:

Type of Gate	Vertical Fixed Wheel Gate
No. of Gate	Three (3)
Type of Hoist	Electrically operated Motorized Double Stem Screw Spindle Hoisting system with manual provision
No. of Hoist	Three (3) set
Clear Opening (W x H)	2.5 m x 1.5 m

Sill Elevation	918.70 masl
Design head	4.80 m
Sealing Arrangement	4-way Upstream
Structural Material	JIS –SS41, SM400B or IS2062 or equivalent

6.4.3.2 Intake Gate at Phedi Khola Headworks

Phedi intake structure will be equipped with Two (2) vertical fixed wheel gates for closures and can be used to control the water flow, if necessary.

Gate will be closed under balanced pressure and open partially with full differential pressure across the gate for filling of downstream conveyance system. Gates will be designed to open against high flood level when downstream conveyance system is empty. Gate is to be designed to be lowered under flowing water condition.

Basic design parameter of the Phedi Intake Gate is as follows:

Type of Gate	Vertical Fixed Wheel Gate
No. of Gate	Three (2)
Type of Hoist	Electrically operated Motorized Double Stem Screw Spindle Hoisting system with manual provision
No. of Hoist	Two (2) set
Clear Opening (W x H)	3.0 m x 0.8 m
Sill Elevation	918.70 masl
Design head	3.55 m
Sealing Arrangement	4-way Upstream
Structural Material	JIS –SS41, SM400B or IS2062 or equivalent

6.4.3.3 Under Sluice Gate at Irkhuwa Headworks

All boulder collected in upstream of intake structure will be flushed out from the under- sluice gate. During normal condition, the gate of under sluice remains closed to ensure available flow is diverted in to the waterways. During flood flow, the gate will be kept fully open position. The regime inside the under sluice will be pressurized so that boulders will be flushed out to downstream of the weir.

Number, type, size and the location of the gate are determined by the expected design flood inflow as well as the requirements for flushing out boulder. During the maintenance of the flushing gates, stoplogs will be installed at upstream of the under sluice gate.

Basic design parameter of the under sluice gate is as follows:

Type of Gate	Vertical Fixed Wheel Gate
No. of Gate	One (1)
Type of Hoist	Electrically operated double stem Motorized Screw Spindle Hoisting system with manual provision
No. of Hoist	One (1) set
Clear Opening (W x H)	2.5 m x 2.5 m
Sill Elevation	916.20 masl
Design head	7.30m
Sealing Arrangement	4-way Upstream
Structural Material	JIS –SS41, SM400B or IS2062 or equivalent

6.4.3.4 Gravel Flushing Gate at Irkhuwa Headworks

One (1) vertical slide gate will be installed for gravel flushing at end of the gravel trap. The flushing gate will normally be in closed position and will only be open during flushing out the deposited sediment and gravels during wet season. Number, type, size and the location of the gates are determined by the expected design flood inflow as well as the requirements for flushing out gravel at all water discharge.

The basic design parameter of the Gravel Flushing Gate at Irkhuwa Headworks is as follows:

Type of Gate	Vertical Slide Gate
No. of Gate	One (1)
Type of Hoist	Manually operated Single Stem Screw Spindle Hoisting system
No. of Hoist	One (1) set
Clear Opening (W x H)	1.0 m x 1.0 m
Sill Elevation	915.54
Design Head	5.20m
Sealing Arrangement	4-way Downstream
Structural Material	JIS –SS41, SM400B or IS2062 or equivalent

6.4.3.5 Settling Basin Inlet Gate

Inlet of settling basin will be equipped with two gates. At which, one slide gate for closure of each opening. These gates are normally kept in the fully open position and only need to close during the maintenance of settling basin. These gates are also used during closing of intake gate. If one inlet gate in one settling basin is taken out of operation for maintenance, normal turbine generation will continue with the other settling basin in operation.

The basic design parameter of the Settling Basin Inlet Gate is as follows:

Type of Gate	Vertical Fixed Wheel Gate
No. of Gate	Two (2)
Type of Hoist	Electrically operated Monorail Hoisting System (with Manual Provision) with fixed gantry structure
No. of Hoist	Two (2) set
Clear Opening (W x H)	3.55 m x 1.40 m
Sill Elevation	918.50 masl
Design Head	2.24 m

Sealing Arrangement	4-way Upstream
Structural Material	JIS –SS41, SM400B or IS2062 or equivalent

6.4.3.6 Settling Basin Outlet Gate

Outlet of each settling basin will be equipped with two vertical slide gates for closure of each opening, totalling 4 gates. Gates will normally be in open position during operation, but will be closed to avoid backwater entering from the downstream when the respective settling basin is emptied for flushing or repair. Back flushing can also be done by operating the gate in partially open position during flushing of the settling basin.

The basic design parameter of the Settling Basin Outlet Gate is as follows:

Type of Gate	Vertical Slide Gate
No. of Gate	Four (4)
Type of Hoist	Electrically operated Monorail Hoisting System (with Manual Provision) with fixed gantry structure
No. of Hoist	Four (4) set
Clear Opening (W x H)	1.85 m x 1.3 m
Sill Elevation	917.86 masl
Design head	2.78m
Sealing Arrangement	4-way Downstream
Structural Material	JIS –SS41, SM400B or IS2062 or equivalent

6.4.3.7 Settling Basin Sand Flushing Gate

All the sand collected in the settling basin will be flushed out through the settling basin flushing channel. The settling basins will be equipped with a flushing channel having one vertical slide gate. Number, size and the location of the gate are determined by the flushing requirements. During periods with high sediment load, basins will be flushed several times a month.

Flushing gates will normally be in closed position and will only be open to flush out the deposited sediment during wet season. A stoplog is located upstream of each gate and will normally in open position and only need to be closed during the maintenance of the gate.

Basic design parameter of the Sand Flushing Gate is as follows:

Type of Gate	Vertical fixed wheel Type
No. of Gate	Two (2)
Type of Hoist	Manually operated Single Stem Screw Spindle Hoisting system
No. of Hoist	Two (2) set
Clear Opening (W x H)	1.0 m x 1.0 m
Sill Elevation	913.50 masl
Design head	7.14m
Sealing Arrangement	4-way Downstream
Structural Material	JIS –SS41, SM400B or IS2062 or equivalent

6.4.3.8 Tailrace Gate

Three sets of vertical fixed wheel Tailrace Gate for closure of each tailrace opening to stop the flash flood entering into the powerhouse through the tailrace chamber and also to block downstream water entering into the draft tube chamber during maintenance of respective turbine units. The gate will normally be in open position and will be closed during emergency condition only.

The basic design parameter of the Tailrace Gate is as follows:

Type of Gate	Vertical Fixed Wheel Gate
No. of Gate	Three (3)
Type of Hoist	Electrically operated Monorail Crane Hoist with steel fixed gantry structure with manual provision
No. of Hoist	Three (3) set
Clear Opening (W x H)	3.45 m x 1.85 m
Design head	5.25 m

Sealing Arrangement	4-way Downstream
Structural Material	JIS –SS41, SM400B or IS2062 or equivalent

6.4.4 Stoplogs

Stoplogs will be designed for the normal, unusual and extreme loading conditions corresponding to pressures from the waterside. Axial forces will be transferred to the side guides and surrounding concrete. Stoplogs guides are assumed to be subjected to an external pressure over the whole length equal to design pressure, as well as the supporting forces from the stoplogs.

Stoplogs are to be operated by manual chain block or screw spindle hoist with suitable capacity. Stoplogs will be provided for the waterways of the following headwork structures:

- Upstream of Undersluice gate
- Upstream of Gravel Flushing Gate
- Upstream of Sand Flushing Gate

6.4.4.1 Under Sluice Stoplog

During the maintenance of the Under-sluice gates, stoplogs will be installed at upstream of it.

Basic design parameter of the Under sluice Stoplog is as follows:

Type of Stoplog	Vertical Fixed Wheel Type
No. of Stoplog	One (1)
Type of Hoist	Manually operated Chain Block Hoisting system and accessories all complete.
No. of Hoist	One (1) set
Clear Opening (W x H)	2.5 m x 2.5 m
Sill Elevation	916.20 masl
Design head	7.30m
Sealing Arrangement	4-way Downstream
Structural Material	JIS –SS41, SM400B or IS2062 or equivalent

6.4.4.2 Gravel Flushing Stoplog

During the maintenance of the Gravel Flushing Gate, a stoplog will be installed at upstream of it.

Basic design parameter of the Gravel Flushing Stoplog is as follows:

Type of Stoplog	Vertical Slide Type
No. of Stoplog	One (1)
Type of Hoist	Manually operated Single Stem Screw Spindle Hoisting system
No. of Hoist	One (1) set
Clear Opening (W x H)	1.0 m x 1.0 m
Sill Elevation	915.542 masl
Design Head	5.20m
Sealing Arrangement	4-way Upstream
Structural Material	JIS –SS41, SM400B or IS2062 or equivalent

6.4.4.3 Settling Basin Sand Flushing Stoplog

During the maintenance of the Sand Flushing Gate, a stoplog will be installed at upstream of it.

Basic design parameter of the Sand Flushing Stoplog is as follows:

Type of Stoplog	Vertical Slide Type
No. of Stoplog	Two (2)
Type of Hoist	Manually operated Single Stem Screw Spindle Hoisting system
No. of Hoist	Two (2) set
Clear Opening (W x H)	1.0 m x 1.0 m
Sill Elevation	913.50 masl
Design head	7.14m

Sealing Arrangement	4-way Upstream
Structural Material	JIS –SS41, SM400B or IS2062 or equivalent

6.4.5 Trash Racks

Trash rack will be designed to prevent matters injurious to the water turbines from entering the penstock and to adequately withstand the impact forces, static loads and vibration phenomena, which are likely to occur due to flow of water passing through the trash rack. Design head for trash rack depends upon the difference in water levels on the upstream and downstream sides at the time of clogging i.e. the critical head in the trash rack structure.

The trash rack shall be of a shape which has a small loss of head and the shape, dimension and support condition shall be decided by taking into account the velocity of the flow so that the running water does not produce vibration. The trash rack and its support beams shall be so structured as to withstand the required differential head, which is decided by taking the possible trash volume into consideration.

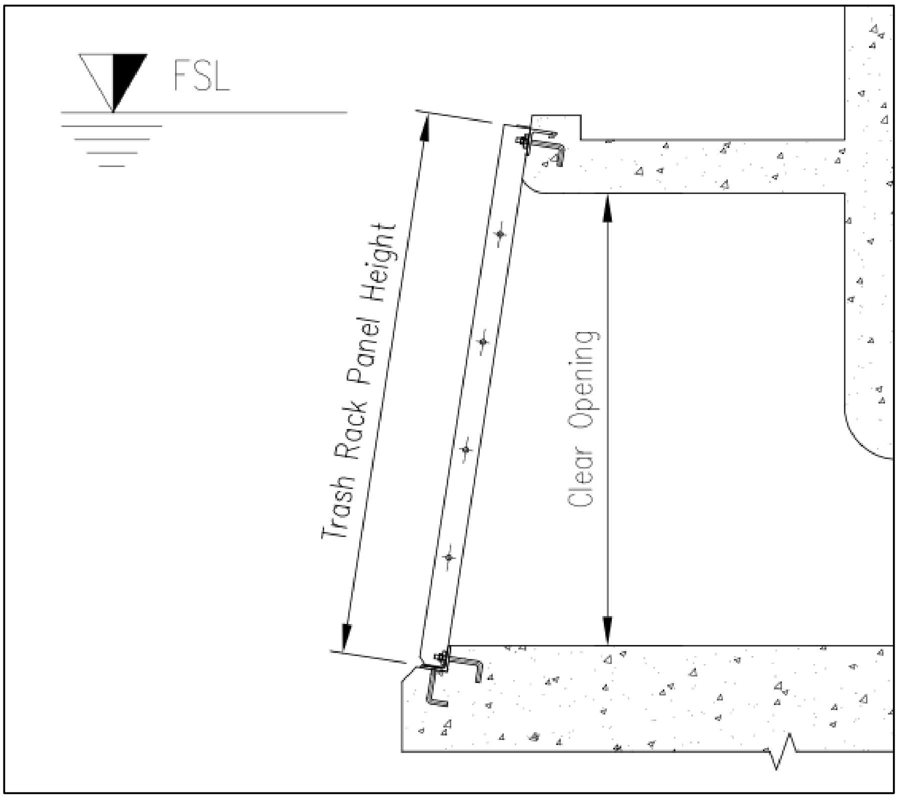


Figure 6-2: Schematic Drawing of Intake Trash rack

During designing of the Trash Rack, following points will be taken care.

- Trash racks bars are installed parallel to the streamlines and are spaced approximately 40 mm to 120 mm apart centre to centre.

- Width of the bar is less than the 12 times of its thickness.
- Minimum width of the bar is taken 50 mm.
- In order to prevent trash rack from buckling horizontally, the supporting space is generally taken as less than 70 times the thickness.
- The flow velocity passing through the trash rack is generally 0.6 m/s to 1.0 m/s.

Differential head for trash rack design is 50% to 100% of the trash rack height depending upon the quantity and type of debris and frequency of cleaning. For intake trash rack, 100% clogging has been considered where for other, 50% clogging is suitable to consider for calculation.

Structural steel conforming to IS 2062 and IS 800 or equivalent will be chosen as a structural material for the trash rack.

6.4.5.1 Irkhuwa Khola Intake Trash Rack

Basic design parameters of the Irkhuwa intake trash racks will be as follows:

No. of Trash rack	One(1)
Trash rack Panel Size (w x h)	9.30 x 2.8 m
Bar Pitch	68 mm
Sill Elevation	918.70 masl
Design head	4.80 m
Structural Material	SM400B or IS2062 or equivalent

6.4.5.2 Phedi Khola Intake Trash Rack

Basic design parameters of the Benkhuwa intake trash racks will be as follows:

No. of Trash rack	One (1)
Trash rack Panel Size (w x h)	3 x 1.47 m
Bar Pitch	68 mm
Sill Elevation	918.70 masl
Design head	3.55 m

Structural Material	SM400B or IS2062 or equivalent

6.4.5.3 Settling Basin Inlet Trash Rack

Basic design parameters of the Settling Basin Inlet Trash rack will be as follows:

No. of Trash rack	One (1)
Trash rack Panel Size (w x h)	9.3 x 2.11 m
Bar Pitch	30 mm
Sill Elevation	918.50 masl
Design head	2.24 m
Structural Material	SM400B or IS2062 or equivalent

6.4.5.4 Headpond Outlet Trash Rack

Basic design parameters of the Headpond Outlet Trashrack will be as follows:

No. of Trashrack	One (1)
Trashrack Panel Size (w x h)	5.8 x 5.70 m
Bar Pitch	40 mm
Sill Elevation	912.64 masl
Design head	7.90
Structural Material	SM400B or IS2062 or equivalent

6.4.6 Hoisting Mechanism

Hoist will be designed to raise, lower and hold the gate in any position between fully closed and fully raised positions. Rated capacity of the hoist, chain and screwed spindles will be adequate to raise or lower the gate at rated speed under the most adverse combination of loads.

6.4.6.1 Screw Spindle Hoisting

Each gate hoist will be designed for a rated capacity equal to the sum of the gate weight, roller chain tractive load, seal friction, and the maximum hydraulic vertical forces with normal stresses considering the adequate jam factor.

For this project, manual and motorized screw spindle hoisting systems have been proposed. Screw spindle hoist will have the structural steel framework, mechanical equipment, i.e., screw stem, extension stem, shafts, bearings, gear reducers, couplings, sheaves, manual operating device etc. and electric equipment such as electric motor, limit switches, electrohydraulic thruster brake, etc. and all other necessary components.

Hoisting system will be mounted in the operating slab with bolt joint so that the gate/ stoplog can be taken out completely from the gate groove during maintenance. The adequate number of intermediate supports will be provided to the extension stem to prevent it from bucking. The maximum width of the gate panel proposed in this project is only 2.2 meter. Hence, only single stem screw spindle hoisting system is preferred to reduce the initial investment as well as the maintenance cost.

In gate operation, the hoisting system will be operated through a local control unit. The hoist will be capable of raising, lowering and stopping the gate at any position between fully open and fully closed by corresponding push-button switches. When it is necessary to make provisions to raise or lower the gates without power, there will be provision of manual cranking system.

6.4.6.2 Control system

For the electric motor driven hoisting system, gate operating will be done through a local control unit. In gate operation, the hoist shall be capable of raising, lowering and stopping the gate by corresponding push-button switches. The gate shall be raised to its fully raised position by "Raise" push-button switch and usually be kept at the fully raised positions.

The limit switches will be installed for the safe and proper operation of the gate. "Fully raised" and "Fully lowered" limit switches to stop the gate will be installed at restricted position. "Over torque" limit switches to stop the gate if hoist is overloaded during raising and lowering. All necessary switches, indicators, relays, transformers and other devices shall be installed within the cabinet.

6.4.7 Steel Pipe

A lane of steel pipe of length 3880.40 meter will be installed to convey water from the Headpond bell mouth to the bifurcation (Y branch). The diameters of the steel pipe will be varying from 2000 mm to 1750 mm and maximum thickness of 25 mm. The pipe after Y-branch and before the unit valve is known as manifold pipes. The diameter of the manifold pipe will be 1400 and 1000mm and thickness proposed is 20 mm and 16 mm respectively.

The material proposed to be used for manufacturing of the steel pipe shall be fine-grained, normalized quality steel according to JIS SM400B or IS2062 E250BR or equivalent standards. The allowable stress acting on the steel penstock shall be 2/3rd of minimum yield strength or 1/3rd of ultimate tensile strength, whichever is less.

For pipe branching (bifurcation), it is prudent to use lower allowable stresses as compared to the penstock, these allowable stresses shall be one half times the minimum specified yield stress or one-fourth times the minimum specified tensile strength, whichever is less. The internal angle between the branching pipes will be confirmed only after the finalization of the machine layout within the powerhouse.

The thicknesses of the high-pressure pipe have been further calculated for verification, considering the most unfavorable situation as the governing factor. Design of pressure pipe has been done considering the internal hydrostatic pressure including pressure rise, external pressure due to backfilling, vacuum pressure, thermal stress, stress due to poison's ratio, buckling stress, deflection, shear stress etc.

For buried pipe, resistance to external loading is a function of pipe stiffness and passive soil resistance under and adjacent to the pipe. These two factors work in unison to create a pipe/backfill system whose stiffness resists the earth and live loads to which the pipe is subjected. The estimated horizontal deflection of a buried pipe will be calculated using the deflection formula, as follows:

$$\Delta x = D_i \left[\frac{K.W.r^3}{E.I + 0.061\ E'.r^3} \right]$$

Ref: AWWA Manual M-11, Equation 6-5

Where,

Δx	=	Horizontal Deflection
D	=	Pipe Inside Diameter
	=	2000, 1950, 1850 and 1750 mm
Di	=	Deflection Lag Factor = 1.1
K	=	Bedding Constant = 0.1
E'	=	Modulus of Soil Reaction = 1500 psi
W	=	Load per Unit of Shell Length (W= Dead Load + Live Load)

t = Shell Thickness

r = Mean Radius of Pipe

I = Transverse Moment of Inertia per Unit Length of Shell Wall

E = Modulus of Elasticity of steel

Allowable deflection for steel pipe is often accepted 5 % of pipe diameter.

