Kingdom of Bhutan
Ministry of Economic Affairs (MOEA)
Department of Hydropower & Power Systems (DHPS)

Project on

Power System Master Plan 2040 in Bhutan

Final Report

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Tokyo Electric Power Company Holdings, Inc. (TEPCO HD)
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Nippon Koei Co., Ltd
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Abbreviations

Abbreviation	Word
ACSR	Aluminium Conductors Steel Reinforced
ADB	Asian Development Bank
AIDS	Acquired Immune Deficiency Syndrome
AIS	Air Insulated Switchgear
APDCL	Assam Power Distribution Company Limited
AREP	Alternative Renewable Energy Policy
ASP	Ancillary Service Provider
ATF	Aviation Turbine Fuel
AWS	Automatic Weather Stations
B/C	Benefit by Cost
BEA	Bhutan Electricity Authority
BHSL	Bhutan Hydro Service Limited
BHU	Basic Health Unit
BLI	Birdlife International
BOOT	Build, Own, Operate and Transfer
BPC	Bhutan Power Corporation
BPSO	Bhutan Power System Operator
BRPL	BSES Rajdhani Power Limited
BSHDP	Bhutan Sustainable Hydropower Development Policy
BTN	Bhutanese Ngultrum
BYPL	BSES Yamuna Power Limited
CAD	Computer Aided Design
CB	Circuit Breaker
CBS	Center for Bhutan Studies
CDM	Clean Development Mechanism
CEA	Central Electricity Authority
CEA	Cumulative Environmental Assessment
CER	Certified Emission Reductions
CERC	Central Electricity Regulatory Commission
CMIP	Coupled Model Intercomparison Project
C. N. P	Centennial National Park
CNRRUB	College of Natural Resources Royal University of Bhutan
CO_2	Carbon Dioxide
COD	Commercial Operation Date
C/P	Counterparts
CSO	Civil Society Organization
DEM	Digital Elevation Model
DEEP	Discovery of Efficient Electricity Price
DETP	Domestic Electricity Tariff Policy
DFR	Draft Final Report
DGPC	Druk Green Power Corporation
DHI	Druk Holding and Investments Limited
DHMS	Department of Hydro Met Services
DHPC	Dagachhu Hydro Power Corporation Limited
DHPS	Department of Hydropower & Power Systems
DHS	Department of Human Settlement
DOA	Department of Agriculture
DOC	Department of Culture
DOE	Department of Energy
DoFPS	Department of Forests & Park Services
DOP	Department of Power

Abbreviation	Word
DOR	Department of Roads
DRE	Department of Renewable Energies
DSM	Deviation Settlement Mechanism
DSR	Debt Service Ratio
DYT	Dzongkhag Yargay Tshogdu
EDP	Economic Development Policy
EIA	Environmental Impact Assessment
EL	Elevation
EN	Endangered Species
ENTSO-E	European Network of Transmission System Operators for Electricity
EUCE	Expected Unit Cost of Electricity
EV	Electric Vehicle
FC	Foreign Currency
FIT	Feed-in Tariff
FR	Final Report
FRL	Full Reservoir (Water) Level
FS	Feasibility Study
FYP	Five Year Plan
GAO	Gewog Administrative Officer
GCM	Global Climate Model
GDP	Gross Domestic Product
G-G	Government to Government
GHG	Greenhouse Gases
GHS	Greater Himalaya Series
GIS	Gas Insulated Switchgear
GIS	Geographic Information System
GLOF	Glacial Lake Outburst Flood
GNH	Gross National Happiness
GNHC	Gross National Happiness Commission
GOI	Government of India
GSHAP	Global Seismic Hazard Assessment Program
GSI	Geological Survey of India
GSW	Galvanized Steel Wire
GYT	Gewog Yargay Tshogchung
HDD	Hard Disc Drive
HDD	Hydropower Development Division
HDMP	Hydropower Development Master Plan
HIV	Human Immunodeficiency Virus
HKH-HYCOS	Hindu Kush Himalayan Hydrological Cycle Observing System
HM	Hydro-Mechanical
HPP	Hydropower Plant
HT	High Tension
HV	High Voltage
IBA	Important Bird and Biodiversity Area
ICIMOD	International Centre for Integrated Mountain Development
ICR	Inception Report
IDC	Interest during Construction
IEA	International Energy Agency
IEE	Initial Environmental Examination
IEX	Indian Energy Exchange
IG	Inter Governmental
IHT	Industrial High Tension
IIT	Indian Institute of Technology