As noted in the Technical Standards for Gates and Penstocks, Hydraulic Gate and Penstock Association (1986) the following formula, which is, also known as the minimum thickness for shipping and handling will be applied to estimate the minimum thickness:

$$t_{min} = \frac{D + 508}{400}$$

This gives minimum handling thickness is 6.27 mm for 2000 mm diameter pipe. However, the thickness is also governed by other criteria such as external pressure or vacuum. The buried pipelines supported by a well-compacted, granular backfill will not buckle due to vacuum. The sum of external loads should be less than or equal to the pipe's allowable buckling pressure, qa, which is determined by the following;

$$\gamma_w . h_w + R_w . \frac{W_e}{D} + P_y \leq q_a$$

hw = height of water above conduit

gw = specific weight of water = 0.0361 lb/cu in. (0.0098 kPa/mm^3)

Py = internal vacuum pressure=atmospheric pressure less absolute pressure inside pipe

We = vertical soil load on pipe per unit length, in lb/in. (kPa/mm)

The principle characteristics of the penstock pipe:

Type	: Partly exposed, partly buried
Quantity	: One lane
Length of penstock up to pipe branching	: 3,880.40 m
Shell thickness	: 8 mm to 25 mm

Y-Branch and Manifold Pipes:

Initial diameter : 1750 mm

Manifold pipe diameter : 1.00 m (Three lanes)

Summary of pipe to be installed for this project is presented below:

Pipe Diameter (m)	Actual Pipe Length (m)	Pipe Thickness (mm)	Material Grade	Quantity (kg)	Remarks
2.00	509.11	8	IS:2062 E250 BR	201,690.23	Bell Mouth to AB#7
2.00	387.27	10	IS:2062 E250 BR	191,968.27	AB#7 to AB#12
1.95	337.30	12	IS:2062 E250 BR	195,846.64	AB#12 to AB#16
1.95	486.53	14	IS:2062 E250 BR	329,912.43	AB#16 to AB#22
1.95	187.62	16	IS:2062 E250 BR	145,546.63	AB#22 to AB#25
1.85	272.70	16	IS:2062 E250 BR	200,787.32	AB#25 to AB#28
1.85	442.72	18	IS:2062 E250 BR	367,111.55	AB#28 to AB#33
1.85	249.46	20	IS:2062 E250 BR	230,086.98	AB#33 to AB#35
1.75	636.03	20	IS:2062 E250 BR	555,265.12	AB#35 to AB#45
1.75	90.56	22	IS:2062 E250 BR	87,064.75	AB#45 to AB#46
1.75	281.10	25	IS:2062 E250 BR	307,622.96	AB#46 to AB#49
1.40	10.80	20	IS:2062 E250 BR	7,564.18	Manifold Pipe
1.00	53.00	16	IS:2062 E250 BR	21,247.56	
			Total Weight (kg)	2,841,714.60	

Design Consideration

Following design parameters has been considered for the detail design.

1	Internal diameter	2.0, 1.95, 1.85 and 1.75m
2	Design discharge	7.80 m3/sec
3	Net head	214.78 m
4	Gross head	229.13 m

5	Max. Pressure rise	35%
6	Maximum internal water pressure	2.44 MPa
7	Material	JIS SM400B or IS2062E250BR or Equivalent
8	Corrosion allowance	2.0 mm
9	Welding efficiency	90 % for field welding 95% for shop welding

Penstock consists of straight pipes, bend pipes, pipe branching, stiffener rings, thrust collars, drain pipe with valves, manhole, anchor bands, bars and other necessary accessories. Detail of these appurtenances has been elaborate in later headings.

6.4.8 Expansion Joints

An expansion joint will be installed at a place where an excessive stress or deformation is liable to be generated in an axial direction by a temperature changes or other external forces. The temperature of steel penstock with water in it is mainly influenced by water temperature, and governed by ambient temperature when the penstock is empty, and is affected by sunshine when exposed.

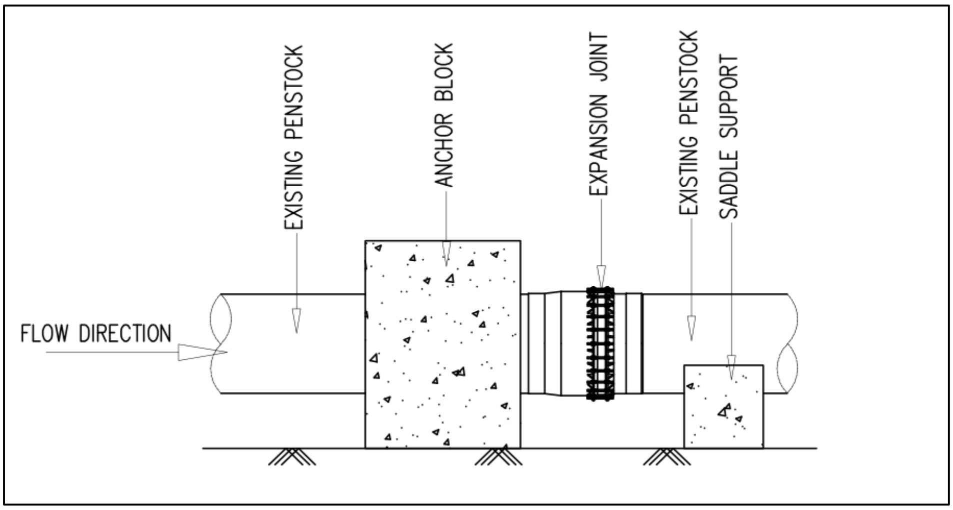


Figure 6: Key Elevation of Expansion Joint

A main purpose of an expansion joint is to enable a penstock to expand in an axial direction depending on this temperature change so as not to generate excessive stresses, and this joint also helps adjusting the length of a pipe when installed.

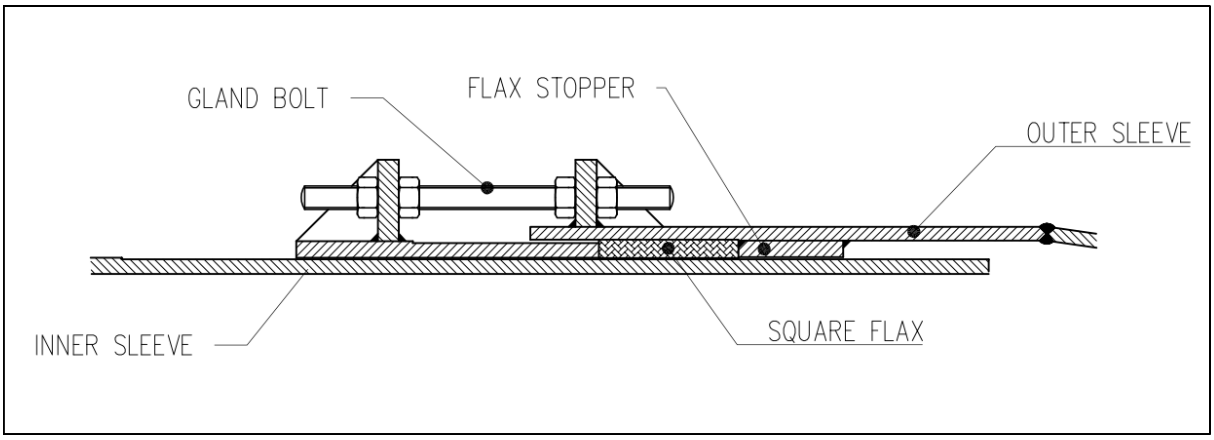


Figure 7: Schematic Drawing of Sleeve Type Expansion Joint

An expansion joint generally used is of a sleeve type which enables a pipe to expand only in an axial direction, and the joint is usually installed just downstream of an anchor block or in the middle of both anchor blocks for almost a horizontal pipeline in view of installation convenience. Design of a sleeve type expansion joint involves design of the following components as illustrated in the IS 11639 (Part 3): 1996 – Expansion Joints and Dresser Couplings.

Minimum Slide Distance of Pipe: During expansion and contraction of pipe due to change in temperature, length of pipe changed. To accommodate these changes in length, minimum sliding length will be calculated.

Gland Bolt: The bolt will be designed to exert enough pressure on the packing so that 1.25 to 1.5 times the internal hydrostatic pressure is mobilized between the sleeve and the packing.

Inner Sleeve: The inner sleeve will be designed to resist the external pressure PZ exerted on it by packing due to bolt force, transferred through the gland.

Gland: The gland flange should be able to resist the bending moment developed by the gland bolt forces.

6.4.9 Manholes

A manhole necessary for maintenance and inspection will be installed to a steel headrace and penstock pipe, taking its length, diameter and gradient into consideration. Manholes are usually spaced 120 to 150 meters apart. The location of a manhole is principally determined so as to gain an easy access and usually to be at the top or lower sides. The manhole proposed in this project is circular type having bore diameter of 600 mm. Design of wall thickness of nozzle pipe, blank flange thickness of manhole cover, thickness of reinforcing plate, bolt size and selection of O-ring will be done using the relevant International Standard.

6.5 Electromechanical Equipment

6.5.1 Mechanical Equipment

The major mechanical equipment will comprise of the following:

a) Hydraulic Turbine
b) Governors
c) Main Inlet valve
d) Pressure oil system
e) Cooling water system
f) Drainage and Dewatering system
g) Mechanical workshop and equipment
h) Air Conditioning and Ventilation System
i) Fire Fighting System
j) Powerhouse overhead travelling crane.

Prior to the discussion on the mechanical equipment, a short analysis to determine the optimum number of generating units is carried out.

Number of units/machines to be installed in the powerhouse is determined by carrying out "Unit Optimization".

For the optimization, single unit option was discarded at the initial stage considering the least flexibility in operation. Moreover, the transportation of a single unit would be incomparably high compared to multiple units. On the other hand, two to three units are sufficient for the desired flexibility in operation and their weight is not a shock to the existing roadway system. Opting for more than three units will have almost no benefit with respect to the installed capacity of the plant but will incur more cost due to increased powerhouse size, assembling duration & difficulties and added complexity in operation.

Therefore, two units and three units' options are taken into consideration for further analysis. A short analysis carried out has taken consideration of energy generated, capital investment cost of electro-mechanical component, technical aspect related with these options, reliability aspect between these two options and concluded that three-unit option is the better one.

6.5.2 Turbine Design

6.5.2.1 Selection Number of Units

The selection of unit capacity is based on the assumption that minimum number of units could be installed for the more economic development of the project, reliability of generation, higher efficiency of generating units, consideration of fluctuation in hydrology in the river and minimum loss of power during maintenance and operation at difference stage of time. Unit capacity is generally determined by considering the available discharge throughout the seasons, load demand, type of operations, efficiency of the machine, etc. Single unit is not preferred due to the fact that total generation loss will occur in time of the unit breakdown and hence two or three units will be suitable for the Project. Considering the above factors three units is the best option for the Project. Therefore, the study of Upper Irkhuwa Hydropower Project reveals that the installation of three (3) power units will be more economical for the following reasons:

- With three (3) turbines, the turbine runs at the rated efficiency during the operation of single unit during dry season while for two units, turbine runs at reduced efficiency at partial load and subjected to the hydrological risk, which might result into the shutdown of unit for the generation below the recommended turbine discharge provided by the manufacturer.
- In dry season, one unit shall run at nearly full load; for selection of turbines during minimum discharge level and its efficiency will be near around rated efficiency and hence the turbine performance and efficiency will be high for selection of three turbines as it relates to higher efficiency of the generating units rather than selection of one unit.
- The required repair and maintenance work of the power units can be performed in the yearly dry season in such a way that with exception of a temporary reduction of the plant power, no energy loss will occur.

6.5.2.2 Turbine Type Selection

The selection of type of turbine primarily depends upon the net head available and design discharge. For the rated net head of 214.78 m and design discharge of 2.60 m^3/s, Horizontal Francis turbine, Vertical Francis turbine and Turgo Impulse turbine is the different alternative choice of the turbine as presented on figure below. Choice of the Turgo Impulse turbine results into lower efficiency while Vertical Francis Turbine results into more investment in civil cost while resulting into same achievable efficiency between Vertical and Horizontal Francis Turbine. as presented onFigure 6-3 considering the achievable efficiency of the turbine unit, manufacturing and civil works cost in comparable to Turgo Impulse Turbine and Vertical Francis Turbine.

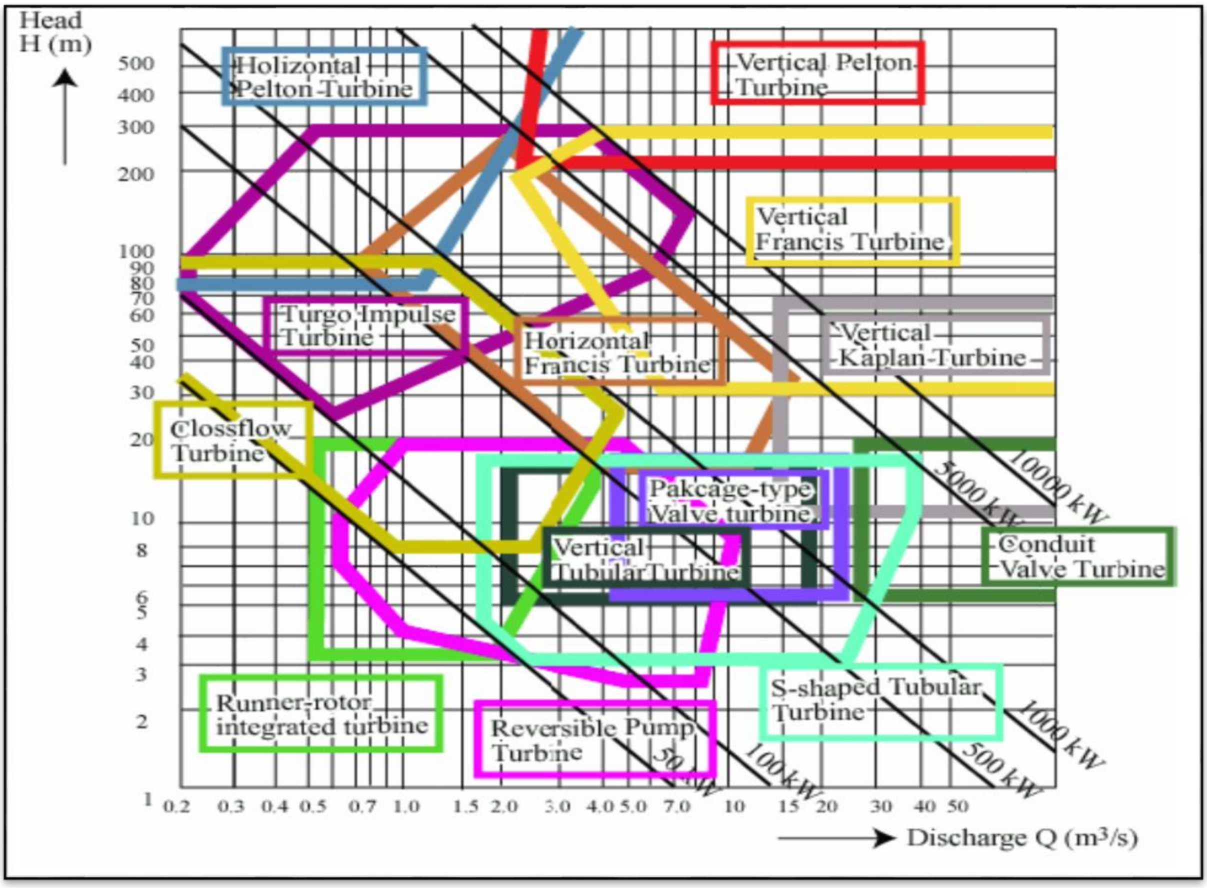


Figure 6-3: Turbine Selection Curve

6.5.2.3 Power and Energy Calculation

The Shaft Power Output of each Turbine is calculated by the following relation:

$$P_{turbine} = \eta_t \text{ x } Q_{turbine} \text{ x } g \text{ x } H_{net}$$

Where,

$P_{turbine}$ (Turbine Output, kW), g/g (Specific weight of water) = 9.81Kn/m^3, Q_{design} (Design Discharge) = 2.60 m^3/sec, H_{net} (Net Head) = 214.78 m and η_t = turbine efficiency = 92 %

$P_{turbine} = \eta_t \text{ x } Q_{turbine} \text{ x } g \text{ x } H_{net}$

= (9.81 x 2.60 x 214.78 x 0.92) kW

= 5,039.92 kW

Adopted Turbine output = 5,045 kW

Similarly, the Rated Generator capacity is determined by multiplying the Rated Turbine output by the generator efficiency (0.97).

$Generator\ Capacity = P_{turbine} \text{ x } \eta_t$

= (5040 x 0.97) kW

= 4,888.80 kW

= (4,888.80/0.85) = 5751.52 kVA

Adopted Generator output = 5750 kVA

Adopted Transformer Capacity = 5750 MVA (Single Phase, 3 + 1 Spare)

6.5.2.4 Turbine

6.5.2.4.1 Description of Turbine

Each turbine is capable of handling 2.6m3/s discharge (design) at a rated net head of 214.78 m, which result in the shaft power of 5,040 kW at maximum efficiency of 0.92. The size and speed of the turbine is such that the total costs of civil, electrical and mechanical works will be minimized.

The Francis runner will be directly coupled to the generator's shaft. The turbine runner and the guide vanes will be made of stainless cast or welded steel (13x4 Cr/Ni) of ASTM A 743 Grade CA6 NM respectively and thus, resistant to cavitation and sand erosion and has good welding ability. To facilitate maintenance, all bearings, joints of regulating mechanism etc. will be self-lubricating type.

The principal characteristics, where the physical dimension is as per the result obtained from simulation on TURBNPRO KC4, of the Francis turbines are as follows:

- Number of turbines : Three (3)
- Shaft arrangement : Horizontal
- Installed capacity for each unit : 5,040 kW
- Turbine Efficiency : 92%
- Rated discharge for each unit : 2.60 m^3/s
- Rated net head : 214.78 m
- Rated speed : 750 rpm
- Runway speed : 1350 rpm
- Runner diameter at outlet : 633 mm
- Spiral Casing Inlet diameter : 610 mm
- Centre line to inlet : 1,396 m

The main parts of turbine are described below:

Runner

The runner will be of the reaction type. The turbine runner shall be of integrally casted disc type having stainless steel quality with 13-4 Cr-Ni material of ASTM A743M Grade CA6NM or equivalent which is well suited for site welding for repairing. The blades are manually ground to the hydraulic shape. The runner will be designed to withstand the loads imposed by any combination of fully open wicket gate operation at any speed including maximum runaway speed and maximum head without exceeding the stress limits.

The runner-shaft connection will be of bolted type with the runner bolted to the flange at the end of the generator shaft. The method of attachment shall permit convenient removal of runner. The bolt holes in the runner will be accurately matched the holes in the mating flange of the shaft. The Francis runner is presented on Figure 6-4.

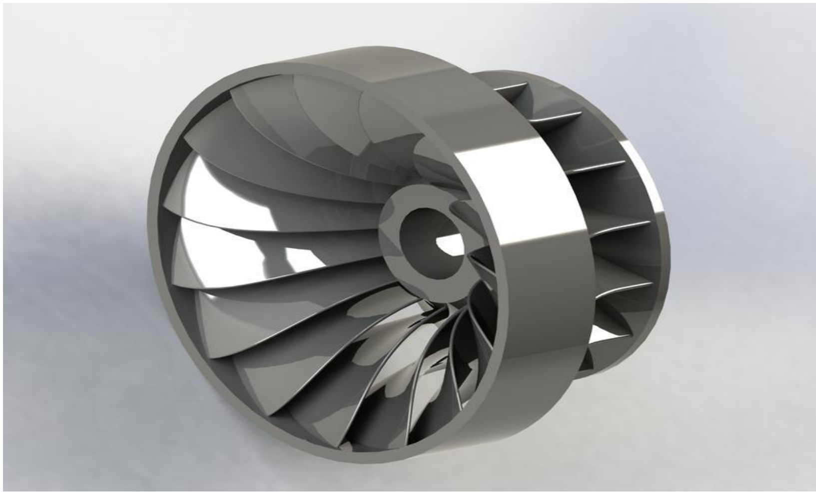


Figure 6-4: Francis Runner

Spiral Casing

The spiral case is a welded structure which is semi embedded vertically. Major components of the spiral case are its segments, stay rings and stay vanes. Stay vanes are a welded steel plate directly welded to Stay rings designed to direct water from spiral casing to the wicket gate. The stay ring is provided with adequate number of fixed stay vanes. The spiral case also consists of an inlet flange for connection to the Turbine inlet pipe before main inlet valve. It incorporates foundation feet and anchor bolts for levelling the foundation feet. A hand/inspection hole for inspection purpose is included. In addition, a drainage pipe connection at the lowest point of spiral case as well as a by-pass connection is provided.

Connection tabs for instrumentation and air relief valve at the top most point of the spiral case is provided**.**

Spiral case and stay rings are designed to withstand maximum transient pressures under the worst condition of head and load with adequate safety margin. Hence, the spiral case will be hydrostatic pressure tested in workshop at 1.5 times of the design pressure.

The spiral case is fabricated using welded steel plate of IS 2062 Grade B or another equivalent international standard.

Turbine Cover

The function of Front cover is to seal the runner room from water leakages and take the axial load acting on the runner crown side chamber. In addition, it contains the wicket gate bearings and gives support to the shaft seal housing. It also contains the runner seal wearing rings. The contact surface at the wicket gate blade position and head cover is corrosion protected by facing plates of same material specified as wicket gate and runner. The wearing ring provides a seal between the runner and the stationary part of the turbine and is bolted to the head cover assembly. Labyrinth seal rings matching the runner grooves will be bolted to the head cover to minimize the leakage water.

The front cover consists of head cover, facing plates, coupling connection with stay ring, hole for wicket gate stem bearing, coupling provision for runner crown seal wear ring, holes for relief pipes, connection for clearance check at crown seal position and coupling provision for shaft seal.

The rear cover consists of wearing plate, face plate, labyrinth seal ring, bearing for wicket gate stem, coupling provision for the draft tube, etc.

The front cover and rear cover are a single plate design made of Structural Carbon Steel plates according to IS 2062.

Wicket Gates

The wicket gates are machined according to designed hydraulic shape and are mounted between the front Cover & rear cover. To allow for smooth movement of the Wicket Gates, self-lubricating bearings are used at its stem. The self-lubricated bearings are mounted in the bearing housing. The wicket gates are casted from ASTM A 743 Grade CA6 NM.

Draft Tube

The draft tube shape is hydraulically optimized and is of circular shape design at its inlet. As an embedded part, the draft tube is normally assembled at site depending upon its size. The draft tube cone is of welded steel plates and have machined flanged for bolting with turbine discharge ring. The draft tube is reinforced sufficiently on the outside by means of suitable ribs. All parts of draft tube are made of Carbon Steel Plates according to IS 2062.

6.5.2.4.2 Preliminary Design on TURBNPRO KC4

Preliminary Design of Horizontal Configuration Francis turbine is designed on the basis of following entered data on it.

Table 6-1: Turbine Data

S.N.	Description	Parameters
1	Rated Discharge in m^3/s	2.6 m^3/s
2	Net Head (m)	214.78 metre
3	Gross Head (m)	229.13 metre
4	Site Elevation (masl)	671 masl
5	Water Temperature (in °C)	17°C
6	Desired Unit setting to Tailwater (in meters)	1 metre
7	Efficiency Priority at Maximum Output (0 to 10)	0
8	Electrical System Frequency (50 Hz or 60 Hz)	50 Hz
9	Minimum Net Head (m)	214.78 metre
10	Maximum Net Head (m)	226.0 metre

Figures related to graphical View, Dimensional and Turbine-Generator Arrangement are illustrated below.

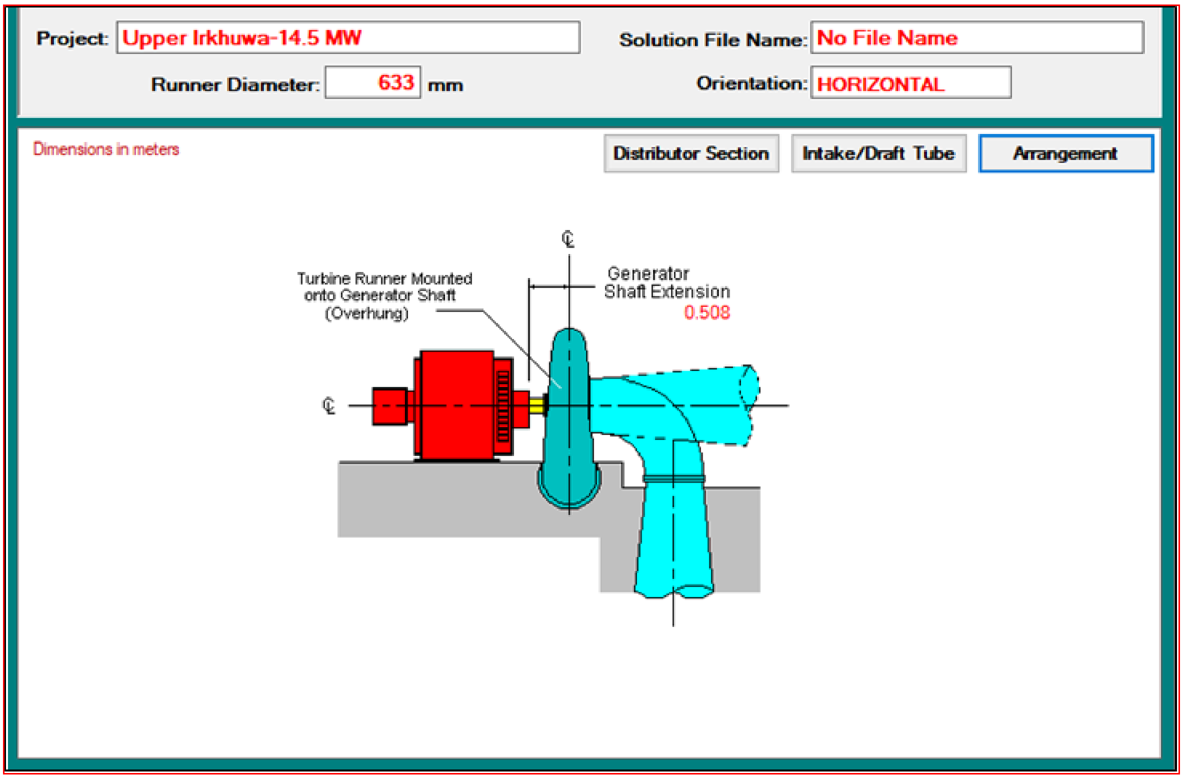


Figure 6-5 Turbine-Generator Arrangement

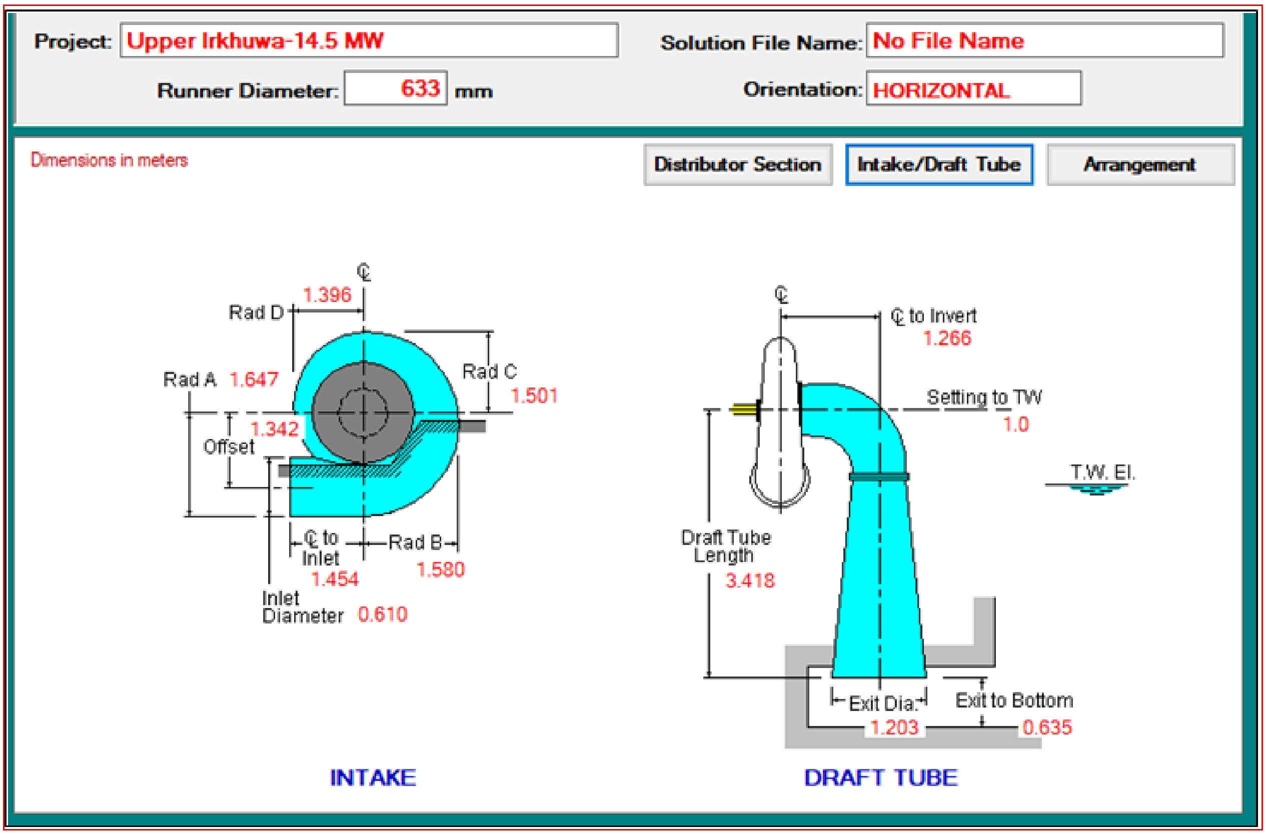


Figure 6-6 Arrangement of Intake/Draft Tube

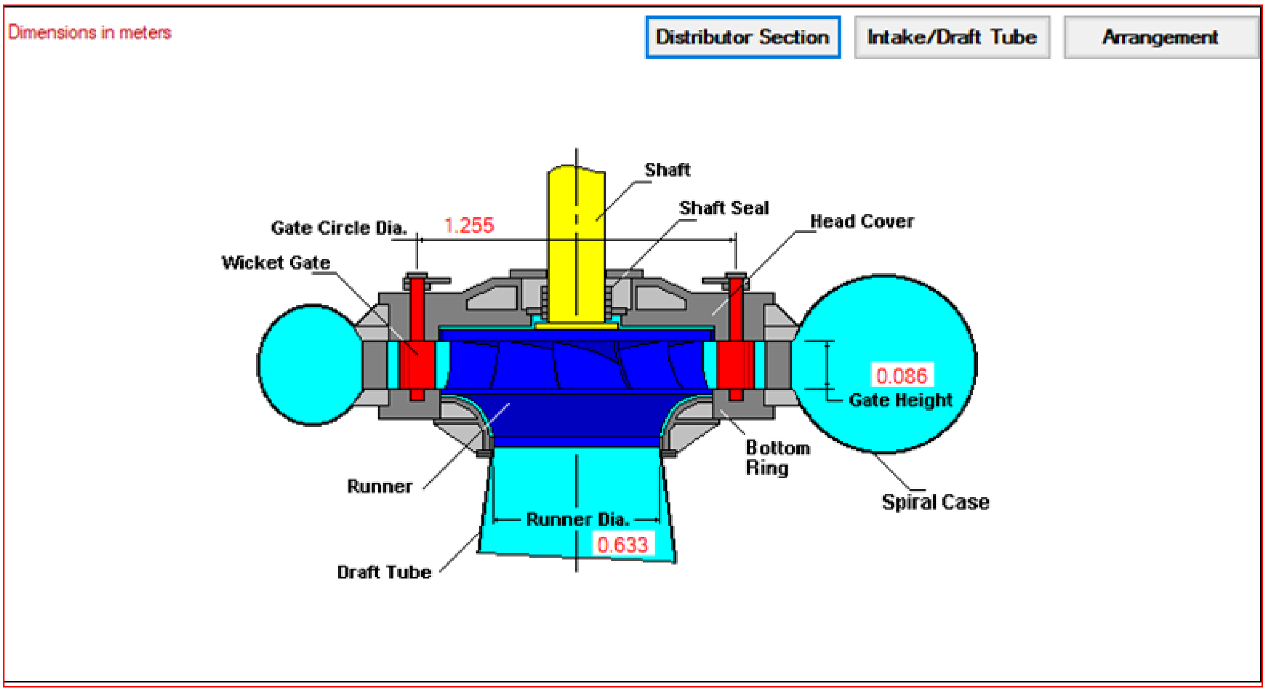


Figure 6-7 Distributor Section

6.5.2.5 Governor

Each turbine is controlled by a microprocessor controlled proportional integral derivative (PID) governor in combination with the oil pressure unit to operate the guide vanes for the regulation of the unit. The main features of the governor include:

a. Programming capabilities for automatic control of wicket gate openings to regulate maximum output of turbine
b. Shutdown of the unit in case of emergency

Governors are provided for the automatic control of the turbines during load variation. The electronic governors in combination with the oil pressure unit acts on the guide vanes for regulating the turbine flow. Each electronic governor has its own oil pressure unit/system. The oil pressure unit consists of a sump tank, N_2 filed accumulator pressure tank, and gear pumps.

For maintaining oil pressure in the system, a jockey pump is supplied. Essential controls and piping connections to the governor relay valve and servomotors of the turbine guide vanes is also provided. The capacity of governor pumps, governor motor and servomotors for guide vanes and opening and closing of main inlet valve shall be suitably selected. Further discussions on oil pressure unit are provided on Section 6.5.2.7 : Pressure Oil Supply System**.**

The governor panel and oil pressure unit will be located on the turbine floor near to the turbine. Conceptual governing system architecture is presented as below:

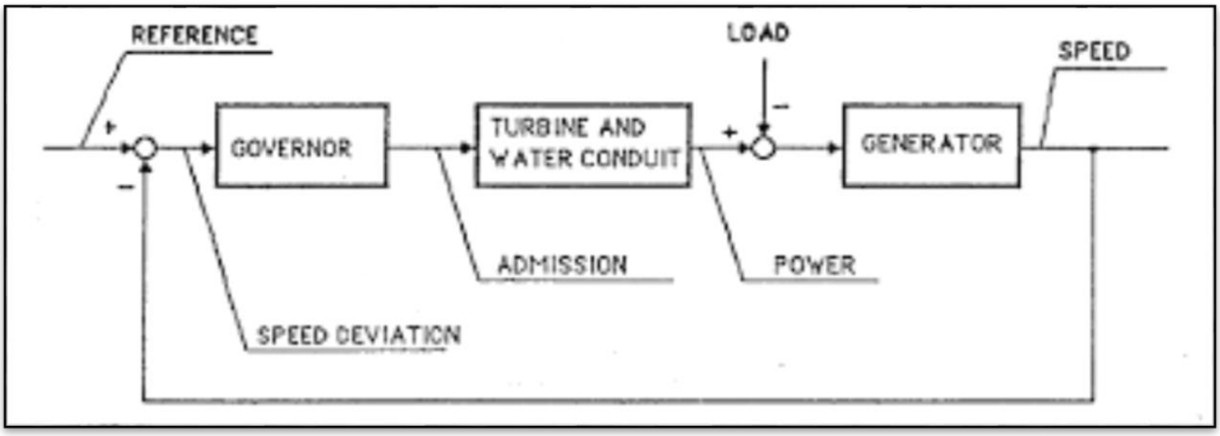


Figure 6-8: Governing System Architect

6.5.2.6 Main Inlet Valve

One main inlet valve will be provided for each power unit. The valve will be of Butterfly Valve with soft service seal arrangement integrated into it in accordance with turbine inlet requirement. For safety reason, each valve will be equipped with smaller by-pass valve for the filling procedure for the turbine distributor piping during normal operation for maintenance of required pressure difference between upstream and downstream level. The by-pass valves, Needle type, will close and open by means of oil hydraulic pressure.

Bolting flanges to the inlet pipe and penstock pipe will connect the main inlet valve. The valve will be open in balanced condition by oil pressure and will be closed by counter weight for safety reason. The Inlet valve will operate under the following conditions:

Normal Operating Conditions:

Valve opening will be initiated after 80% pressure balancing between the upstream and downstream side is reached, whereas valve closing will take place under no-flow conditions (turbine wicket gate's closed)

Emergency Operating Conditions:

In case of failure of wicket gate regulation system, the valve will close under the maximum turbine flow and head at the turbine inlet in the shortest time without causing the pressure in the penstock to rise above its design value.

The characteristic of Main Inlet Valves are as follows:

Valve type	: Butterfly Valve
Head	: 229.13 m
Approx. Nominal Pressure (PN)	: 30 bars
Approximate diameter	: 650 mm
Operating system	: Hydraulic for opening and, counterweight for closing and bypass system for pressure balance during initial opening
Total number of valves	: 3, one for each unit.

6.5.2.7 Pressure Oil Supply System

Each set of generating unit will have a high-pressure oil system, which will consist of two sets of direct-coupled pump of sufficient capacity, one acting as on the "duty" and other as the "stand-by". It will supply the pressure oil to the pressure tank from the sump tank through a strainer. Each pump will be Equipped with a check valve and a safety release valve.

The pressure oil supply system of each unit consists of an oil sump tank, pressure accumulator for governor oil servomotor mechanism, two motor driven oil pumps, control valves, piping, monitoring system and other accessories.

The pressure requirement will depend upon the amount of energy required to move the turbine wicket gate, inlet valve etc.

Oil Pressure system is arranged as a single system for the governor, main inlet valve and by-pass valve actuators of the unit. The oil pressure system will have sufficient capacity for operating the turbine servomotors, main inlet valve, and other necessary system.

6.5.2.8 Cooling Water System

Cooling Water system for cooling of generator bearings, OPU heat exchanger and turbine shaft seal (if applicable) for each unit shall be provided by pumping water from tailrace canal. Cooling water system shall be provided with three (3) sets of motor-driven centrifugal pumps (three centrifugal pumps for unit which will be on duty and one common standby centrifugal pump for the units).

The water system will be served by a filter station comprising of:

- Two pre-filter in each supply line,
- Two pumps complete with motor for raw water pumping from cooling water sump,
- Two sets of filtration system with back flushing arrangement for flushing to drainage Sump,
- Required number of flow meter,
- Required number of valves gauges and piping works.
- Measuring devices and instruments with cables

6.5.2.9 Drainage and Dewatering System

Horizontal centrifugal/submersible drainage pumps of adequate capacity will be installed to remove normal seepage & drainage water along with necessary piping; valves and fittings shall be provided accordingly. Location of drain sump shall be placed suitably and shall be finalised during construction period.

Turbine dewatering system shall be provided for dewatering of all the hydraulic portion as required. A pipe shall be installed in the draft tube for lowering the dewatering pump in each unit & water shall be pumped out into tailrace canal.

6.5.2.10 Mechanical Workshop

Mechanical workshop will be equipped with machine tools and devices appropriate for the maintenance and repair of all mechanical components and machining of the smaller components of the mechanical, electrical equipment and hydraulic steel structure. The workshop will service the power plant for minor repair and maintenance work at the site, and this could reduce the outage time.

6.5.2.11 Air Conditioning and Ventilation System

The powerhouse air-conditioning system will be used to provide fresh, filtered and cooled air to the control room, office rooms and other important areas. Packaged type air conditioner will be used for control room and office room while wall mounted fans of required size are installed on powerhouse area for the purpose of ventilation.

6.5.2.12 Fire Fighting System

Sufficient number of portable dry chemicals and CO_2 cylinder will be provided at various locations. The dry chemicals will be designed for fighting fires in solids, oil and electrical equipment. The CO_2 units will be designed for fighting fires in oil and electrical installations.

6.5.3 Electrical Equipment

6.5.3.1 General

The purpose of the study pertaining to electrical equipment is to identify and dimension the principal components of the powerhouse electrical equipment for safe and economic plant operation of Upper Irkhuwa Hydropower Project. The powerhouse electrical equipment of the project includes generators, transformers, switchgears, protection schemes, control systems, earthing systems, lighting systems, communication systems, etc. The ratings of the equipment are designed safely to cope with all normal and fault conditions, avoiding any overstressing of material and equipment. Also, equipment will be of standard design (IEC/IEEE/IS/BS whichever is applicable), providing highest degree of safety, reliability, availability and ease in operation.

6.5.3.2 A.C Synchronous Generator

6.5.3.2.1 Description of Generator

Self-excited, self-regulated, horizontal axis, three phase, cylindrical pole synchronous generators built in accordance with IEC standard are proposed to be used. The generators will have capacity to incorporate sufficient flywheel inertia to achieve stable frequency control when running in isolated mode. The generator shall have oil lubricated sleeve bearing.