Abbreviation	Word
IKL	Isokeraunic Level
INDC	Intended Nationally Determined Contribution
INR	Indian Rupee
IPCC	Intergovernmental Panel on Climate Change
IPP	Independent Power Producer
IS	Indian Standard
ITMO	Internationally Transferred Mitigation Outcomes
ITR	Interim Report
IUCN	International Union for Conservation of Nature
JCC	Joint Coordination Committee
JDWNRH	Jigme Dorji Wangchuck National Referral Hospital
JICA	Japan International Cooperation Agency
JV	Joint Venture
KHyE	Kholongchhu Hydro Energy Limited
KT	Kakhtang Thrust
LB	Left Bank
LC	Local Currency
LHS	Lesser Himalayan Series
LILO	Line-in-Line-out
LPG	Liquefied Petroleum Gas
LS	Lower Stage
LV	Low Voltage
MBT	Main Boundary Thrust
MCA	Multi Criteria Analysis
MCM	Million Cubic Meter
MCT	Main Central Thrust
MePDCL	Meghalaya Power Distribution Corporation Limited
MHEP	Mangdechhu Hydro Electric Project
MOAF	Ministry of Agriculture and Forests
MOE	Ministry of Environment (in Japan)
MOEA	Ministry of Economic Affairs
MOF	Ministry of Finance
MODSIM	(Name of Software)
MOWHS	Ministry of Works and Human Settlement
MP	Master Plan
MSEDCL	Maharashtra State Electricity Distribution Company Limited
MTI	Ministry of Trade and Industry
MV	Medium Voltage
NAPA	National Adaptation Programmes of Action
NBC	National Biodiversity Center
NCHM	National Center for Hydrology and Meteorology
NDC	Nationally Determined Contribution
NEC	National Environment Commission
NGO	Non Governmental Organization
NHPC	National Hydroelectric Power Corporation
NKRA	National Key Result Areas
NLC	National Land Commission
NLCS	National Land Commission Secretariat
NLDC	National Load Despatch Centre
N. P	National Park
NPPF	National Pension and Provident Fund of Bhutan
NPV	Net Present Value
NSB	National Statistics Bureau

Abbreviation	Word
NTFP	Non-Timber Forest Product
NTGMP	National Transmission Grid Master Plan
NVVN	NTPC Vidyut Vyapar Nigam Limited
ODA	Official Development Assistance
OJT	On the Job Training
OLR	Over Load Relay
O&M	Operation and Maintenance
OPGW	Optical Ground Wire
ORC	Outreach Clinic
OS	Operation System
PA	Paris Agreement
PAVA	Property Assessment and Valuation Agency
PC	Personal Computer
PCD	Planning and Coordination Division
PDA	Project Development Agreement
PFI	Private Finance Initiative
PG	Power Grid
PGCIL	Power Grid Corporation of *India* Limited
PH	Powerhouse
PHCB	Population and Housing Census of Bhutan
PHEP	Punatsangchhu Hydro Electric Project
PHPA	Punatsangchhu Hydroelectric Project Authority
PIU	Project Implementation Unit
PLF	Plant Load Factor
PMU	Project Management Unit
PoC	Point of Connection
POSOCO	Power System Operation Corporation Limited
PPA	Power Purchase Agreement
PPP	Public Private Partnership
PS	Pooling Station
P/S	Power Station
PSIF	Private Sector Investment Finance
PSMP	Power System Master Plan
PSS/E	Power System Simulator for Engineering (Name of software)
PV	Photovoltaics
Q&A	Question and Answer
QGIS	(Name of Software)
QR	Quarterly Report
RB	Right Bank
RBL	Riverbed Level
RCP	Representative Concentration Pathways
R&D	Record of Discussions
RDD	Research & Development Department
REAP	Rural Economy Advanced Programme
REMP	Renewable Energy Master Plan
RERAR	Renewable Energy Resource Assessment Report
RES	Renewable Energy Source
RGOB	Royal Government of Bhutan
RICB	(Name of substation)
RLDC	Regional Load Despatch Centre
RMA	Royal Monetary Authority
RMAB	Royal Monetary Authority of Bhutan
RoE	Return on Equity

Abbreviation	Word
RoR	Run-of-River
ROW	Right of Way
RRAS	Reserves Regulation Ancillary Services
RSPN	Royal Society for the Protection of Nature
SC	Shunt Capacitor
SEA	Strategic Environmental Assessment
ShC	Shunt Capacitor
SHM	Stake Holder Meeting
SHPP	Small Hydropower Plant
ShR	Shunt Reactor
SJVN	SJVN Limited
SNR	Strict Nature Reserve
SP	Strategic Partnership
SPC	Special Purpose Company
SPV	Special Purpose Vehicle
STD	South Tibetan Detachment
SWAT	(Name of Software)
TAS	Near-Surface Air Temperature
TB	Tuberculosis
TBD	To be determined
TCD	Transmission Construction Department
TD	Transmission Department
TDR	Tariff Determination Regulation
TF	Transformer
TF	Task Force
TG	Turbine Generator
THDC	THDC India
THyE	Tangsibji Hydro Energy Ltd.
T/L	Transmission Line
TOR	Terms of Reference
TPDDL	Tata Power Delhi Distribution Limited
TPSD	Transmission & Power System Division
TSS	Tethyan Sedimentary Series
TWL	Tail Water Level
UK	United Kingdom
UK	Upper Karnali (Name of Project)
UN	United Nations
UNDP	United Nations Development Programme
UNESCO	United Nations Educational, Scientific and Cultural Organization
USD	United States Dollar
US EIA	United States Energy Information Administration
UWICER	Ugyen Wangchuck Institute for Conservation and Environmental Research
WB	West Bengal
WBPDCL	West Bengal Power Development Corporation Limited
WBSEDCL	West Bengal State Electricity Distribution Company Limited
WEO	World Energy Outlook
WG	Working Group
W. S	Wildlife Sanctuary
WWF	World Wide Fund for Nature

Executive Summary

1. Background

Bhutan's national finances have been supported by revenue from hydro business tax revenue and selling hydropower electricity. Revenue from selling electricity to India accounted for approximately 20% of national revenue in 2014. It is estimated that hydropower potential is 23,760MW, but the installed capacity of hydropower plants is approximately 1,600MW, which is about 7% of the potential. In consideration of this situation, the Royal Government of Bhutan (RGoB) has determined "Promotion of hydropower development and improvement of the power system" as an important program, and designated hydropower development as an important economic policy.