The stator core of the generator will be constituted of stacking of laminations made of silicon alloy steel sheets. In the axial direction the stator core is subdivided into a number of partial stacks separated by spacers. These spacers form radial cooling ducts allowing the cooling air to pass. Stator winding of the generator is a double layer, multi-turn lap type coil winding. The stator winding is short pitched to suppress harmonics and to obtain nearly sine wave curve. It will be made of individually insulated stranded copper conductors, stacked and form-pressed to constitute coils or half coils with the design cross section. Each coil will be insulated for the full generator voltage.

The rotor will be of the cylindrical pole type and built in accordance with the best practice and designed to withstand safely all overloads and other stresses encountered during abnormal operating or runaway speed conditions. The poles will be built of thin steel laminations, bolted under high pressure and furnished with dovetails for fastening to the rotor rim. Rotor will be designed so as to allow dismantling of the poles without excessive disassembly of the stator or rotor.

The damper winding will be installed on pole faces with interconnecting type windings in order to maintain the stable operation of the generator. The generator will be capable of withstanding, without damage, a 30-second, 3-phase short circuit at its terminal when operating at rated MVA, at rated power factor and at 10% over voltage with fixed excitation. The generator shaft will adopt single shaft structure. It will have maximum rigidity and strength so as to guarantee no abnormal deformation and vibration at various speeds (including maximum runaway speed) when run together with the turbine. The generator shaft shall be made of a high-quality medium carbon steel, properly heat treated and accurately machined all over and polished at the bearing surfaces and at all accessible points for alignment checks. A complete set of test reports covering metallurgical strength & ultrasonic tests performed on each shaft shall be furnished.

The generators will have enough electric heaters and de-humidifiers and arranged in fan shield of generator to protect them from moisture during shut down and to enable a start up at any time without drying procedure. Insulation and other parts of the generators will not be damaged when electric heater runs.

Resistance type temperature detectors of PT-100 simplex / duplex type shall be installed between the upper and the lower layer of the same phase and are symmetrically distributed in the stator winding over all three phases to indicate the temperature obtained during operation. Additionally, Dial Type Bearing Temperature detector shall be installed on sufficient number on both the driving and non-driving ends bearing. An auxiliary terminal box having suitable terminal blocks shall be mounted on the generator frame to terminate the resistor element connections. The temperature detector leads shall be kept flexible to facilitate disconnecting them without breakage.

Table 6-2: Generator Data

S.N.	**Description**	**Parameters**
1	Type	Cylindrical pole, synchronous
2	Capacity	5,750 kVA
3	Number of Units	3
4	Power Factor	0.85
5	Rated Generator Voltage	11 kV ± 10%
6	Generator Current	301.79 A
7	Frequency	50 Hz ± 5 %
8	Insulation Class	F
9	Protection	IP23
10	Excitation System Type	Brushless
11	Efficiency	97 %
12	Heating class	B

S.N.	Description	Parameters
13	Number of Poles	8
14	Synchronous Speed	750 rpm

Generator fire protection will be provided by Portable Firefighting, CO_2 cylinder, for minor fires and protected by opening the appropriate breaker as required.
The generator shall have following major protection systems:

a) Reverse power relay,
b) Loss of field relay,
c) High speed trip relay,
d) Generator differential protection relay,
e) Under and over frequency relays,
f) Loss of synchronization relay,
g) Field ground detect relay,
h) Negative phase sequence relay,
i) Over voltage/Under voltage relay, and
j) Stator earth fault relay.

6.5.3.2.2 Generation Voltage Level

The generated voltage for Upper Irkhuwa Hydropower Project is 11 kV. Switchgear panels will be located inside the switchgear room together with switchgear components (like VCBs, CTs, PTs, etc.). These switchgear panels will have in-built bus bar cabinets housed in its back. Each generator's output terminals will be connected to this 11-kV bus bar system with XLPE power cable of adequate size. The switchgear and other protection and control components will accompany them in the switchgear panel to complete the incoming generation power circuit.

The switchgears will be provided with housing to install the required set of current transformers and potential transformers for metering and protection.

Each generator will be synchronized on 11 kV bus bar through closing of its designated vacuum circuit breaker on the fulfilment for all the required condition for the synchronization. All the generator circuit breakers and fuse switches/Miniature Circuit Breaker/contactor/relay switches will be arranged in one continuous row accessible from the front side with sufficient space on both side of the switchgear assembly for safe operations. Individual switchgear panels, for each generator incomer and outgoing feeder will be provided to complete the generation level switchgear system.

This switchgear system will work in co-ordination with the control panels accommodated in the control room.

6.5.3.2.3 Generator Braking

Generator shall be provided with hydraulic operated brakes of sufficient capacity to bring rotating parts of generator and turbine to stop from 30 % of rated speed.

6.5.3.2.4 Generator Grounding

The principal objective of grounding synchronous generator system is the protection of the generator and associated equipment against damage caused by abnormal electrical conditions. Grounding in Upper Irkhuwa Hydropower Project is achieved by the intentional insertion of resistance on the secondary of Neutral Grounding Transformer as shown in SLD. Each generator unit will be equipped with transformer, self-ventilated, dry, resistive type grounding system. The rated voltage of the resistor shall be 110 V and shall be made up of alloy of Chrome, Aluminium and Iron or others, which shall be decided later on design period.

6.5.3.2.5 Excitation and Automatic Voltage Regulator (AVR)

Each generator of Upper Irkhuwa Hydropower Project will be equipped with brushless excitation system consisting of a 3-phase AC exciter and silicon diode type rotating Rectifier Bridge mounted on the generator shaft extension. The system shall be complete along with surge suppressor, automatic voltage regulator of solid-state type with Thyristor Bridge and field suppression equipment, etc.

The protection against voltage spikes shall be provided. The AVR shall have fast response and anti-hunting features. The AVR shall be provided with cross compensating devices for parallel operation of generators.

The excitation transformer of sufficient size, with 11 kV on primary side shall be used. The Transformer shall be of dry type.

The excitation shall be suitable for maintaining the voltage for a grid voltage variation of ± 10% & for a frequency variation of ± 5%. The AVR shall be sensitive enough to track and respond the changes up to +/- 0.5% of normal voltage (average of 3 phases) of the Generator when operating under steady load conditions (for any load) or excitation within operating range and shall initiate corrective action without hunting. The response time of excitation system shall be less than 20 ms.

After the initial maximum voltage following any load rejection up to 100% of rated load, the AVR shall restore the terminal voltage to a value not more than 5% above or below the voltage being held before load rejection and shall maintain the voltage within these limits throughout the period of generator over speed.

The AVR shall have the following features:

a. Two auto channels with one manual mode for voltage control
b. Voltage / frequency during accelerating and decelerating of machine
c. Power factor / KVAR control mode
d. Reactive power sharing
e. KVAR limit
f. Short circuit limit
g. Diode failure indication
h. Provision to operate on isolated mode

Besides these, equipment for limiting and regulating (both automatic/manual mode) on generator rotor current shall be included. Voltage setting devices and necessary control switches shall be included. This equipment shall be of a tropical design and shall work satisfactorily at a temperature of maximum 40°C with respect to ambient temperature or if other, which shall be decided detailed during design period.

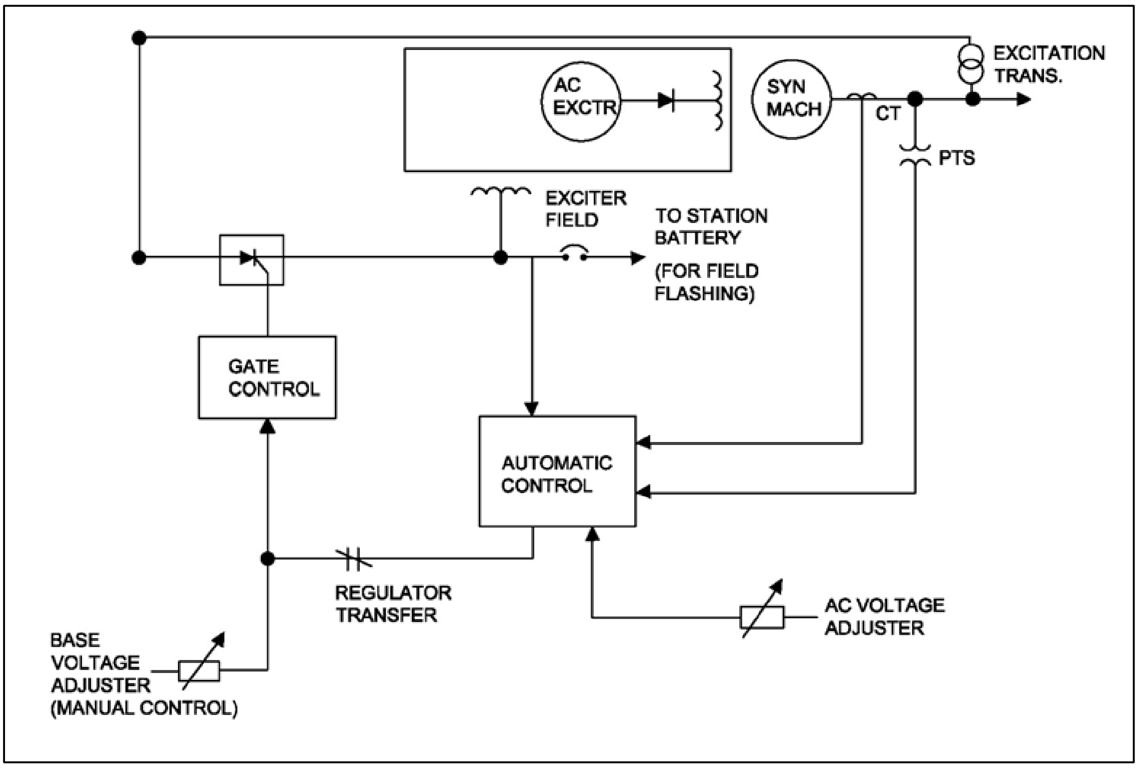


Figure 6-9: Brushless Excitation System

6.5.3.3 Power Transformers

Power transformer is used to step-up the voltage level to 132 kV so as to evacuate the generated power from generating units to the nearest substation at the desired voltage level. The main Generator Power Transformer on Upper Irkhuwa Hydropower Project will be four numbers, three on duty and one as spare, of Single Phase, 5,750 kVA, single-phase, outdoor, oil immersed, and ONAN type to step up the voltage from 11 kV to 132 kV for evacuation of the power to proposed Sitalpati Switchyard. Single Phase Power Transformer each of rated capacity 5,775 kVA is selected rather than a Single Three Phase Generator Power Transformer considering the logistics aspect for the transportation to the Powerhouse area and higher reliability. The description of Generator Power Transformer at Irkhuwa Khola switchyard is presented in Table 6-3.

Table 6-3: Data for Generator Power Transformer

S.N.	**Description**	**Parameters**
1	Number of Transformers	3 + 1 spare
2	Type	3-phase, outdoor, oil immersed
3	Cooling	ONAN
4	Rating	5,750 kVA
5	Rated Voltage	Primary side – 132 kV and Secondary Side -11 kV
6	Maximum Voltage (Line to Line)	Primary side – 145 kV and Secondary Side -12 kV
7	Current on HV side and LV side	HV side 75.44 A and LV side 905.39 A
7	Type of Tap changing	On Load on High Voltage side
8	Tap Changing Range	±10% in Steps of 2.5
9	Principal tapping	132 kV
10	Vector Group reference	YNd11
11	Efficiency	≥ 99 %

The transformer will be installed outdoor. The transformer will be oil immersed and designed for the cooling system as specified. The transformer will be capable of operating continuously at its rated output at all tap positions without exceeding the temperature rise limits.

The incoming side (low voltage side) will be suitable for terminating appropriately sized XLPE cables inside the cable terminating chamber. The termination arrangement will include cable terminations for delta connection of the transformer windings besides the phase cable termination. The outgoing side high voltage terminals will be brought out through high voltage bushing for connecting to other high voltage apparatus of the switchyard. The neutral points will be brought out on suitable bushings installed and will be solidly grounded via appropriate conductors.

Following Protections are implemented in Power Transformers located at the switchyard of Upper Irkhuwa Hydropower Project:

a) Transformer Differential Protection
b) Restricted Earth fault Protection (64T)

c) Thermal Protection (49)
d) Pressure Relief device (63)
e) Buchholz (gas operated relays) protection
f) Low Oil level alarm
g) Over voltage/Under voltage protection
h) Over Frequency/Under Frequency protection

6.5.3.4 Station Transformer

Auxiliary transformer or station supply transformers provide electrical supply to the power house electrical equipment. The auxiliary transformer, used for station power supply, shall be three phase, outdoor oil immersed and ONAN cooling type of 250 kVA.

Table 6-4: Data for Station Transformer

S.N.	Description	Parameters
1	Number of Transformers	1x 3-Phase
2	Type	Outdoor
3	Cooling	ONAN
4	Rating	250 kVA
5	Rated Voltage (Line to Line)	Primary side – 11 kV and Secondary side - 0.415 kV
6	Type of Tap changing	Off Circuit Tap Changer (OCTC)
7	Tap Changing Range	±5% in Steps of 2.5
8	Principal tapping	0.4 kV
9	Vector Group reference	Dyn11

6.5.3.5 11 kV Switchgear

6.5.3.5.1 General

Upper Irkhuwa Hydropower Project consists of three (3) numbers of AC generators each rated 11 kV, 50 Hz, 5,750 kVA, 0.85 power factor (lag) and connected to 132 kV system outdoor switchyard through three number of Single-phase power transformers and one as a spare, each rated at 5,750 kVA. Each generator output is connected to the 11-kV busbar through a 11-kV switchgear consisting of vacuum circuit breaker (VCB).

Each generator shall be synchronized through rated 12 kV Vacuum Circuit Breaker (VCB) to the grid. All the generator circuit breakers, miniature circuit breakers and fuse switches will be arranged in one row accessible from the front side with sufficient space on both sides of the switchgear assembly for safe operations. There will be following number of switchgears in switchgear room insider the powerhouse.

a. 3 No. of 11 kV Generator output switchgear
b. 1 No. of 11 KV Generator Power Transformer ingoing switchgears
c. 1 No. of 11 kV switchgear for Auxiliary transformer
d. NGT & LAVT panels with LA, PTs and surge protection capacitor of appropriate ratings

Each switchgear comprises of:

a. Vacuum Circuit Breaker
b. Cable box for incoming and outgoing XLPE insulated copper cables
c. Current transformers
d. One unit of voltage transformer sets for synchronization for each generating unit.
e. NGT & LAVT panels with LA, PTs and surge protection capacitor of appropriate ratings
f. Air insulated three phase bus-bar system, extensible to make connection with the bus-bars of other adjacent panels.

6.5.3.5.2 Vacuum Circuit Breaker

The circuit breaker shall be outdoor, Draw-out type horizontal arranged, three phase, single throw, spring charged motor operated, vacuum type, trip free in any position, complete with operating mechanism and supporting structure. The contact shall be designed to have adequate thermal and current carrying capacity for carrying full-rated current without exceeding allowable temperature rise as per IEC. The surfaces of either of both moving and stationary arcing contacts, which are exposed directly to the arc, shall be faced with suitable arc resisting material.

The operating mechanism of the circuit breakers shall be spring charged by 110 V D.C motor and with mechanical charging. The tripping circuit mechanism and the closing circuit mechanism shall each have a nominal voltage rating of 110 volts DC.

Table 6-5: Data for Generator and Transformer Incomer Circuit Breaker

S.N.	Description	Parameters
1	Type	Vacuum, Metal Enclosed, Cubicle Indoor Type
2	Rated Voltage	12 kV
3	Rated Current	1250 A for Transformer VCB/ 630 A for Generator VCB
4	Frequency	50 Hz
5	Insulation level (Power Freq. withstand/BIL)	28 kV/75 kVpK

S.N.	Description	Parameters
6	Short Circuit Breaking Current	25 kA rms
7	Short Circuit current Duration	3 secs
8	Operating Sequence	O-0.3 sec-CO-3 min-CO
9	Closing Coil & Opening Coil Supply Voltage	110 VDC
10	Motor Supply Voltage	230 V AC

6.5.3.5.3 Current Transformer

The current transformers will be of dry, synthetic resin insulated type. All secondary connections will be connected to a terminal block which will be located in a dust-proof and watertight terminal box and will be clearly labelled. An earth connection to the housing will be provided.

The indoor current transformers will be designed to carry continuously a current of 125% of the rated current. The rated current of the secondary windings will be 1 A.

Table 6-6: Details of 11 kV Current Transformer

S.N.	Description	Parameters
1	Rated current ratio	400/1 A for Generator and 1250/1 A for Transformer Ingoing (For Details, Refer SLD)
2	Burden	30 VA
3	Accuracy Class	0.5-Instruments,5P20/PS-Protection
4	Insulation Level:	
5	Impulse withstand voltage (Peak)	75 kV
6	Power frequency withstand voltage (1 min, rms)	28kV

6.5.3.5.4 Voltage Transformer

The indoor voltage transformers will be of the single-phase dry synthetic resin type. All primary and secondary connections will be clearly marked. An earth connection to the housing will be provided. Earthing of the cores and the neutrals will be done on the transformers and not on the terminal boxes. The windings for measuring purposes will be designed for accuracy according to class 0.5 as per the voltage level. The voltage transformers will have an additional secondary winding for earth fault protection, connected in open delta with a resistive burden. The accuracy class will be 3P. The secondary will be provided with miniature circuit breakers with alarm contacts and primary will be protected with a fuse.

The burdens of all windings will not be less than 125% of the overall computed (design) burden of the connected apparatus including cables.

Table 6-7: Details of 11 kV Potential Transformer

S.N.	Particular	Specifications
1	Type	Indoor, dry synthetic resin type
2	Rated primary voltage	11 kV/√3
3	Rated secondary voltage	0.11 kV/√3
4	Impulse withstand voltage (peak)	75 kV
5	Power Frequency withstand voltage(peak)	28 kV
6	Frequency	50 Hz
7	Burden	30 VA
8	Accuracy	0.5 - Instruments, 3P-Protection

6.5.3.5.5 Surge Arresters

The surge arresters will be of the gapless metal oxide type. The generator will be protected against incoming voltage surges either by the impact of external (lighting) and internal (switching) events by the means of surge arresters connected between phases and earth. The indoor surge arresters will be mounted on steel structures in the switchgear panel and will be fitted with a pressure relief device.

The Surge arrester for the protection of generator will be of rated arrestor voltage of 10 kV.

Table 6-8: Details of 10 kV Surge Arrester

S.N.	Particular	Specifications
1	Type	Indoor, gapless Zno arrester
2	Frequency	50 Hz
3	System voltage	11 kV
4	Rated voltage	10 kV per phase
5	Impulse withstand voltage (peak)	75 kV
6	Power frequency withstand voltage	28 kV
7	Nominal discharge current	10 kA

6.5.3.6 Control and SCADA System

The computer supervisory and control system at shall adopt the full distributed mode in open environment in accordance with international open system concepts so that compatibility of selection of various computers, translatability of system expanding and renewal of equipment shall be assured. The open environment shall include application development environment, user interface environment and interlink of system environment, which shall comply with the specifications of the open environment recommended by international open system organizations. The computer supervisory and control system shall have station control level and local control unit level. The station control level, real time supervisor and control centre of the plant shall be responsible for automatic functions of the whole plant (AGC, AVC, generating optimization control etc.), historical data process (various operation tables, operation archives of important equipment and various operating parameters etc.) and man machine dialogue of whole plant (operation monitor of plant equipment, accident and failure alarm, manual intervention of operating equipment, modifying and setting of various parameters for the Computer Supervisory and Control System). Station control level shall be made up of the relevant equipment located at computer room and central control room. The computer will adopt dual computers for redundancy and hot standby. At normal condition a computer works and the other is backing-up. When master computer receives failure, the computer is changed-over by back-up.

The local Control unit (LCU) shall have turbine-generator local control unit. Each LCU shall manipulate production procedures and accomplish the supervision and control functions under controlling. LCUs will be connected with the production procedures by means of input and output interface, with the network by communication interface and exchanging information with control level through network. The information shall be exchanged among LCUs. LCUs may be independent from control level relatively. They shall directly finish real time data acquisition and pre-processing, supervision, adjustment and control etc. of unit equipment conditions with station control level divorced.