At present, based on the Power System Master Plan (PSMP) formulated in March 2004, 10,000MW of hydropower development is being implemented with assistance from Government of India (GoI). Since the revision of PSMP 2004, availability of the hydro-meteorological data and access to remote areas have improved. In addition, the necessity of business planning in consideration of economic and social impacts, and external conditions and the environment are changing greatly. In the view of these factors, revision of the PSMP is an urgent issue. It is also an urgent task to improve the capacity of the Department of Hydropower & Power Systems (DHPS) supervising the PSMP, because their capacity to review and update the PSMP according to changes in the environment and to formulate a comprehensive PSMP based on this is limited.

Under such circumstances, RGoB requested to revise the PSMP up to 2040 in consideration of the latest situation, including the power system network with neighboring countries, and improve the capacity of the DHPS.

The Project includes support for creating the PSMP 2040 and aims to improve the mid and long term planning capacity of DHPS staff for the PSMP.

2. Purpose

The purpose of the survey is:

i. To reassess the overall hydropower potential including the techno-economic potential of the country considering the availability of the detailed hydrological information & data based on the newly established hydrological network and advanced planning technologies.

ii. To ensure judicious identification and selection of the most optimal and promising projects and rank them in the order of viability by undertaking Multi Criteria Analysis (MCA) or other internationally acceptable methods.

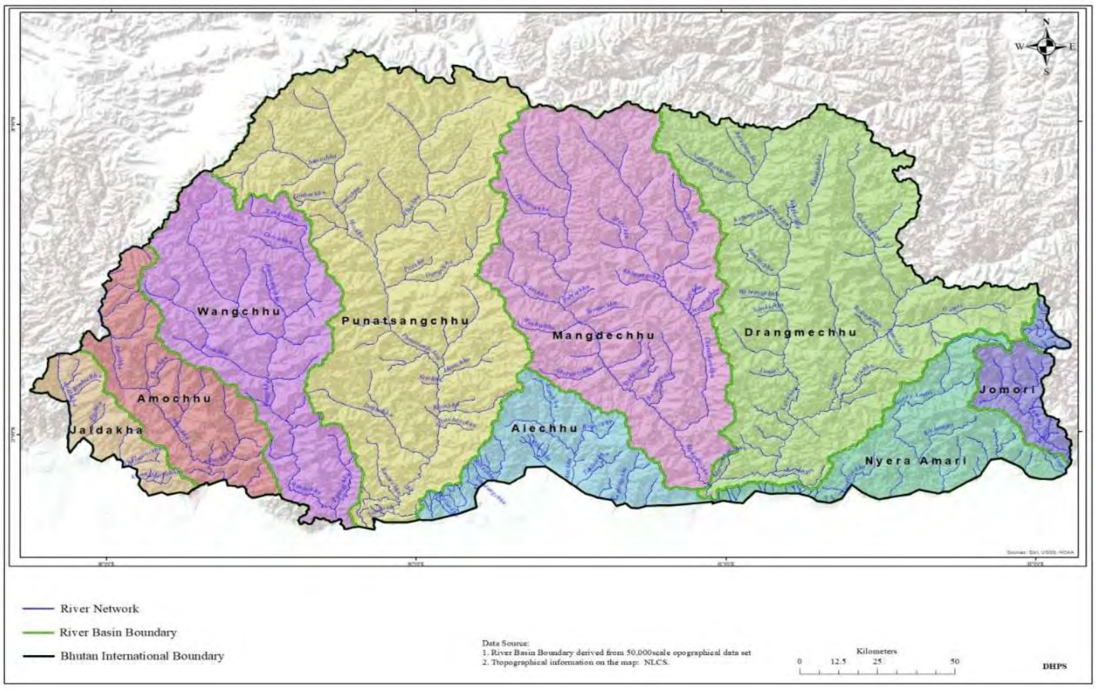
iii. To engage in effective consultative processes among the concernedstakeholders for identification, selection and development of a list of projects by 2040 for optimum utilization of river basin potentials based on market opportunities and nation's absorptive capacity.

iv. To build and enhance the institutional capacity to assess, plan, review, update and implement the PSMP.

3. Area of Study:

The Himalayan Kingdom of Bhutan is a landlocked country, which is bordered by China in the north and India to the south, east and west. It lies between latitudes 26.7°N and 28.4°N and longitudes 88.7°E and 92.2°E covering an area of 38,394km^2. Its landscape ranges from 100 masl in the sub-tropical plains in the south to 7,500 masl in the northern sub-alpine region. The average rainfall varies between 500mm and 2,000mm in the north to 2,000mm to 5,000mm in the south. The rivers carry large flows during the monsoon season while snow-fed flows during the dry season are significant. The river system is divided into five sub-basins. The principal rivers from west to east are the Amochhu, the Wangchhu, the Punatsangchhu/Sankosh and the Manas. All of the rivers drain into the River Brahmaputra.