The operator's console in the central control room shall be equipped with CRT display that displays operation conditions of the power station. When the power station is under normal operation, the operator can monitor the conditions of each equipment in the power station. The major monitoring items shall be as follow: Operating conditions and output of generating units.

a. Operating conditions of auxiliary equipment of the generating units
b. Operating conditions of the transformers
c. Status of circuit breakers, disconnectors, and earthing switches.
d. Operating conditions and transmission power of power lines
e. Opening level of gates, inlet valves, etc.
f. Operation mode of station service power, and
g. Other important parameters.

When the system receives any fault or the equipment has abnormality during operation, the supervisory control system shall automatically give alarm in both sound and picture striking to the eye to indicate nature, location, time and abnormal parameter values of the event.

6.5.3.7 DC Power Supply

For the utmost reliability, the Control, Protection, Alarm, and Tele-metering equipment will be fed from a dc supply. The emergency lighting can be dc, autonomous individual units or with UPS (uninterruptable power supply). For the purpose of this study, a dc battery supplied emergency lighting has been selected. The DC Auxiliary system in Upper Irkhuwa Hydropower Project will have one set of 110V/3000 Ah DC battery bank. A DC–DC converter shall generate 48 V DC, from 110 V DC system and 24 V DC, if required. The NiCd maintenance free batteries with rated life of at least twenty (20) years are used for DC Auxiliary system of Upper Irkhuwa Hydropower Project.

One no. of float and float cum boost charger, for each 200 Ah DC battery bank, (SCR controlled) operating on 3-phase, 415 V, 50 Hz, AC supply of solid-state design to charge the battery shall be used. The operation of the charger shall be automatic. Normally, float charger will be feeding the load and charging battery. In case battery requires boost charging the same shall be done automatically.

The following meters shall be provided in the charger

- A.C Voltmeter 0 – 500 V
- D.C. Ammeter
- D.C Voltmeter 0-200 V, DC
- Centre zero DC Ammeter 50 A- 0 – 50 A for battery.
- AC supply failure relay
- Rectifier fuse failure relay
- Charger failure relay
- Battery earth fault relay
- Over current Relay.
- Auxiliary Relay.

6.5.3.8 Powerhouse Electric Overhead Travelling Crane

One Powerhouse Electric Overhead Travelling Crane of 30/5T capacity to handle the equipment inside the powerhouse will be installed. The capacity of main hoist (30 ton) is determined considering a single piece generator set. The auxiliary hoist of 5 ton will be used for lifting smaller loads inside the powerhouse during installation as well as operation period.

The Double Girder type crane will be complete with drives for cross travel, long travel and lifting motion, runaway rails of adequate size, end carriages & gantry rail. All motions operated from a pendant, operated by an operator on the machine hall floor. Squirrel cage induction motor of required capacity shall be installed on Double Girder interlinked to the rope drum through gear box used for hoisting the load by wire rope through pulley.

The gears will be helical type and all bearing and other wearing surface will be splash oil lubricated. The DC Electromagnetic shoe with EHT braking system will be provided.

6.5.3.9 Switchyard at Power House

132 kV outdoor type switchyard shall be constructed near the powerhouse to evacuate the generated power. The switchyard components shall be suitable for hot, humid and moderately polluted environment. The switchgear system for this switchyard shall be equipped with circuit breakers, current transformers, potential transformers, disconnecting switches with/without earthing and lightning arrestors. The switchgear system here will work in coordination with the associated control panels accommodated in the control room and shall ensure the overall protection of the switchyard.

Technical specification of major Switchgear equipment's and Instrument Transformer to be erected at the switchyard area shall be as mentioned below on Table 6-9,

Table 6-10, Table 6-11 and Table 6-12 respectively.

Table 6-9: Data for 145 kV Vacuum Circuit Breaker

S.N.	Description	Parameters
1	Type	Vacuum, Metal Enclosed, Cubicle Outdoor Type
2	Rated Voltage	145 kV
3	Rated Current	1250 A
4	Frequency	50 Hz
5	Insulation level (Power Freq. withstand/BIL)	275 kV/650 kVpK
6	Short Circuit Breaking Current	40 kA rms
7	Short Circuit current Duration	3 secs
8	Operating Sequence	O-0.3 sec-CO-3 min-CO
9	Closing Coil & Opening Coil Supply Voltage	110 VDC
10	Motor Supply Voltage	230 V AC

Table 6-10: Data for 145 kV Isolator with and without E/S

S.N.	Description	Parameters
1	Applicable standard	IEC
2	Type	3 pole, single throw, outdoor, Centre Break
3	Frequency	50 Hz
4	Rated voltage	145 kV
5	Rated current	
	a) Continuous at 40-degree C ambient	1250 A
	b) Short time current for 3 sec	40 kA
6	Insulation level	
	a) Impulse withstand voltage	170 kV
	b) Power frequency withstand voltage (1 min, rms)	70 kV
7	Main contacts	
	- Material of fixed contacts	copper alloy
	- Coating of fixed contacts	Silver plated
	- Material of moving contacts	
	- Coating of moving contacts	Silver plated
	- Material of the contacts of the earthing switch (if applicable)	copper alloy
	- Coating of the contacts of the earthing switch (if applicable)	Silver plated
8	Operating mechanism	Manual operated
9	No of operations switch can withstand without deterioration of contacts	Minimum 1000
10	Auxiliary power supply	
	a) Space heater and cubicle	230 V, 1-Ph
	b) Control circuit	110 V DC
11	Local operating device provided	Yes
12	Insulator	
	a) Reference standard	IEC
	b) Creepage distance in air	900 mm
	c) Number of Stacked/type	1/Solid Core Post Type

S.N.	Description	Parameters
13	Enclosure protection	IP-55W
	Thickness of sheet (minimum)	2 (for steel) mm, 3 (for Al. alloy) mm
14	Earthing switch (if applicable)	
	a) Operating mechanism	Hand Operated
	b) Type of interlocks furnished	Mechanical

Table 6-11: Details of 132 kV Potential Transformer

S.N.	Particular	Specifications
1	Type	Outdoor
2	Rated primary voltage	132 kV/√3
3	Rated secondary voltage	0.11 kV/√3
4	Insulation Level	275 kV/650 kV
5	Frequency	50 Hz
6	Burden	30 VA
7	Accuracy	0.2 – Instruments,3P-Protection

Table 6-12: Details of 132 kV Current Transformer

S.N.	Description	Parameters
1	Rated current ratio	75/1 A (For Details, Refer S.L.D)
2	Burden	30 VA
3	Accuracy Class	0.2-Instruments,5P20/PS-Protection
4	Insulation Level:	
	Impulse withstand voltage (Peak)	550 kV
	Power frequency withstand voltage (1min, rms)	275 kV

6.5.3.10 Grounding / Earthing System

Adequate earthling is necessary to be provided inside the powerhouse and the switchyard. The grounding/earthling grid will be designed as per **IEEE Std 80-2000: IEEE Guide for Safety in**

AC Substation Grounding such that the touch and step potentials will be within the safety margin. The overall grid earth resistance will not exceed 1 ohm.

The low grounding resistance will be achieved by increasing the grounding area i.e., interconnecting the powerhouse ground system with the tailrace pond and other areas (as satellite area). The ground resistivity measurements will be required which will be performed during the detail design of the grounding grid.

Power House roof shall be provided with lightning spikes properly connected to ground electrode whether pipe, rode or plate type earthing separately.

6.5.3.11 Diesel Generator

It is proposed that one emergency generator set be installed in the diesel generator building to provide an emergency source of power in the event of a system and power outage. The diesel generator would be of adequate rating to supply sufficient power to enable the black starting of one unit, and the operation of cooling system, a governor oil pump, a bearing oil pump and feed the battery chargers. The diesel Generator for power house purpose will be of 75 kVA, 400 V, 50 Hz, 3-phase type. The diesel generator shall have heating class B, insulation class F and IP23 type of Protection of enclosure.

6.5.3.12 Communication System

For communications between Upper Irkhuwa Hydropower Project Power house, other power houses / substations together with the Load Dispatch Centre (LDC) of NEA, trunk dialling telephone system either CDMA, V-SAT communication or Landline phone will be used.

In the control room one or more telephone services will also be installed for trunk dialling communications with the LDC and other substations.

An automatic PABX telephone system is envisaged for the communication between different sections of powerhouse, offices, the residence of operational staffs, guard house and head work area.

6.5.3.13 Illumination

400V/230V, 50 Hz, 4-wire star connections supply will provide single phase supply for the illumination circuits for normal lighting. The normal lighting in the rooms of the power house through corresponding Distribution Boards (DBs) will be by energy efficient LED fixtures. Apart from this arrangement, emergency DC supply circuits and fixtures will provide illuminations, in critical areas when supply from Station auxiliary transformer fails. In the entrance incandescent lamp lighting fixtures will be installed. The lighting level / illuminations designed are presented below:

- 450 lux – for the Control room, Office room, Electrical workshop, Mechanical workshop, service bay in the Alternator/Generator floor.
- 300 lux – for the LV-switchgear room, MV- switchgear room, Battery room and other facilities.
- 200 lux – for the pump pits and surge tank area.
- 150 lux – for the stair cases.

Socket outlets will be provided in the office room; control room; battery room and service bay, alternator and turbine floor.

6.5.3.14 Black Start/ Island Mode Operation

The power plant shall have black start facilities and shall be able to operate in islanding mode operation. The detail of islanding mode of the operation shall be as fixed in the connection agreement or as per the NEA grid code.

6.5.4 Inter-connection at Sitalpati S/S

6.5.4.1 General

132 kV outdoor type switchyard shall be constructed at NEA under construction Sitalpati S/S (132/33 kV) to evacuate the generated power. The switchyard components shall be suitable for hot, humid and moderately polluted environment. The switchgear system for this switchyard shall be equipped with circuit breakers, current transformers, potential transformers, disconnecting switches with/without earthing and lightning arrestors, metering units, etc. for 132 kV outgoing circuits as per the arrangement and standard of the already installed electrical equipment over there. A single line diagram for the standard Interconnection arrangement is provided in the List of Electrical Drawings. The switchgear system here will work in coordination with the associated control panels accommodated in the control room and shall ensure the overall protection of the switchyard.

6.5.4.2 Relay, Control, Measurement and Protection

For the interconnection at the interconnection switchyard on 132 kv Single Bus Bar at Under Construction Sitalpati S/S, the following switchgears equipment are required:

a. Three Nos. of 132 kV Oil Filled Inductive Current Transformer: Protection and Metering
b. Three Nos. of 132 kV Oil Filled Inductive Potential Trf.: Protection and Metering
c. One set of 145 kV Outdoor Vacuum Circuit Breaker
d. One set of 145 kV Isolator with and without E/S
e. Three Nos. of 110 kV Lighting Arrester
f. Three Nos. of 132kV Oil filled Capacitive Current Transformer: For Revenue metering
g. Three Nos. of 132kv Oil filled Capacitive Potential Transformer: For Revenue metering

Above provided switchgear system here will work in coordination with the associated control panels accommodated in the control room at Substation for the protection, control, relay and metering of all Electrical Parameter of Transmission Line and its associated bay in order with respect to the widely international used standard – IEC/IEEE/IS. Numerical Protective Relay standard installed on Panel used for the control, monitoring and Protection of the required bay and Numerical relay will be of well accepted international standard (i.e. Siemens, G.E or any other reputed make list)

6.5.4.3 Specification of Switchyard Equipments

Generated power shall be transmitted through 5 km 132 kV ACSR wolf conductor through 132 kV Transmission line and interconnected to 132 kV Bus Bar at Sitalpati S/S. 132 kV outdoor type switchyard shall be constructed at the Sitalpati S/S for the interconnection at the Bus Bar to evacuate the generated power.

The switchyard components shall be suitable for hot, humid and moderately polluted environment. The switchgear system for this switchyard shall be equipped with Generator Power Transformer, Circuit breakers, Current transformers, potential transformers, disconnecting switches with/without earthing and Lightning Arrestors The switchgear system here will work in coordination with the associated control panels accommodated in the control room and shall ensure the overall protection of the switchyard.

The details of 145 KV SF_6Circuit Breaker is presented in Table 6-13 below.

Table 6-13: Data for 145 KV Circuit Breaker

S.No.	Description	Parameters
1	Type	SF_6, Metal Enclosed, Cubicle Outdoor Type
2	Rated Voltage	145 KV
3	Rated Current	1250 A
4	Frequency	50 Hz
5	Insulation level	275kV/650kVpK
6	Short Circuit Breaking Current	40kA
7	Short Circuit Current Duration	3 Secs
8	Operating Sequence	O-0.3S-CO-3Min-CO

9	Closing Coil & Opening Coil Supply Voltage	110 V DC
10	Motor Supply Voltage	230 V AC

The details of 145 kV Disconnecting Switch with and without E/S is presented in **Error! Not a valid bookmark self-reference.** below.

Table 6-14: Details of 145 kV D.S with and without E/S

S.N.	Description	Parameters
1	Applicable standard	IEC
2	Type	3 pole, single throw, outdoor, Centre Break
3	Frequency	50 Hz
4	Rated voltage	145 kV
5	Rated current	
	a) Continuous at 40-degree C ambient	1250 A
	b) Short time current for 3 sec	40 kA
6	Insulation level	
	a) Impulse withstand voltage	170 kV
	b) Power frequency withstand voltage (1 min, rms)	275 kV
7	Main contacts	
	- Material of fixed contacts	copper alloy
	- Coating of fixed contacts	Silver plated
	- Material of moving contacts	
	- Coating of moving contacts	Silver plated
	- Material of the contacts of the earthing switch	copper alloy
	- Coating of the contacts of the earthing switch	Silver plated
8	Operating mechanism	Motor and Manual operated
9	No of operations switch can withstand without deterioration of contacts	Minimum 1000
10	Auxiliary power supply	
	a) Space heater and cubicle	230 V, 1-Ph

S.N.	Description	Parameters
	b) Control circuit	110 V DC
	c) Operating motor	400/230 V AC
11	Local operating device provided	Yes
12	Insulator	
	a) Reference standard	IEC
	b) Creepage distance in air	900 mm
	c) Number of Stacked/type	1/Solid Core Post Type
13	Enclosure protection	IP-55W
	Thickness of sheet (minimum)	2 (for steel) mm, 3 (for Al. alloy) mm
14	Earthing switch (if applicable)	
	a) Operating mechanism	Hand Operated
	b) Type of interlocks furnished	Electrical & Mechanical

The details of 132 kV Potential Transformer and Current Transformer is presented in Table 6-15, and Table 6-16.

Table 6-15: Details of 132 kV Current Transformer

S.N.	Particular	Specifications
1	Type	Outdoor
2	CT Ratio	125/1 A (Refer SLD for Detail)
3	Impulse withstand voltage (peak)	650 kV
4	Power Frequency Withstand voltage	275 kV
5	Frequency	50Hz
6	Burden	30 VA
7	Accuracy	CL 0.5, 3P, 0.2

Table 6-16: Details of 132 kV Potential Transformer

S.N.	Particular	Specifications
1	Type	outdoor
2	Rated primary voltage	132 kV/√3(Refer SLD for detail)
3	Rated secondary voltage	0.11kV/√3(Refer SLD for detail)
4	Impulse withstand voltage (peak)	650 kV

S.N.	Particular	Specifications
5	Power Frequency Withstand voltage	275 kV
6	Frequency	50Hz
7	Burden	30 VA for Protection and Measurement/ 15 VA for Revenue Metering
8	Accuracy	CL 0.5, 5P20/PS, CL 0.2

The details of 132 kV Lightning Arrestor is presented in Table 6-17 below:

Table 6-17: Details of 110 kV Lightning Arrestor

S.N.	Particular	Specifications
1	Type	Outdoor, gapless Zno arrestor
2	Frequency	50 Hz
3	System voltage	kV
4	Rated voltage	110kV per phase to Earth
5	Impulse withstand voltage (peak)	650 kV
6	Power frequency withstand voltage	275 kV
7	Nominal discharge current	40 kA for 3 sec.

6.5.4.4 Metering Scheme at Interconnection Substation

To measure import and export of energy between User and Owner's system, Bi-directional (Import and Export) Energy Meters (Main and Check Meters) of accuracy class 0.1 shall be installed at proposed substation as shown in SLD. The Main and Check Meters shall be able to record the followings:

- Voltage (KV)
- Current (A)
- Power Factor (Lead and Lag)
- Frequency (Hz)
- MW or KW
- MWh or KWh (import and export)
- MVAr or KVAr (import and export)

In addition, KW meter, KVAr meter, PF meter, Ammeter and Voltmeter shall be installed at control panel inside control building of substation for 132/33 kV system to measure respective quantities.

6.5.5 Transmission Line

Upper Irkhuwa Hydropower Project will construct 132 kV single circuit ACSR Dog conductor transmission line of approximate transmission line length of 10 km up to the 132-kV busbar at the switchyard of under construction Sitalpati Substation (132/33 kV), NEA located at Sankhuwasabha District, Nepal.

7 Power and Energy

7.1 General

This chapter deals with the power generation from the project. The energy from the plant is computed based on the available hydrological data, gross head available and head loss in different forms (entrance loss, friction loss, transition loss, bend loss and exit loss). The prime factor in generation of electricity is the discharge which in fact varies daily and seasonally. Moreover, the efficiency of the turbine and hydraulic loss of head also vary with variation of discharge. The generation of monthly energy considering the above factors has been discussed in this chapter.

7.2 Methodology

Energy generation varies according to the available discharge in the river. There will be daily and seasonal variation in the flow and hence will be the production of energy. The water surface elevation (HRWL) will also be different according to the flow which however is not considered in the estimation of energy.

The plant capacity of this project at 45.00% exceedance flow is 14.50 MW and the corresponding design discharge is 7.8 m3/s. The generated energy will be sold to Nepal Electricity Authority (NEA).

7.3 Input Parameters

The following parameters are used in the energy calculations:

7.3.1 Hydrology

The turbine design discharge has been fixed 7.80 m^3/s (2.6 m^3/s for each unit) at 45.0% exceedance flow. The minimum downstream release will be 10% of the driest mean monthly flow which will be about 0.31 m^3/s (according to the flow used for energy generation). The monthly flow which has been used to calculate energy is shown in Table 7-1.

Table 7-1: Monthly flow used for energy estimation

Months	Bais	Jest	Ash	Shr	Bha	Ashw	Kar	Man	Pau	Mag	Falg	Chaitra
Avg	4.01	8.73	25.79	40.94	37.49	23.11	11.81	6.73	4.66	3.59	3.10	3.12

7.3.2 Headloss

The project will have a gross head of 229.13 m from weir crest to tail water level. The net head after deduction of head losses like frictional loss, turbulence loss and other singular losses vary according to the turbine discharge. The head loss varies from 3.14m at the minimum flow and

14.35m at the maximum flow and thus the net head available will be 214.78m to 225.99m. The summary of monthly headloss calculated for the corresponding monthly flows are presented in Table 7-2.

Table 7-2: Summary of Monthly Headloss

Bais	Jest	Ash	Shr	Bha	Ashw	Kar	Man	Pau	Mag	Falg	Chaitra
4.38	14.29	14.35	14.35	14.35	14.35	14.35	10.17	5.48	3.76	3.14	3.16

7.3.3 Efficiency of the machineries

Considering the head and discharge available for power generation, Francis turbines have been found to be the most suitable choice for the project. The following efficiencies applicable for Francis turbine and generating units have been considered in computation of power potential study.

Efficiency of turbine - 92%

Efficiency of generator - 97%

Efficiency of transformer - 99%

Overall efficiency of turbine and generator - 88.35%

7.3.4 Energy Loss

The overall energy loss including outage, transmission and self-consumption has been estimated as 4% of the gross energy generated in each month.

7.3.5 Design Energy and Plant Load Factor

The design energy and plant load factor has been calculated for installed capacity of 14500 kW and has been presented here under;

- Installed Capacity 14500 kW
- No. of units 3
- Type of turbine Francis
- Turbine Efficiency 92%
- Generator Efficiency 97%
- Gross head 229.13 m
- Net Head 214.78 m
- Design Discharge 7.80 m³/s

- Environmental flow 0.31 m³/s
- Annual generation 93.20 GWh
- Annual Plant load factor 76 %

7.4 Energy and Power

As per Rules of Power Purchase Agreement (PPA) of Nepal Electricity Authority, (NEA), the price of the energy is NRs. 8.40 (Escalated Value NRs. 10.42 after 8 year) for the months Paush, Magh, Falgun, Chaitra. The rest of the month has the energy price of NRs 4.80 (Escalated Value NRs. 5.95 after 8 year). The breakdowns of the energy estimate per month are given in the Table 7-3. The power output from the plant is estimated by the following formula:

$$P = 9.81 \, x \, \eta \, x \, Q \, x \, H \; (kW)$$

Therefore, P = 9.81 x 0.883 x 7.80 x 214.78= 14.50MW

Where:

η = 0.883 (combined efficiency of turbine and generator)

Q = 7.80 m^3/sec (Design flow)

H = 214.78m (Effective net head)

The net energy generation in the dry season will be 31.79GWh and that in the wet season will be 61.42GWh, the total energy during a year will be 93.20GWh including outage.

Table 7-3: Power and Energy Computation

UNITS ENGINEERING CONSULTANCY PVT. LTD
KUPONDOLE,LALITPUR
Project: UPPER IRKHUWA KHOLA HYDROPOWER PROJECT
Location:Bhojpur

POWER AND ENERGY COMPUTATION

INPUT DATA

Design Discharge(Q_{40})=	7.80	m3/s
Length of Pipe(L)(up to bifurcation)=	3873.50	m
Head Pond level=	920.90	msl
Turbine level=	691.77	msl
Gross head=	229.13	m
Outage(KWh)=	4.00%	%
Dry Season Cost(Nrs)	8.40	Cost/Kwh
Wet Season Cost(Nrs)	4.80	Cost/Kwh

Efficiency

Turbine	92.00%
Generator	97.00%
Transformer	99.00%
Overall Effiency	88.35%

Month	Available Flow (m^3/s)	D/S Release (m3/s)	Total turbine Discharge (m3/s)	No. of units	Discharge at turbine (m3/s)	Head Loss	Net Head (m)	Power output (kW)	Days	Energy (KWh): Gross Energy (Kwh)	Outage (KWh)	Monthly Average Net energy (KWh)	Monthly Average Dry energy (KWh)	Monthly Average Wet energy (KWh)
Baisakh	4.01	0.31	3.70	1.00	3.70	4.38	224.75	7207.22	31.00	5362171.68	214486.87	5147685.00	5147685.00	
Jestha	8.73	0.93	7.80	1.00	7.80	14.29	214.84	14523.40	31.00	10805409.60	432216.38	10373193.00	5019286.94	5353906.06
Ashar	25.79	17.99	7.80	1.00	7.80	14.35	214.78	14519.30	32.00	11150822.40	446032.90	10704790.00		10704790.00
Srawan	40.94	33.14	7.80	1.00	7.80	14.35	214.78	14519.30	31.00	10802359.20	432094.37	10370265.00		10370265.00
Bhadra	37.49	29.69	7.80	1.00	7.80	14.35	214.78	14519.30	31.00	10802359.20	432094.37	10370265.00		10370265.00
Asoj	23.11	15.31	7.80	1.00	7.80	14.35	214.78	14519.30	31.00	10802359.20	432094.37	10370265.00		10370265.00
Kartik	11.81	4.01	7.80	1.00	7.80	14.35	214.78	14519.30	30.00	10453896.00	418155.84	10035740.00		10035740.00
Mangsir	6.73	0.31	6.42	1.00	6.42	10.17	218.96	12183.46	29.00	8479688.16	339187.53	8140501.00	3929897.03	4210603.97
Poush	4.66	0.31	4.35	1.00	4.35	5.48	223.65	8431.88	30.00	6070953.60	242838.14	5828115.00	5828115.00	
Magh	3.59	0.31	3.28	1.00	3.28	3.76	225.37	6406.63	29.00	4459014.48	178360.58	4280654.00	4280654.00	
Falgun	3.10	0.31	2.79	1.00	2.79	3.14	225.99	5464.66	30.00	3934555.20	157382.21	3777173.00	3777173.00	
Chaitra	3.12	0.31	2.81	1.00	2.81	3.16	225.97	5503.26	30.00	3962347.20	158493.89	3803853.00	3803853.00	
								Total	**365.00**	**97,085,935.92**	**3,883,437.44**	**93,202,499.00**	**31,786,663.97**	**61,415,835.03**

Plant capacity/Installed capacity,MW	14.52
Dry Energy (16 mangsir-15 jestha), GWh	31.79
Wet Energy (16 jestha-15 mangsir), GWh	61.42
Total Saleable Annual Energy(GWh)	93.20
Plant Factor(PF)	0.76
Total Revenue(NRs.)	561,803,985.49

Table 7-4: Power and Energy Computation (As Per PPA)

Table I

Installed Capacity (kW)	14,500	Rated Turbine Efficiency	91.00%
Design Discharge (m3/s)	7.80	Rated Generator Efficiency	97.00%
Min Release (m3/s)	0.308	Rated Transformer Efficiency	99.00%
Gross Head (m)	221.50	Combined Efficiency	87.39%
Outage + Losses + Self Consumption (%)			4%

Table II

Month	No. of Days*	River Discharge (m^3/sec)	Discharge for Power Generation (m^3/sec)	Net Head (m)	Average Power (kW)	Maximum Power (kW)	Monthly Generation before Outage & Losses (kWh)	Outage Including Losses (kWh)	Contract Energy (kWh)
	A	B	C	D	E	E1	F	G	H = F - G
Baishakh	31	4.196	3.888	219.83	7,401	9,104	5,451,346	218,054	5,233,292
Jestha	31	9.821	7.800	217.80	14,500	14,500	10,680,120	427,205	10,252,915
Up to 15th	15								4,961,088
16th	16								5,291,827
Ashadh	32	28.756	7.800	217.80	14,500	14,500	11,024,640	440,986	10,583,654
Shrawan	31	41.674	7.800	217.80	14,500	14,500	10,680,120	427,205	10,252,915
Bhadra	31	36.902	7.800	217.80	14,500	14,500	10,680,120	427,205	10,252,915
Ashwin	31	22.006	7.800	217.80	14,500	14,500	10,680,120	427,205	10,252,915
Kartik	30	10.670	7.800	217.80	14,500	14,500	10,335,600	413,424	9,922,176
Mangsir	29	6.110	5.802	219.01	11,003	13,080	7,581,574	303,263	7,278,311
Up to 15th	15								3,764,644
16th	14								3,513,667
Paush	30	4.374	4.066	219.77	7,738	8,740	5,515,438	220,618	5,294,821
Magh	29	3.427	3.119	220.07	5,944	6,395	4,095,455	163,818	3,931,637
Fagun	30	3.155	2.847	220.14	5,427	5,716	3,868,476	154,739	3,713,737
Chaitra	30	3.077	2.769	220.16	5,279	5,960	3,762,823	150,513	3,612,310
Total	365						94,355,832	3,774,233	90,581,599

नोटः १। यस टेवलमा दिइएको भन्दा फरक दिन संख्या परेका महिनाहरुमा यस टेवलको आधारमा निस्कने प्रति दिनको कन्ट्रयाक्ट इनर्जीले महिनाको वास्तविक दिन संख्यालाई गुणा गरी सो महिनाको कन्ट्रयाक्ट इनर्जी निर्धारण गरिनेछ।

२। सम्झौताको बुंदा ३८.१८ मा व्यवस्था भए अनुसार व्यापारिक उत्पादन (COD) भएको प्रत्येक ५ वर्ष पुरा भए पछि प्रत्येक महिनाको कन्ट्रयाक्ट इनर्जी (Contract Energy) परिवर्तन गर्न सकिनेछ।

Table III

सुख्खायाम (१६ मंसीरदेखि १५ जेष्ठसम्म) को कुल इनर्जी (kWh)	30,260,552	33.41%
वर्षायाम (१६ जेष्ठदेखि १५ मंसीरसम्म) को कुल इनर्जी (kWh)	60,321,047	66.59%
जम्मा (kWh)	90,581,599	100.00%

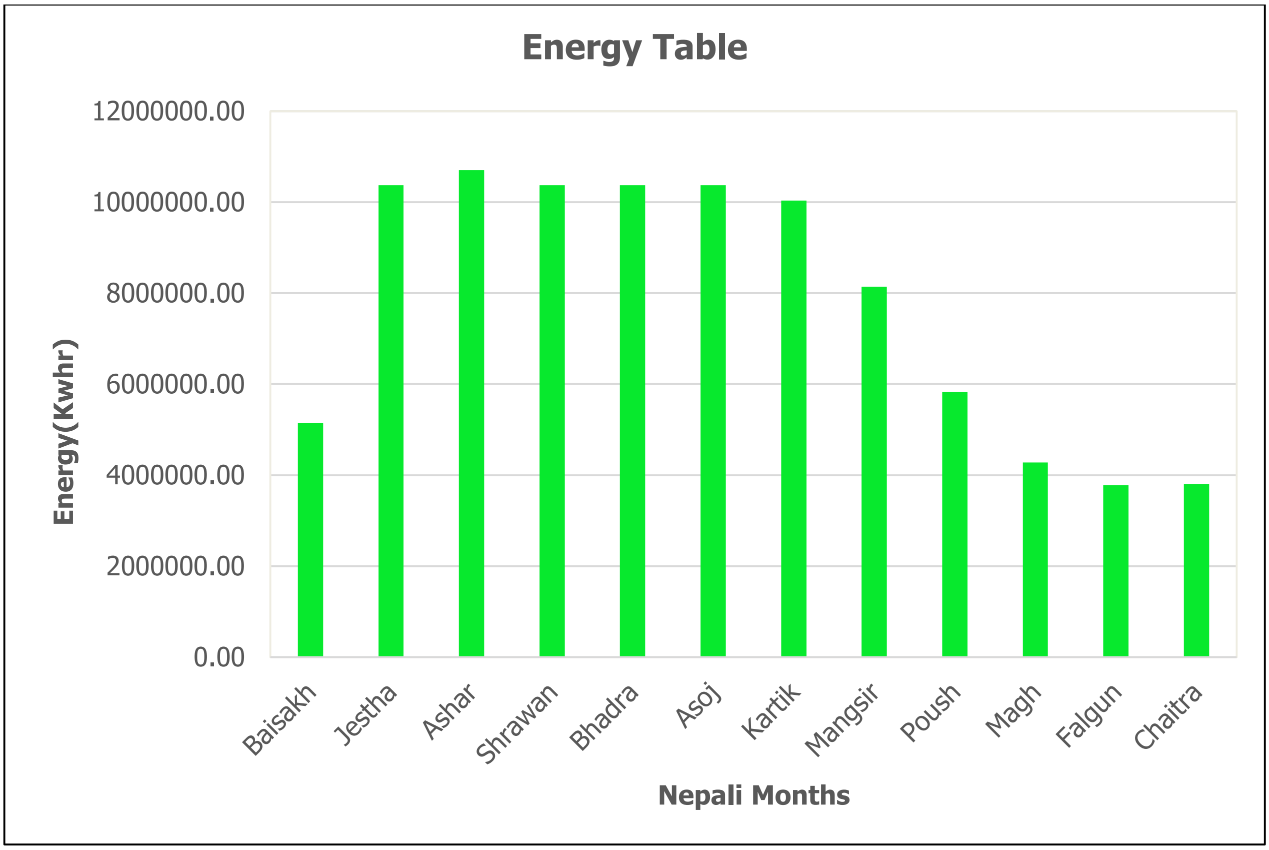


Figure 7-1: Monthly Energy Generation

8 THE COST ESTIMATE

8.1 Introduction

This section of the report describes the methodology used for derivation of the project cost and the estimated costs. This final estimate is based on the detailed layout and study of the optimum project configuration selected from the optimization studies. The rates are based on different projects in Nepal, Planned or under construction in the past five years. The rates are based on 2077/2078 price level.

Quantity take offs were carried out on the final drawing with plan metering, as required. The estimate process was carried out in parallel with Construction Planning is presented in Chapter 10 as these activities are complementary to each other.

8.2 Criteria, Assumptions and Cost Components

The following criteria and assumptions are the basis used for cost estimation:

- The cost estimate and financial analysis has been based on the NPR.
- The exchange rate US $ 1 = NPR 118.0 used
- All costs has been first estimated on a per unit basis for each of the components and then added to obtain the entire project cost.
- Lump sum costs adopted where breakdown cost is not available.
- Material costs reflect real costs incurred at other projects of similar size or having similar scope of works.
- Construction material obtainable from the local market whereas some of the steel items and all of the electromechanical equipment need to be imported.
- Some skilled and all of the semi-skilled and unskilled manpower can be obtained locally.
- The unit costs include profit, and overhead, which the contractor would charge.
- VAT has been excluded for electromechanical equipment, interconnection equipment and transmission line as VAT has been waived for hydropower projects.
- 1% of custom tax added.
- Contingency sum added on civil, hydro-mechanical, electromechanical and transmission line.

It is expected that an open competitive bidding process will be followed for awarding the contracts and the project will not be forced to use higher rates for any reason.

8.3 Estimating Methodology

The project is divided into a number of major components for the estimating process as follows:

- Civil construction works, including on site access
- Weir, intake, approach canal, settling basin
- Head pond
- Headrace alignment
- Surge tank
- Penstock pipeline
- Powerhouse and tailrace
- Permanent electromechanical equipment
- Turbine
- Generator
- Transformer
- Auxiliary equipment
- Gates, Valves and Hosing devices
- Switchyard and Transmission line
- Construction Camp
- Engineering and Management costs
- Resettlement, Land Acquisition and Environmental Provisions
- Financing and Insurance
- Physical Contingencies

8.4 Civil Works Estimate

For civil construction works, a contractor type estimate was prepared. The estimating process was carried out in the following steps:

- Division of the project into a number of distinct structures like headworks, settling basin, penstock pipe, powerhouse, tailrace and switchyard etc.
- Identification of distinct construction tasks or measurable pay items, such as overburden excavation, rock excavation, stone masonry, and fill work, concrete works etc.
- Calculation of the appropriate quantity of each item from map and drawings

- Development of unit rate construction works based on prevailing market rates appropriately adjusted for the project area, adopted method of construction as described in the section –Construction Planning and standard norms and practices of the country.
- Calculation of cost for each activity by multiplying quantity obtained by rates derived.
- Calculation of cost for each structure by summing up costs calculated of different works required for the structure.

8.5 Resources Costs

8.5.1 Labor Rates

For estimating purposes, the labor force was subdivided into four categories of workers, namely unskilled, semi-skilled, skilled and highly skilled. It is also assumed that work force required for the project will be form the local market and only specific skilled labor will be outside.

Considering the overall construction requirements for the project, a 6 days X 8-hour work week was selected as the basis for planning and estimating the major construction activities.

8.5.2 Construction Equipment

The access road has to be upgraded to transport the heavy machineries and equipment. For rate analysis purpose, equipment rates were derived from the Cost Reference Guide for Construction Equipment, a widely used publication.

8.5.3 Construction Material

It has been assumed that most of the construction material likes cement, reinforcement steel will be supplied from local market and specific materials like penstock liners, gates will be imported from India or overseas.

8.6 Electrical and Mechanical Equipment

The costs for the electrical and mechanical equipment are estimated by a combination of methods including:

- Interpretation of budget prices supplied by potential suppliers, for the large and more expensive equipment such as turbines, generators, power transformers, and inlet valves.
- In-house estimates using established international prices and/or relationships for routine items. The in-house information is based on years of collection of price data, and often eliminates the errors of variations of prices occurring due to changes in supply and demand.
- Percentage of lump sum provisions on a ratio basis based on experience, for lesser miscellaneous items.

8.7 Switchyard and Transmission Lines

The costs of the switchyard components were based on:

- Partly on budget prices supplied by potential suppliers, and
- Partly on in-house estimates using established international prices
- Cost on loop in and loop out arrangement.
- The cost of the transmission lines were based on the current costs incurred in transmission line construction by NEA.
- A provision has been made for the health and security item covering the costs of overalls, construction boots, helmets and gloves as well as consumables at the first aid centers supplied by contractors and owner.

8.8 Unit Rates

Unit rate have been derived for the major construction activities. Standard norms of practice and consultant's in-house experience have been utilized in derivation of the unit rates. The prices of material and other equipment were obtained from local market and also collected from projects under construction. The unit rates of civil part construction for fiscal year 2077/2078 are tabulated in Annex.

8.9 Contingencies

The estimated costs include contingencies which allow for unforeseen cost increases that may become necessary as more information is obtained and evaluated. In view of the extent of investigations carried out to date, the present stage of preliminary designs and cost analysis performed, the following contingencies have been allowed:

- Civil and others 5 %
- Hydro-mechanical works 3 %
- Electro-mechanical and Transmission 3 %

8.10 Environmental Programs

An allowance of 1.50 % of the total construction cost for environmental programs have been included.

8.11 Engineering and Management

An allowance of 3 % of the total base cost has been allocated to cover the following:

- Detailed field investigations

- Preparation of detailed designs and tender documents
- Preparation of detailed construction drawing
- Prequalification of tenders
- Evaluation of tenders
- Supervision of construction, testing and commissioning
- Management of procurement
- Administration of construction contracts
- Measuring the work
- Reviewing and approving contractor's submittals
- Cost of owner's and consultant's equipment, supplies, communication and transport

8.12 Total Estimated Cost

On the basis of the analysis described above, the cost of the 14.50 MW Upper Irkhuwa Hydropower Project, including contingencies, engineering and administration, is estimated as NRs. 2,639,339,644.0 including IDC which is divided into following group, subheadings presented in Table 8-1.The project has been planned to complete within 2.0 years. The total expenditure on the first and second year will be 40% and 60%, respectively. These cost disbursements include advances provided to suppliers and contractors.

Note: All the costs are in Nepalese Rupee.

Summary of the project cost is shown in Table 8-1.