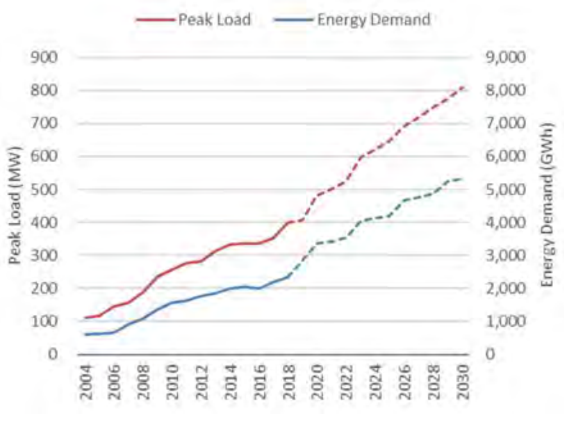
By virtue of its geographical location, the country is blessed with abundant hydropower potential. Hydropower has been the country's main engine of growth and the main source of revenue over the last three decades since the commissioning of the first mega project in 1986. It has driven economic growth and greatly boosted progress in meeting many of the country's social-economic development objectives contributing about 13% of GDP, 35% of exports and approximately 27% of national revenue (NSB, 2015). Considering the huge potential, developments of hydropower projects has been identified as one of the five economic jewels of the country.
The potential of hydropower was reassessed covering the entire country.



4. Power Demand Forecast

The maximum power demand was 399MW in 2018, but it is assumed that this will increase to 808MW in 2030. The annual electricity energy was 2,328GWh in 2018, but it is assumed that this will increase to 5,317GWh in 2030. The annual growth rate for 12 years until 2030 is estimated to be 7.1% on average. The annual load factor was 66.6% in the actual data from 2018, but it is assumed that this will gradually increase in the future, reaching 75.1% in 2030.

Growth in demand is attributable to an increase in demand in four industrial parks that are planned to be built in conjunction with the start of operation of the Punatsangchhu-I&II hydropower electric plants (HEPs) and Mangdechhu HEP, in addition to the general demand increase.



(Source: Power Data 2018, DHPS)

Figure 1 Domestic Power Demand Forecasts

5. Basic Data and Conditions for PSMP2040

(1) Power Sales to Neighboring Countries

The current power transaction price in India is on average about Rs. 4.0/kWh. Most of the power trading in India is electricity supplied from thermal power plants and it is thought that the transaction price will rise according to the rise in fuel prices. Assuming that the proportion of fuel costs is 70% of the electricity transaction price and the fuel cost will rise by 1.0% per annum for the next thirty years, the electricity transaction price will rise on average by about 12% over the 30 years. In other words, the average electricity trading fee for 30 years is assumed to be around Rs 4.5/kWh, and if electricity from Bhutan's hydropower can be provided at this price, it can compete equally with other power suppliers in India. Taking these points into consideration, the necessary expenses in India (Rs 0.3/kWh) are deducted, and it is estimated that an income of Nu. 4.2/kWh can be obtained when electricity generated by hydropower in Bhutan is sold for demand outside the country.

(2) Providing ancillary services

The values calculated based on the results in India and the results in ENTSO-E differ greatly, with the actual value in India being Rs. 1.7/kWh and that in ENTSO-E being Rs. 3.3/kWh. The actual value in India requires a relatively slow response of within 15 minutes. Hydropower can provide quick response for frequency control in seconds - higher than the actual value in India. Considering this point, the value of providing ancillary services to be used in this survey shall be Nu. 3.3/kWh (Rs. 3.3/kWh), which is the actual value in ENTSO-E.

(3) Value of Firm power

Since the supply capability that can be supplied throughout the year generally increases as Firm power increases, the value of Firm power is calculated as the extent to which the development of thermal power plants can be postponed. In Bhutan, there is no such effect of postponing the development of thermal power plants, but there is in neighboring countries such as India.

In Bhutan, along with an increase in Firm power, it is expected the value as international energy security that supply to domestic demand will be possible without depending on imports from India even if domestic electricity demand increases accordingly. Moreover, effects such as securing employment and revitalizing the domestic economy can be expected. Because it is difficult to quantify these merits, these are evaluated as the effect of postponing the development of thermal power plants in India.

The value at which Firm power increases will be evaluated as Nu. 9,775/kW, as an annual benefit.

(4) E-Flow

In this MP, at all project sites other than dam type sites, 10% of the drought flow rate is used for E-flow and economy is evaluated as the E-flow amount deducted from the electricity generated. When implementing a specific project, it is necessary to evaluate the impact on the ecosystem due to the decrease from the original river flow rate during the EIA, and to flow an E-flow that does not affect the ecosystem.

(5) Setting of designed Unit Discharge

As for the Plant Load Factor (PLF) of hydropower projects in Bhutan, while PLFs of the existing hydropower plants are 63% for Chhukha HPP and 54% for Tala HPP, most of the hydropower projects at the planning stage in Bhutan are set with a PLF of 45% to 50%. For the moment at this stage, PLF for site identification of potential hydropower sites was uniformly set as 50% in order to equally compare the project sites identified.