Table 8-1: Summary of project cost

AARATI POWER LTD.
UPPRR IRKHUWA KHOLA HYDROPOWER PROJECT (14.50 MW)
Bhojpur

SUMMARY OF COST

Summary of Cost							
S.No.	**Description**	**Amount (NPR)**	**Contingency (%)**	**Contingency amount (Nrs)**	**Tax/Vat**	**Total amount (Nrs)**	**Remarks**
A	**Preliminary Works**	95,000,000.00				**95,000,000.00**	
B	**Civil Construction works**						
B1	General items	30,000,000.00		-		30,000,000.00	
B2	Diversion Weir			-	-	-	
	Irkhuwa Khola-Diversion Weir	67,269,062.08	5%	3,363,453.10	7,345,781.58	77,978,296.76	
	Phedi Khola-Diversion weir & Flood Wall	47,432,835.18	5%	2,371,641.76	5,179,665.60	54,984,142.54	
B3	Undersluice	30,029,201.97	5%	1,501,460.10	3,279,188.86	34,809,850.93	
B4	Approach Canal, Side Intake and Gravel Trap			-	-	-	
	Irkhuwa Khola-side Intake, Gravel Trap & Spillway	21,959,414.70	5%	1,097,970.74	2,397,968.09	25,455,353.52	
	Phedi Khola-Intake & Gravel Trap	6,973,613.72	5%	348,680.69	761,518.62	8,083,813.02	
	Phedi Khola-Approach canal	9,541,980.00	5%	477,099.00	1,041,984.22	11,061,063.22	
B6	Settling Basin	86,604,426.32	5%	4,330,221.32	9,457,203.35	100,391,851.00	
B7	Flood Protection Works	39,212,940.55	5%	1,960,647.03	4,282,053.11	45,455,640.68	
B8	Alignment E/W Excavation, Backfilling and protection Structure	60,848,576.50	5%	3,042,428.83	6,644,664.55	70,535,669.88	
B9	Anchor block	68,296,223.38	5%	3,414,811.17	7,457,947.59	79,168,982.14	
B10	Saddle suport	20,732,550.49	5%	1,036,627.52	2,263,994.51	24,033,172.53	
B11	Khola Crossing	11,008,442.05	5%	550,422.10	1,202,121.87	12,760,986.02	
B13	Powerhouse	94,479,325.97	5%	4,723,966.30	10,317,142.40	109,520,434.66	
B14	Tailrace	16,541,490.50	5%	827,074.52	1,806,330.76	19,174,895.78	
B15	Powerhouse Protection	15,322,500.00	5%	766,125.00	1,673,217.00	17,761,842.00	
B16	132 Kv Switchyard for both end	13,166,333.33	5%	658,316.67	1,437,763.60	15,262,413.60	
	Sub-total	**639,418,916.73**		**30,470,945.84**	**66,548,545.71**	**736,438,408.28**	
C	**Hydromechanical works**						
C1	General items	8,500,000.00		-		8,500,000.00	
C2	Price schedule for Trashrack, Gates/ Stoplogs and Hoisting Systems	23,519,720.00	3%	705,591.60	3,149,290.51	27,374,602.11	
C3	Price schedule for Headrace/Penstock pipe erection , painting and testing all complete and its Accessories	127,711,657.86	3%	3,831,349.74	17,100,590.99	148,643,598.58	
C4	Miscellaneous items Spare Parts	421,000.00	3%	12,630.00	56,371.90	490,001.90	
C5	Steel Headrace Pipe and Penstock Pipe Procurement	374,300,372.25	3%	11,229,011.17	3,855,293.83	389,384,677.25	
	Sub-total	**534,452,750.11**		**15,778,582.50**	**24,161,547.23**	**574,392,879.84**	
D	**Electromechanical works**						
D1	Electrical mechanical component of powerhouse and its Accessories @210 per kW	359,310,000.00	3%	10,779,300.00	5,551,339.50	375,640,639.50	
	Sub-total	**359,310,000.00**		**10,779,300.00**	**5,551,339.50**	**375,640,640**	
E	**Transmission Line and substation**						
E1	Transmission line 132 KV (10 Km)	130,000,000.00	3%	3,900,000.00	17,407,000.00	151,307,000.00	NRS 13000000/km
E2	Construction power	18,500,000.00	3%	555,000.00	2,477,150.00	21,532,150.00	
	Sub-total	**148,500,000.00**		**4,455,000.00**	**19,884,150.00**	**172,839,150**	
	Total Base cost (A+B+C+D+E)	**1,616,529,288.98**				**1,954,311,078**	
F	**Land Acquisition ,Compension and lease**	125,000,000.00				125,000,000.00	
G	**Office and equipment**	9,000,000.00				9,000,000.00	
H	**Vehicle**	7,455,500.00				7,455,500.00	
I	**Acces Road Upgrading and New track opening along the alignment**	75,000,000.00				75,000,000.00	
J	**Infrastructure**	20,000,000.00				20,000,000.00	
K	**Social ,Envir Mitigations @ 1.5% of base cost**	24,247,939.33				24,247,939.33	
L	**Administration and Project management cost @ 5% of base cost**	80,826,464.45				80,826,464.45	
M	**Engineering and Project Supervision@ 3.0% of base cost**	56,578,525.11				56,578,525.11	
N	**Total cost of The Project**					**2,352,419,506.52**	
O	**Insurance and FC fee @1.2% of base cost with VAT (excl. taxes and contigencies)**					21,920,137.16	
P	**Intrest during construction(IDC)**					265,000,000.00	
	Grand Total Cost (M to P)					**2,639,339,643.68**	
					Per MW Cost	**182,023,424**	

The distribution of the cost for different components of Civil works is presented in Figure 8-1 below.

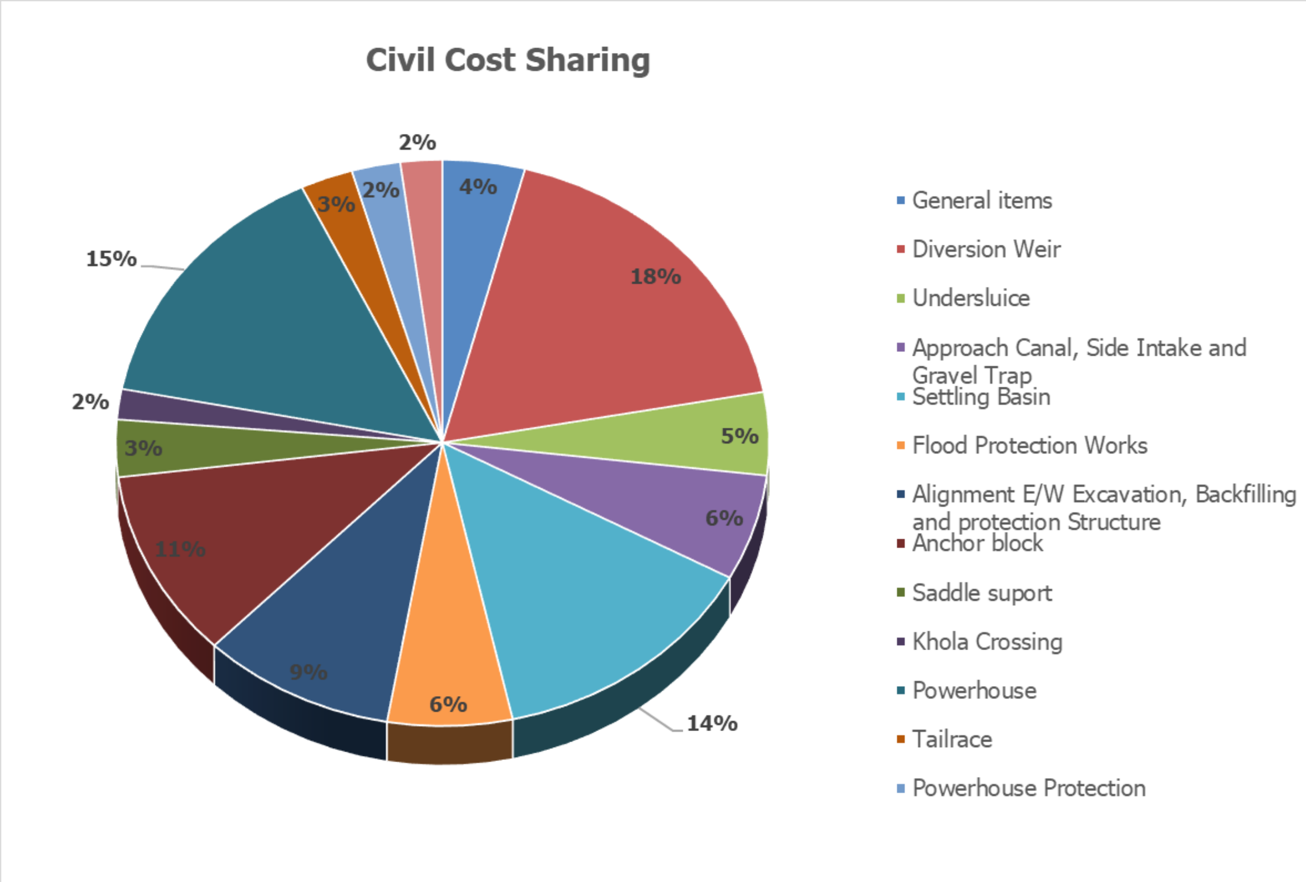


Figure 8-1: Distribution of the project cost

9 PROJECT EVALUATION

The ultimate aim of a power project is to produce power and energy at financially viable cost. Financial analysis takes the view of the individual project participants. The financial costs associated with project are based on normal accounting conventions. Thus, assets are valued in terms of their engineering costs and are depreciated over their normal lives which may be determined by law rather than technical or financial criteria.

Financial analysis is connected with the estimation of the financial implications of a proposed development. It is based on the use of market prices and therefore includes any taxes or royalties which will be levied on the factors of production and any subsidies, capital or operating, which may be received as part of development. All costs are charged and all revenues credited to the analysis in the actual amounts expended or received at the time of expenditure. For this analysis the financial rate of return and cash flow is assessed from the perspective of a utility owner/operator.

9.1 Decision Making Tools

Discounted cash flow method will be used for the financial analysis. Financial internal rate of return (FIRR) is the decision-making tool. Project is considered to be feasible if the internal rate of return on the equity is acceptable to the developer. Other decision-making tools are benefit cost ratio (B/C) and net present value (NPV), which are calculated from the net cash flow. A discount rate of 10% is considered for the base case analysis.

Financial analysis is done for the leased period, which is 32 years. Base year for the cost and benefit is taken as 2021.

9.2 Debt-Equity Ratio and Interest

Debt equity ratio of 70:30 is assumed as a base case with an interest rate of 10% on debt. It is assumed that the loan will have a grace period for two years during construction and will be paid in twelve years from operation. Interest during construction (IDC) is capitalized. The loan and the interest will be repaid in equal installment after the commencement of the project. Since, all the loan amount will not be disbursed in the beginning of the year, the interest is not calculated on the whole loan amount. The interest is calculated for 40% of the loan amount in the first year, 60% of the loan amount in the second year. More detailed calculations shall be done during the financial closure of the project regarding disbursement of loan and service charges of the bank.

9.3 Operation & Maintenance (O&M), Insurance and Other Costs

Operation and maintenance (O&M) Cost including local development cost has been calculated in capital cost estimate chapter. The O&M and insurance cost is estimated as 1.5% of financial analysis for first year and it is assumed that the cost will be increased by 3% per annum

9.4 Electro-mechanical Replacement Cost

Electromechanical replacement cost is not considered for financial analysis of the project. The electromechanical replacement cost will be managed from operation and maintenance cost. Operation and maintenance cost are 1.50% of construction cost which is sufficient for the replacement of electromechanical equipment if some amount of O&M cost is reserved each year. Therefore, electromechanical replacement cost will be managed by reserving some amount from O&M cost for 20 years.

9.5 Royalties and Taxes

As royalties on installed capacity and energy are chargeable to the power plant having capacity more than 1000 kW. The royalty on installed capacity is NRs 100/kW for first 15 years and NRs 1000/kW for remaining period. Similarly, royalty on energy is 2% for first 15 years of operation and 10% for remaining period.

In addition to this, income tax is 0% for the first 10 years of operation, 10% from 11 to 15 years and 20% after 15 years of operation is considered. No custom and local taxes are considered on other items as these will be purchased from the local market.

9.6 Annual Generation and Outage

Annual generation will be constant throughout the analysis period. Scheduled and unscheduled outage including self-consumption and transmission loss is assumed to be 4% of the total generation.

9.7 Financial Analysis Results

Financial analysis of the Project is carried out to assess the financial viability of the Project. There are different modes of financing. In this study, the project is analyzed assuming that the project will be developed through local private developer using local currency. The developer will arrange the required finance through commercial bank and equity. The project will be developed according to the prevailing hydropower policy of Nepal. The entire energy will be sold to NEA through mutually agreed Power Purchase Agreement (PPA). Financial parameters like FIRR, NPV, BC ratio and RoE are computed from the net cash flow of project.

The criteria and assumptions made in financial analysis are:

- O&M and insurance cost is considered as 1.5 % of Financial Year for first year and Increment by 3% on yearly basis.
- Taxable amount is equal to gross revenue less O&M cost, royalty, interest on loan and

depreciation value.

- ❖ Debt cover ratio is equal to gross revenue less tax, royalty, O&M cost and EM replacement cost over interest on loan and loan repayment.
- ❖ Debt cover ratio is equal to gross revenue less tax, royalty, O&M cost and EM replacement cost over interest on loan and loan repayment.
- ❖ Royalty applicable for small hydropower project (10-20 MW) is NRs 100/kW of gross revenue for the first 15 years of operation and NRs 1000/kW of gross revenue after 15 years according to policy of GoN.

Input parameters for financial analysis are presented in Table 9-1.

Table 9-1: Input Parameters

Description	**Value**	
Project cost w/o IDC	NRs. 2,374,339,644.0	
Installed Capacity:	14500	Kw
Construction Period (Loan drawdown Period):	2	years
Loan Equity Ratio (With IDC):	70:30	
Loan Repayment Period Quartly Basis:	12	years
Bank Loan Interest:	10	%
Bank Loan Arrangement Fees:	0.5	%
Dry Energy	30.26(As per PPA)	GWh
Wet Energy	60.32(As per PPA)	GWh
Dry Season Rate (6 Months):	8.4	NRs/Kwh
We Season Rate (6 Months):	4.8	NRs/Kwh
Price Increment in energy rate for 8years(after COD):	3	%
Operation & maintenance cost yearly increase by:	3	%
Royalty on Capacity for 15 Years:	100	NRs
Royalty on Capacity after 15 Years:	1000	NRS

Royalty on Revenue for 15 Years:	2	%
Royalty on Revenue after 15 Years:	10	%
Cost Escalation by:	0	
Generation loss effect by:	0	
Staff Bonus Provision(% of earning after Interest,after 3 years) :	2	%
Income Tax-	0% for first 10 years	
	10% for 11 to 15 years	
	20% After 15 years	
Discount factor :	10	%
Depreciation rate is as per Life of Project:	30	Years
Financial Analysis Period	32	Years
Start of Construction Activity	2022	AD
Commercial Operation Year	2024	AD
Operation & Maintainance Cost	1.5% of FA for First Year & increament by 3% on Yearly basis	

Table 9-2: Results of financial analysis

Internal Rate of Return (IRR)	18.19 %
EIRR	29.42%
NPV(In NRs '000)	1722647
BC ratio	1.76
Revenue Per MW	37498.60
Cost Per MW	182023424.0

Internal Rate of Return (IRR)	18.19 %
Pay Back Period (Simple)	5.20
Pay Back Period (Discounted)	7.86
Minimum DSCR	1.79
Loan Per Megawat (In NRs '000)	127416.40
Cost Sensitivity (As Increased by)	51.22%
Revenue Sensitivity (As Decreased by)	28.26%

Table 9-2 presents the financial indicators computed for the project. Minimal criteria of financial feasibility are net present value (NPV) must be positive, benefit cost ratio (BC ratio) must be greater or equal to 1 and financial internal rate of return (FIRR) must be greater or equal to opportunity cost of capital. In this case opportunity cost of capital could be considered as prevailing interest rate of bank. From the above criteria this project is financially feasible. Utility or operator may want to know the rate of return on his investment after bank financing. Hence return on equity (RoE) also presented in this financial analysis so that operator can have idea about how much return he will get on his investment.

9.8 Sensitivity analysis

The financial return on the project is sensitive to various parameters that are assumed during review. To better understand the effect of each of these parameters and their impact on the returns, a sensitivity analysis has been carried out. The sensitivity analysis looks at varying interest rates, project cost over the construction period and variation in revenue generation. The different parameters considered in the sensitivity analysis have been described more in detail below.

Sensitivity analysis is carried out for above scenarios assuming the following:

Case - A : Revenue decreases by (5% to 25%)

Case - B : Project cost increment by (5% to 25%)

Case - C : Interest rate has been increased (9% to 17%)

Case - D : Cost overrun, and Revenue decreases by (5% to 15%)

A-Revenue sensitivity

Sensitivity analysis has been carried out varying the energy generation. For the present study, the energy generation has been decreased by 5%, 10%, 15% and 25%. Results of revenue sensitivity are given in Table 9-3.

Table 9-3 Result of revenue sensitivity

Cost is Constant						
Interest Rate is Constant	10%					
Revenue is Decreased by		0%	5%	10%	15%	25%
Result						
IRR	%	18.19%	17.21%	16.22%	15.21%	13.13%
EIRR	%	29.42%	26.94%	24.47%	22.03%	17.24%
NPV	Value	1,722,647	1,501,900	1,281,153	1,060,406	618,912
BC Ratio	Times	1.76	1.66	1.56	1.47	1.27
Revenue Per MW	Amount,000	37,499	35,624	33,749	31,874	28,124
Cost Per MW	Amount,000	182,023	182,023	182,023	182,023	182,023
Simple Payback Period	Years	5.2	5.48	5.79	6.14	7.01

B -Project cost variation sensitivity

Sensitivity analysis has been carried out varying the project costs over the construction period. For the present study, the project cost has been increased by (5%, 10%, 15% and 25%). Results of cost over run sensitivity are given in

Table 9-4.

Table 9-4 Result of Cost Sensitivity

Revenue Is Constant						
Interest Rate is Constant	10.00%					
Cost is Inflated by		0%	5%	10%	15%	25%
Result						
IRR	%	18.19%	17.26%	16.41%	15.62%	14.20%
EIRR	%	29.42%	27.07%	24.94%	23.00%	19.64%
NPV	Value	1,722,647	1,589,325	1,456,004	1,322,683	1,056,041
BC Ratio	Times	1.76	1.67	1.58	1.51	1.37
Revenue Per MW	Amount,000	37,499	37,499	37,499	37,499	37,499

Cost Per MW	Amount,000	182,023	191,125	200,226	209,327	227,529
Simple Payback Period	Years	5.2	5.46	5.73	6	6.54

C-Interest rate sensitivity

An interest rate of 10 % has been considered for the base case where as sensitivity analysis has been carried out for interest rates of 9%, 10%, 12%, 15% and 17%. Results of interest rate sensitivity are given in Table 9-5.

Table 9-5 Result of interest rate sensitivity

Cost is Constant						
Revenue is Constant						
Interest Rate is		9%	10%	12%	15%	17%
Result						
IRR	%	18.37%	18.19%	17.83%	17.31%	16.98%
EIRR	%	30.97%	29.42%	26.33%	21.84%	19.04%
NPV	Value	1,747,625	1,722,647	1,672,935	1,598,981	1,550,087
BC Ratio	Times	1.78	1.76	1.72	1.67	1.64
Revenue Per MW	Amount, 000	37,499	37,499	37,499	37,499	37,499
Cost Per MW	Amount, 000	180,196	182,023	185,679	191,161	194,817
Simple Payback Period	Years	5.15	5.2	5.3	5.44	5.54

D-Revenue and Cost sensitivity

Sensitivity analysis has been carried out varying the project costs over the construction period and varying the energy generation. For the present study, the project cost has been increased by 5%, 10% & 15% and revenue has been decreased by 5%, 10% & 15 %). Results of cost over run and revenue sensitivity are given in Table 9-6.

Table 9-6 Results of cost over run and revenue sensitivity

Interes Rate is Constant		10%			
Revenue is Decreased by		0%	5%	10%	15%
Cost is Increased by		0%	5%	10%	15%
Result					
IRR	%	18.19%	16.32%	14.57%	12.91%
EIRR	%	29.42%	24.72%	20.50%	16.75%
NPV	Value	1,722,647	1,368,578	1,014,510	660,442
BC Ratio	Times	1.76	1.57	1.41	1.25
Revenue Per MW	Amount,000	37,499	35,624	33,749	31,874
Cost Per MW	Amount,000	182,023	191,125	200,226	209,327
Simple Payback Period	Years	5.20	5.76	6.39	7.11

9.8.1 Results

From the financial analyses of project, financially the project looks viable as the NPV is positive. The benefit cost ration (BCR) is more than 1.0 thus on the safer side. The sensitivity analysis reveals that the project is feasible even with 15% reduction in the estimated energy and increase in total cost by 15%.

10 CONSTRUCTION PLANNING AND SCHEDULE

10.1 Broad Program

The Project has been proposed to be constructed in a period of around two years. It has been proposed to obtain all statutory and non-statutory with in the 6 months.

The Financial Closure shall be achieved within January 2022. Before that various contracts shall be awarded. The physical construction of main civil works will be commenced from the 15th of January 2022.

The various works are scheduled in such a way that the construction of project will be completed in a period of 24 months. The Implementation schedule of major activities is presented in a Bar Chart form.