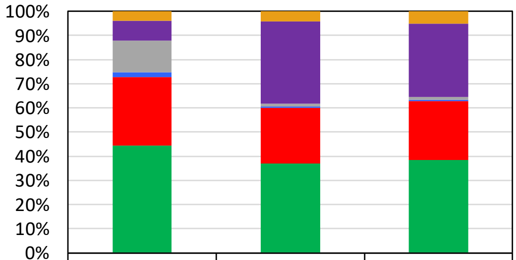
In order to easily calculate designed discharge once the catchment area is determined, the designed unit discharge was set for each river basin. At this potential site identification stage, PLF was set equal to the Flow Utilization Factor without consideration of plant stoppages. The designed unit discharge was calculated as the design discharge per km^2 of catchment area when its PLF is 50%.

6. Identification of Potential Hydropower Sites

The total number of potential sites is 155, installed capacity is 36.9GW, and design energy is 154.1TWh.

When the existing power plants at 6 sites, the earmarked projects at 13 sites, and 20 sites with an installed capacity of less than 25MW are excluded, 116 sites remain, with an installed capacity of 22.4GW.

Furthermore, there are 3 project sites (0.2GW) in which many resettlements are required and 44 project sites (8.6GW) in which all the project's components (dam, reservoir, waterway, powerhouse) are located within protected areas. These projects are deemed very difficult to develop. Excluding these sites, there remain 69 potential sites, totaling 13.6GW, 59.5TWh.



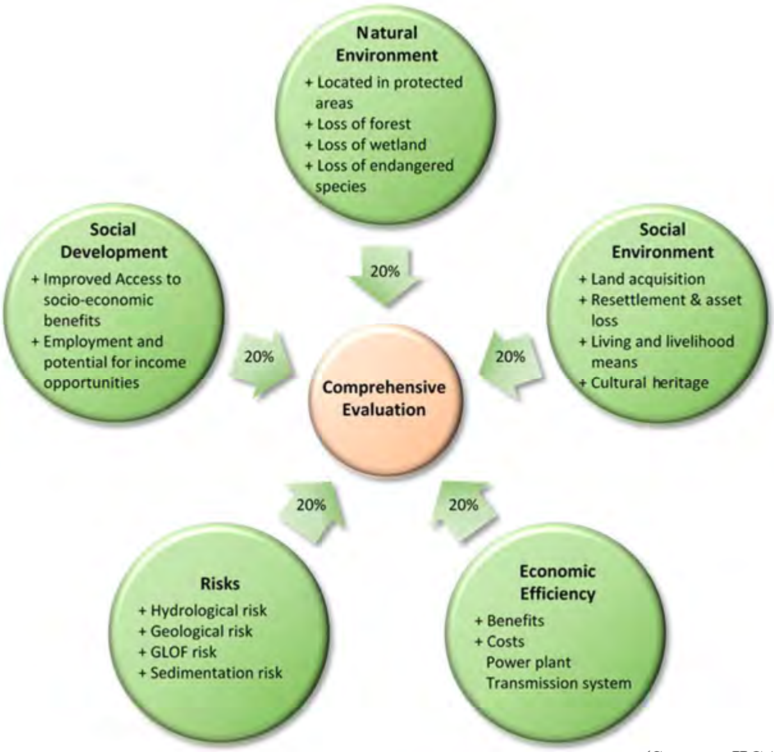
	Site NO.	Installed Capacity (MW)	Design Energy (GWh)
Existing	6	1,606	7,957
Earmarked	13	12,510	46,612
<25MW	20	381	1,671
Many relocations	3	202	884
Protected area	44	8,575	37,560
Longlist Sites	69	13,614	59,461
Total	155	36,888	154,145

(Source: JICA Survey Team)

Figure 2 Breakdown of Potential Sites

7. Environmental Assessments

In selecting promising sites (Short listed sites) from all potential sites, based on the purpose of an SEA, a comparative evaluation of all sites was conducted in consideration of not only economic efficiency but also environmental aspects. Specifically, using the MCA (Multi Criteria Analysis) method, each site is evaluated multilaterally and compared, and the development priority of each site is determined. As shown below, the criteria for evaluation are divided into five items, which are environmental considerations (natural and social), social development (positive impact), economic aspects, and risks such as geological and hydrological aspects.

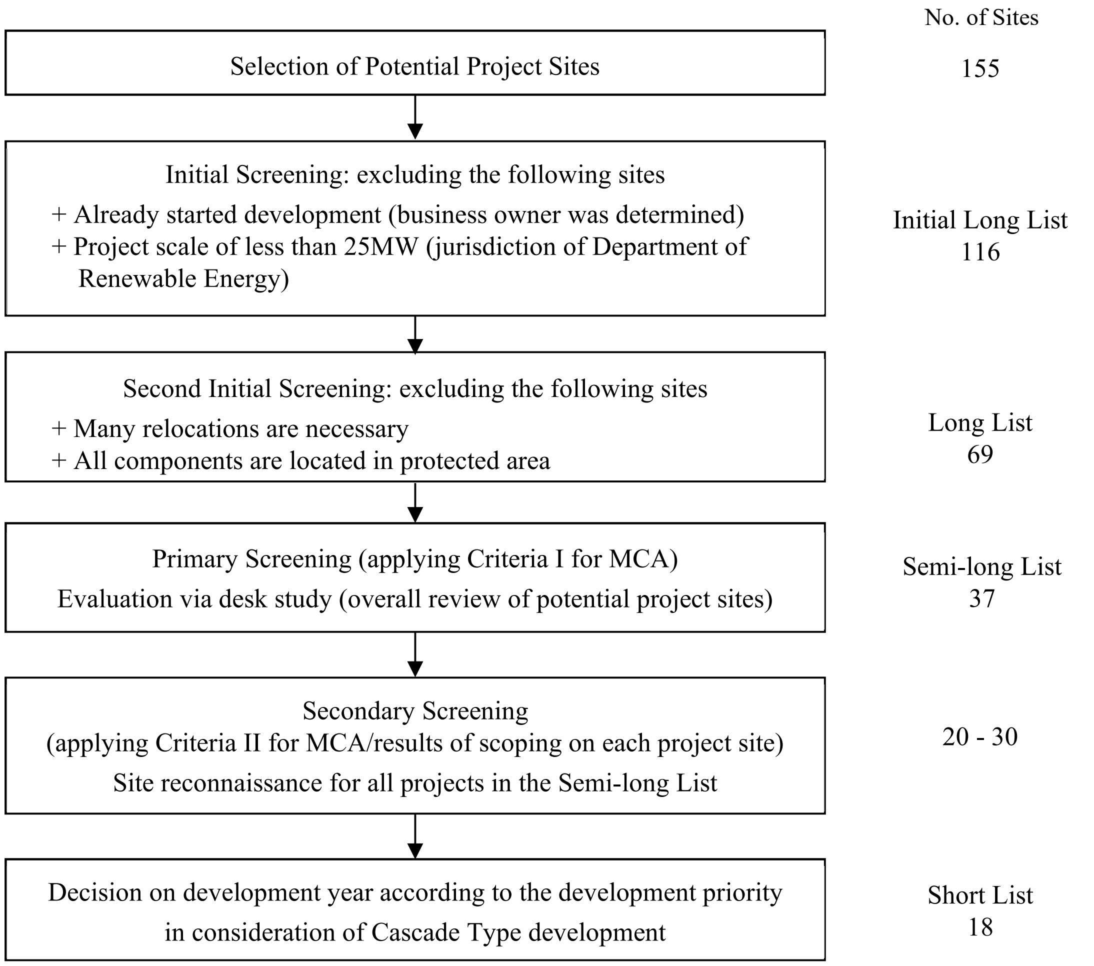


(Source: JICA Survey Team)

Figure 3 Comprehensive Evaluation Method for each site

8. Evaluation of the Potential Project and Ranking

Screening was carried out for the potential project sites in line with the following work flow.



(Source: JICA Survey Team)

Figure 4 Screening Method

The primary screening was carried out to screen out the sites with lower development priority. Since 69 sites are evaluated via desk study in the primary screening, it is impossible to accurately reflect the site conditions. Accordingly, criteria I for MCA are basically those that can be judged on the desk and the evaluation is put on hold for items for which the presence or absence of a problem cannot be confirmed. Based on the evaluation results in the primary screening, 37 sites are selected as candidate sites for site reconnaissance.

Since the secondary screening is evaluated after checking the site conditions for every project via site reconnaissance, criteria II for MCA are to be those that can take into account the detailed conditions of the site. Based on the evaluation results in the secondary screening, 18 sites are selected as Short listed sites.

9. Proposal on Power Development Plan

The development plan for the promising 18 sites extracted by this MP is shown below.

Table 1 Development Plan for the promising Sites extracted by this MP

	Project code	Name of Project	Installed Capacity (MW)	Annual Energy (GWh)	Construction cost (million Nu)			Unit cost (Nu/kW)	Unit cost (Nu/kWh)
					Power plant	T/L	Total		
2031-35	A-8	Dorokha	550	2,407	46,103	4,341	50,444	91,717	21.0
	C-10	Chamkharchhu-II	414	1,814	34,377	4,251	38,628	93,303	21.3
	P-30	Pinsa	153	672	8,947	1,596	10,543	68,911	15.7
		Total	1,117	4,893	89,427	10,188	99,615		
2036-40	A-5	Tingma	783	3,428	37,491	5,307	42,798	54,659	12.5
	M-6	Jongthang	227	995	22,878	2,913	25,791	113,617	25.9
	G-14	Uzorong	840	3,678	78,776	5,298	84,074	100,088	22.9
		Total	1,850	8,101	139,145	13,518	152,663		
2041-50	P-17	Tseykha	215	943	21,463	2,340	23,803	110,712	25.2
	P-26	Thasa	706	3,094	79,615	2,852	82,467	116,809	26.7
	P-29	Kago	58	255	5,116	988	6,104	105,239	23.9
	P-34	Darachhu	89	389	8,650	1,427	10,077	113,225	25.9
	P-35	Dagachhu-II	71	311	7,276	1,250	8,526	120,087	27.4
	M-11	Wangdigang	502	2,200	49,895	2,877	52,772	105,124	24.0
	M-17	Buli	69	302	6,070	1,010	7,080	102,609	23.4
	C-7	Chamkharchhu-IV	451	1,974	37,916	4,416	42,332	93,863	21.4
	K-13	Minjey	673	2,948	81,444	5,941	87,385	129,844	29.6
	G-10	Gamrichhu-2	108	471	10,552	1,778	12,330	114,168	26.2
	G-11	Gamrichhu-1	150	656	13,642	1,739	15,381	102,541	23.4
	N-1	N.A. Kangpara (G)	71	312	6,134	1,814	7,948	111,939	25.5
		Total	3,163	13,855	327,773	28,432	356,205		
		All Total	6,130	26,849	556,345	52,139	608,484		