10.2 Major Components

The project comprises of the following major components;

a) Diversion weir and intake structure on Irkhuwa and Phedi Khola

b) Gravel trap, flood spillway and gravel flushing canal lined with steel.

c) Settling basin, spillway and sediment flushing duct (with steel lining).

d) Headrace Pipe.

e) Penstock and Anchor Blocks/saddle support.

f) Hydro-mechanical component.

g) Power House and tailrace.

h) Electro-mechanical Equipment

i) Switch Yard

k) Residential and office buildings

l) Transmission Line

10.3 Access to site

10.3.1 Access in India

A preliminary assessment of transportation facilities within India was made based on the information collected during various on-going and completed projects. Calcutta is the preferred port for handling cargo from overseas as there is necessary lifting crane capacity, adequate terminal facilities, and stacking area and railway yards. The port is selected to meet the following objective:

- To determine the most feasible rail route for import of machinery and electro-mechanical equipment
- To establish probable transit times to railheads
- To define the most feasible land routes from the railheads to the nearest Nepal border towns
- To define the required terminal facilities at Calcutta port for items being imported from third countries besides India
- To establish the need of using special wagons for transporting the permanent equipment by rail
- With regards to transportation, this route has been selected for transportation of foreign goods from India or Overseas.
- Biratnagar custom

10.3.2 Access in Nepal

The project can be accessed through East-West Highway from Kathmandu to Chainpur bazar, Bhojpur. It takes approximately seven hours by walking to reach headworks site at Gothe bazar. For the imported materials, the bordering point at Biratnagar will serve as the nearest rail head from where major truck haul will be made to Biratnagar. From Biratnagar, the access will be via Biratnagar, Itahari, Dharan, Chainpur at Bhojpur and finally to the project site. The total length of the road from the inland container depot at Biratnagar to the project site is approximately 515 kilometers.

10.4 CONSTRUCTION MATERIALS

10.4.1 General

All the construction material like gneiss, quartz boulders and stone are available within the 10 km area from the project site. These shall be transported to the working area by tractor /truck. Fine aggregate (sand) & coarse aggregate is available in various pockets of Upper Irkhuwa Khola bed with in the project area. Whereas insufficient sand needs to be managed from another quarry also. The material will be screened and transported to the project site by tractor /truck.

10.4.2 Stone for Masonry Work

Good quality stone suitable for masonry work is available in plenty nearer to the major components of the project. These shall be transported by tractor/truck from local quarries to the site as required.

10.4.3 Reinforcement steel and cement

Reinforcement steel and cement in bulk quantities will be transported from Biratnagar bazar by road transport to the project site.

10.4.4 Structural Steel for Penstock and other Hydro-mechanical Works

Steel for the fabrication of penstock, gates, stop logs, trash racks etc. shall be procured from India and China. The fabrication work shall be carried out at project site. Or penstock pipe can be directly purchased from India or China.

10.4.5 Other Materials

CGI sheets, industrial gas and other materials required by the project will be transported to the site from Biratnagar or Kathmandu by road transport.

10.5 CONSTRUCTION CONTRACTS

The major components of works for project execution are weir, undersluice and intake, gravel trap, settling basin, penstock pipe, powerhouse, transmission line and substation. For execution of all these components, contract packaging under different type of packaging would be appropriate type with post or pre qualifications of contractors/ manufacturers. The packages can be divided as presented in Table 10-1.

Table 10-1: Contract Packaging

Work Packages	Items of Works
Various petty contracts	For infrastructure works at the project level
Civil works contracts	Headworks(for Irkhuwa Khola and Phedi Khola), settling basin, head pond, crossing structure, penstock pipe alignment, anchor blocks and saddle supports, powerhouse and tailrace and switchyard.
Hydro mechanical contract	Penstock pipes, trash racks, expansion joints gates and valves
Electro-mechanical contract	Electro-mechanical equipment, transmission line and switchyard
Transmission line and interconnection contract	Transmission line and interconnection

According to the volume, the works can be procured through National or International bidding through pre or post qualification criteria.

10.6 Land Acquisition

A total of about 120 ropanis of land area will be required for project. The required private lands have to be purchased for permanent works. The community and government owned land will be obtained from the concerned authority for the project life. Other land required for the construction purpose will be taken on lease.

10.7 Mobilization

It is assumed that the tender awarding will be done within August 2021 so that mobilization will be started immediately and construction works will begin. Construction works will start from the establishment of camps, workshops, construction power lines, water supply, batching plant and preliminary works like river diversion, earthworks, etc. Thus, mobilization of materials, accessories, machineries and manpower shall be done as per need of the works. Excavators, wheel loaders, dumpers, batching plants, compressors, water pumps, etc. shall be mobilized to site at the beginning stages. Mobilization will be continued throughout the construction period and as per specific requirement of works.

10.8 Construction Power

Necessary arrangement will be done to tap power at project site. For reliable supply, diesel generator will be operated to manage trip and insufficient power requirement.

10.9 Camp Establishment

There will be separate temporary and permanent camp facilities. The guest house and other permanent houses in the Upper Irkhuwa Hydropower Project will be used as permanent camp for the staff of Employer.

Temporary camps will be established near the Headworks site for contractor's staff and labors. In addition, temporary office, workshop, equipment and material yard, store, water supply and sanitation system, etc. will be constructed. Such camp structures will be temporary in nature and dismantled after the completion of construction works.

10.10 Construction Planning

According to the scope of works, the entire site activities have been divided into three major components: Civil works, Hydro-mechanical works and Electro-mechanical works. The construction sequence of Upper Irkhuwa HHP has been planned in fast track basis for construction power, so two shifts of 8 hours working with two-hour overtime is allocated in general construction basis. Additional working hour require will be finalized at the time of construction.

10.10.1 Construction facilities

Access Road

The Upper Irkhuwa Hydropower Project is situated in Dobhane, Khatama and Kudakaule Village Development Committees (VDCs) of Bhojpur district in eastern Nepal. Tumlingtar Bazaar, in the Sankhuwasabha district, is 185 km north along Koshi Highway from Itahari Bazaar on the East-West Highway. Both headworks and powerhouse sites of the project lie on the right bank of Irkhuwa Khola. Total of about 4 km of access road from the Gothe Bazaar needs to be constructed to reach the whole alignment of project components. Other improvement is necessary for 25 km road from Tumlingtar as well as Bridge in Arun river at Tumlingtar.

Preparatory works

The preparatory works include establishment of camp facilities for employer's and contractor's staff, and transportation of construction equipment by the contractor.

Employer’s camp

Site facilities like office building and staff residence are to be accommodated in rental houses during mobilization, however necessary infrastructure needed for construction and operation phase in headworks and powerhouse site will be constructed during the construction of hydropower project component, for which necessary provisions are allocated accordingly.

Contractor's camp

The camp will include residence for its staff, workshops/mechanical yards, laboratories, construction materials, and equipment storage and maintenance areas.

Altogether 13 weeks are allocated for all preparatory work.

10.11 Construction of Civil Components

Major Civil Components of the Project are:

- Headworks structure consists of diversion weir, side intake, approach canal, undersluice, gravel trap, settling basin, and headpond with spillway arrangement
- Water conveyance structures consists of pressure headrace pipe
- Anchor blocks and saddle supports for Penstock pipe
- Powerhouse, tailrace and Switchyard
- Protection works at headworks, headrace alignment and powerhouse.

10.11.1 Headworks

River Diversion Work

The construction works at the headworks start with construction of coffer dams and diversion canal. Due to the nature of the river, river diversion will be done at the right bank of the river. For the diversion canal, the natural gully on the right bank will be utilized.

The coffer dam height will be such that the average annual flood shall not overtop it. It will comprise of GI sheets as center core for control of seepage, and gabion boxes at the outer surface exposed to the river flow for protection against scouring. This coffer dam will prevent water flow in the normal water course so that construction works in the weir and intake area can be done. A downstream coffer dam, if required, will also be constructed so that back flow of the river will not affect the work area. This downstream coffer dam will be similar in size as of the upstream coffer dam.

Under sluice and Intake

River diversion will be done as explained above before the construction of the bed load hopper, divide wall, under sluice and intake orifice. Hard stone lining works will be done before flow is passed through the under sluice.

Gravel Trap and its flushing.

Construction of these structures will be started after the completion of foundation of intake headwall. The gravel trap works will start from the bed slab connected with the intake. The side slopes of the excavation will be stabilized during construction and with provision of berms. Flushing conduit will be completed after or in parallel with the gravel trap construction.

Diversion Weir

Weir construction will be commenced after substantial completion of the under sluice. Any seepage water in the river will be diverted through the under sluice. The diversion weir construction requires excavation in the river bed. Thus, sufficient dewatering arrangement will be made to make the working area free of impounding. The weir construction starts from construction of the cutoff walls. Downstream concrete floor will also be constructed in monolithic with the main concrete weir or providing dowels with contraction joints. U/S impervious concrete floor will be constructed after the completion of weir body. Boulder riprap of the weir will also be done after the completion of u/s floor.

Settling Basin and Head Pond

The settling basin requires excavation on boulder mix soil and compacted backfilling with boulder mixed soil deposit at the ends of settling basin. Excavation works will be completed at required reach and in parallel with the concrete works but fairly before. There will be separate crew for handing the construction of these works. It will be started from the parallel sections. It will be divided into panels having expansion joints. The transition section and the gate structures will be completed at the later stage of the works. The work on bottom portion of flushing conduit will be completed before commencement of works of head pond. The head pond and spillway works will be done in parallel.

Flood walls and river training works

After the completion of construction work for the diversion weir, stilling basin boulder rip-rap work will be carried out from end to the downstream. Flood wall of necessary height has been provisioned at the upstream left bank and right bank to prevent flood effects.

10.11.2 Penstock Pipe alignment.

Steel pipe, both buried and exposed will be the main waterway for this project. The total length of the pipe is 3873.50m (without bifurcation) connecting the head pond to powerhouse. The construction of waterway begins with excavation, protection and construction of anchor blocks and support piers. Different crew will be involved in the construction in parallel.

The civil contractor will prepare necessary stage of construction for erection of steel penstock pipe. The hydro mechanical contractor will procure, manufacture and install the penstock pipe in co-ordination with the civil contractor. Construction will commence from mid part whereas the anchor block attached with the surge tank will be completed at the end.

10.11.3 Powerhouse, tailrace and switch yard

The work at powerhouse, tailrace canal and switch yards will be relatively simple, but will become critical activity if the detail design of the electro-mechanical work will not available in time. Hence, after the financial closure of the project the contract for the electro-mechanical works should be awarded, so that data needed for power house sizing, foundation design and structural detailing are available in time and sufficient time is available for design and manufacture of electro-mechanical component.

The powerhouse works will commence from the excavation work and will progress from the foundation concrete, followed by structural concrete and the building works. Finally, the installation of electro-mechanical works and final finishing work will be carried out. In parallel, the work at tailrace canal, switch yard and protection will be carried out. As the project has to construct loop in and loop out arrangement it should be planned and start on time.

10.11.4 Hydro-mechanical Works

The penstock pipe procurement, manufacture and transport will be done independent of other activities and installation will be done in parallel with anchor blocks and support pier works. The hydro-mechanical embedding work such as, frames for gates, stop logs, draft tubes etc. should follow the respective civil works at headworks and powerhouse. As per requirement hydro-mechanical installations should be carried out in parallel and after the construction of civil works. Therefore, well planning and coordination should be made between the civil and hydro-mechanical contractor.

10.11.5 Electro-mechanical Works

The contract for electro-mechanical works for the design, fabrication, supply, installation and testing will be awarded even before the financial closure of the project. It is estimated that the fabrication and transportation, machinery installation and testing work of the electro-mechanical equipment to the site will be completed within 22 months from the date of contractual agreement. Therefore, acceleration work on the civil construction works will be necessary.

10.11.6 Transmission Line Works

Total 16 months have been scheduled for the contract award and installation of 10 km long 132 kV transmission line from Sithalpati Sub-station to the switchyard of the Upper Irkhuwa Hydropower Project. Thus, the total construction period of the project will be 24 months. About 1 month is allocated for dry and wet test and 3 weeks is allocated for trial commissioning of the project. The planned commercial operation date (COD) is 5th March 2024.

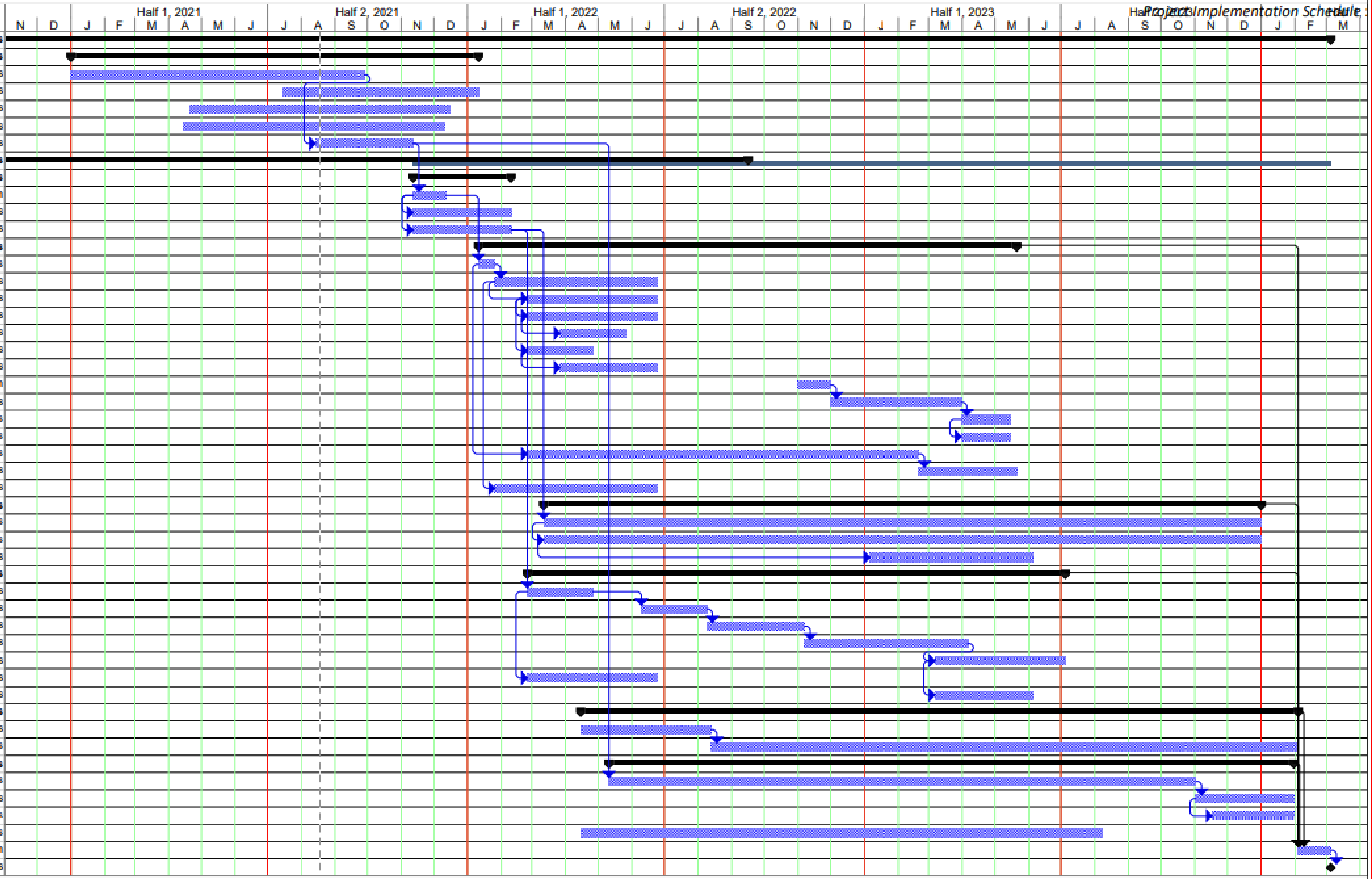
10.12 IMPLEMENTATION SCHEDULE BAR CHART

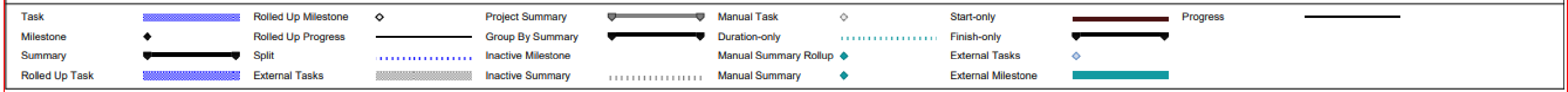
The construction program in the form of Bar Chart is enclosed here in after this page.

Super Chepe HP

Project Implementation Schedule

Task Name	Duration
Upper Irkhuwa HP	**41.87 mons**
Preconstruction Works	**12.5 mons**
Detail engineering design	9 mons
Financial Arrangement	6 mons
Land Acquisition	8 mons
Access Road	8 mons
Tendering and Contract Awarding	3 mons
Construction Works	**24 mons**
General items	**3 mons**
Mobilization	1 mon
Construction Power	3 mons
Establishment of Camps	3 mons
Headworks Construction	**16.5 mons**
River Diversion 1st phase	0.5 mons
Under Sluice and divide	5 mons
Intake	4 mons
Gravel trap	4 mons
Gravel flushing	2 mons
Spillway	2 mons
Approach canal	3 mons
River diversion 2nd phase	1 mon
Weir	4 mons
Upstream Riprap	1.5 mons
Downstream Riprap	1.5 mons
Settling Basin and Flushing	12 mons
Forebay and Spillway	3 mons
River Training Works	5 mons
Water Way construction	**22 mons**
Anchor Block	22 mons
Support Pier	22 mons
Crossing	5 mons
Powerhouse Construction	**16.5 mons**
Powerhouse excavation	2 mons
Powerhouse Foundation	2 mons
Powerhouse Substructure	3 mons
Powerhouse Superstructure	5 mons
Tailrace	4 mons
River Training at Powerhouse area	4 mons
Switchyard civil works	3 mons
Hydro-mechanical Works	**22 mons**
Material Procurement and Manufacture	4 mons
Penstock and gate Installation	18 mons
Electromechanical works	**21 mons**
Manufacture and Transportation	18 mons
Electro-mechanical installation	3 mons
Switchyard Installation	2.5 mons
Transmission Line	**16 mons**
Trial commissioning	**1 mon**
Commissioning	0 mons





11 CONCLUSION AND RECOMMENDATION

11.1 Conclusion

This Study of Upper Irkhuwa Hydropower Project concludes the following:

- Topographically, the project site is easy for construction. Location of headwork site, powerhouse site and alignment of water conveyance system is favorable from topographical as well as geological point of view. Being a medium head and medium discharge plant, the project will be easy in construction.
- A design discharge of 7.80 m3/s is conveyed through 3874.00 m long penstock pipe to hit three units of Horizontal axis Francis turbines for electricity generation.
- The intake will be founded on thick alluvial deposits of the left bank of Upper Irkhuwa Khola. Most structures will be constructed in the colluvial deposit no major geological hazards observed in and around the project area except few small scaled slides.
- The project will have an installed capacity of 14500 kW to produce on an average year 93.20 GWh of energy, of which 31.79 GWh is dry energy and 61.42 GWh is wet energy at a rated head of 214.78 m.
- The electricity generated from the project will be evacuated to INPS at Sub-station at Sithalpati, Bhojpur through 10 km long 132 kV transmission line.
- The project will require 24 months to construct at a costs NRs 2653.29 million (including IDC) at 2077/2078 price level.
- The project will have a benefit/cost ratio of 1.76; and will yield a rate of return of 18.19% at 10 % interest rate, reflecting a financially attractive project.
- Financially the project is viable producing a 29.42% return on equity for 30:70 equity financing, 10 % commercial interest rate and considering financial expenditures like royalties, insurance premiums and taxes etc. if energy is sold at a present price of NRs 8.4 and 4.8 per kWh for dry and wet energy respectively.

11.2 Recommendation

Power evacuation is challenging in every project planned in Nepal, so developer should have careful attention on transmission line and proposed sub-station.

The flow measurement and gauge reading of the river shall be continued for better flow estimation and confirmation of the low flows.

The Kholsi and gully that crosses the headrace alignment should be monitor and managed after each rainy season.

Geophysical investigations of ERT and SRT are recommended at the important location of the project components for the further optimization of the project component.

The project is in the development phase proper follow up and co-ordination is must to start the construction of the project on scheduled time. Likewise, to complete the project within the estimated construction time, timely planning of resources and proper management of works in the design and construction is recommended.

Similarly, the local material especially sand is not sufficiently available in the vicinity of the project. Hence, the outsourcing of the sand is must for timely completion of the construction.