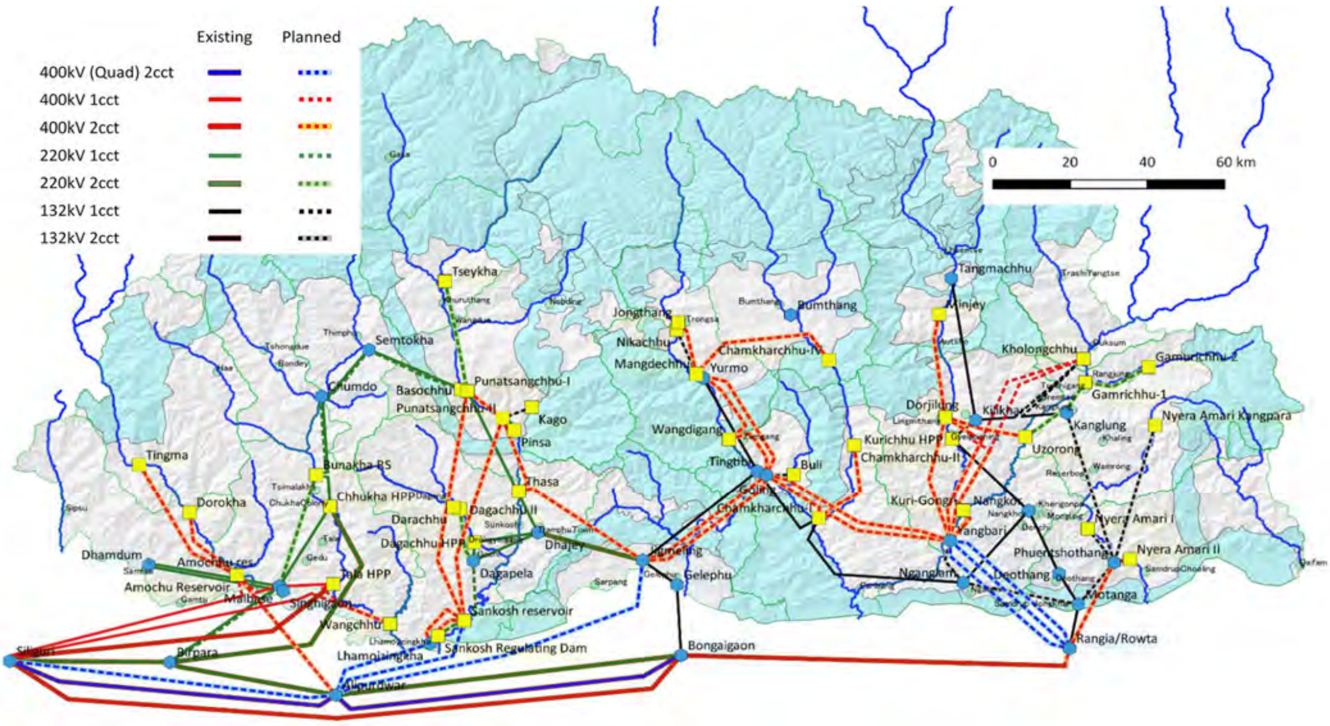
Note: The construction cost is an estimated value calculated using the construction cost calculation kit created in this MP.

(Source: JICA Survey Team)

Although this is the same as the development time for the already decided sites at the planning stage, which are out of scope of this MP, three sites with high development priority, identified as a result of the MCA evaluation, shall be developed from 2031 to 2035.

10. Grid Master Plan

Based on the above power development plan, the future concept of the grid system (2050) is as follows. Field surveys were conducted on the power transmission lines for short listed sites and pooling stations. The validity of the routes and location points, and the necessity of route changes, etc. were confirmed.



(Source: JICA Survey Team)

Figure 5 Future Concept of the Grid System (2050)

From 2035 onwards, in addition to the power transmission lines for each project, second 220kV transmission lines between Punatsangchhu-I to Bunakha and Malbase to Birpara will be required. In addition, the 400kV transmission line (Quad) between Yangbari and Rangia is insufficient, with two routes/four lines. Three routes/six lines are required.

11. Financial and Economic Analysis

The financial analysis of a hydropower generation project is presented taking the Pinsa site as a model case. Various implementation modalities are compared in the analysis, such as the existing G-G scheme in cooperation with GOI, ODA scheme using donor loans, PPP scheme with private sector investment, etc.

A cash flow projection is developed for each implementation modality to estimate all cash in-flows and out-flows of RGoB in each case. Net present value (NPV) of the cash flows has been calculated with a 10% discount rate for comparison as shown in Table 2. Also, RGoB's NPV has been estimated in the case of a three-year construction delay as well as with the assumption of a 6% exchange risk premium for foreign currency loans.

Table 2 Results of Financial Analysis (Comparison of RGoB Total Net Cash Flow)

NPV (2026-2061) @ 10% DR (BTN million)	Funding Requirement for RGoB During Construction	Total Cash Flow of RGoB (Net Present Value)						
		Base Case	3 Year Construction Delay			PSIF and ODA loan for RGoB (+ 6.0% exchange risk premium)		
		NPV	NPV	Difference		NPV	Difference	
1-1: G-G (RGoB 100%)	None	9,922	6,102	-3,819	-38%	-	-	-
1-2: G-G (JV Case: RGoB 50%)	None	4,961	3,051	-1,910	-38%	-	-	-
2: ODA	2,065	11,756	7,667	-4,089	-35%	9,101	-2,655	-23%
3: PPP	2,065	7,558	5,097	-2,460	-33%	6,375	-1,183	-16%
4-1: IPP (Energy Royalty 12 ~ 18%)	None	3,568	2,738	-831	-23%	-	-	-
4-2: IPP (Arun III case)	None	8,609	6,662	-1,947	-23%	-	-	-
4-3: IPP (UK case)	None	7,974	5,852	-2,121	-27%	-	-	-

(Source: JICA Survey Team)

In the ODA scheme, the NPV of RGoB's cash flows has been estimated as 11,756 million Nu., the largest among other schemes reflecting the concessional conditions of an ODA loan, especially its repayment period, which can be as long as 30 years including the grace period. However, this decreases to 9,101 million Nu. when assuming an exchange risk premium of 6.0% per annum for the foreign loan. The IPP scheme features benefits for RGoB in that there is virtually no obligation for RGoB to provide its own funds for initial investment or to make debt repayments during operation because it does not require equity investment by RGoB and all financing requirements must be secured by the private investors. For IPP Scheme – 2, where RGoB benefits from 21.8% free energy in addition to the royalty revenue, the NPV of RGoB amounts to 8,609 million Nu. It is not a big difference compared to the G-G scheme.

12. Recommdations and Wayforward

Recommendations and load map are proposed. It is necessary for DHPS to tackle the issues that are expected to be encountered in advancing this MP in the future.

(1) Feasibility Studies for Promising Sites

(2) Diversification of Off-taker and Fund Source
(a) Correct understanding of Indian grid operation rules
(b) Consultation with Off-takers (Bangladesh, Nepal etc.)
(c) Strengthening of interconnected transmission lines

(3) Steady promotion of Grid Expansion Plan based on Future Concepts
(a) Promotion of grid expansion plan based on future concepts
(b) Study on transmission and substation facilities' standard designs
(c) Enhancement of transmission facilities to sell electricity to neighboring countries
(d) Measures to improve the reliability of Thimphu city power supply
(e) Facility design for Yangbari PS

(4) HR Capacity Building

Chapter 1. Introduction

1.1 Background

Bhutan's national finances have been supported by revenue from hydro business tax revenue and selling hydropower electricity. Revenue from selling electricity to India accounted for approximately 20% of national revenue in 2014. It is estimated that technically feasible hydropower potential is 23,760MW, but the installed capacity of hydropower plants is approximately 2,326MW, which is about 10% of the technical potential. In consideration of this situation, the Royal Government of Bhutan (RGoB) has determined "Promotion of hydropower development and improvement of the power system" as an important program, and designated hydropower development as an important economic policy.

At present, based on the Power System Master Plan (PSMP) formulated in March 2004, 10,000MW of hydropower development is being implemented with assistance from Government of India (GoI). Since the revision of PSMP 2004, availability of the hydro-meteorological data and access to remote areas have improved. In addition, the necessity of business planning in consideration of economic and social impacts and the environment are changing greatly. In the view of these factors, revision of the PSMP is an urgent issue. PSMP needs to be reviewed and updated as the environment changes. However, the Department of Hydropower & Power Systems (DHPS), which supervises PSMP, has limited ability to formulate comprehensive PSMP. Therefore, it is also an urgent task to improve the capacity of the DHPS.

Under such circumstances, RGoB requested to revise the PSMP up to 2040 in consideration of the latest situation, including the power system network with neighboring countries, and improve the capacity of the DHPS.

The Project includes support for creating the PSMP 2040 and aims to improve the mid and long term planning capacity of DHPS staff for the PSMP.

1.2 Purpose

The purpose of the survey is:

v. To reassess the overall hydropower potential including the techno-economic potential of the country considering the availability of the detailed hydrological information & data based on the newly established hydrological network and advanced planning technologies.

vi. To ensure judicious identification and selection of the most optimal and promising projects and rank them in the order of viability by undertaking Multi Criteria Analysis (MCA) or other internationally acceptable methods.

vii. To engage in effective consultative processes among the concernedstakeholders for identification, selection and development of a list of projects by 2040 for optimum utilization of river basin potentials based on market opportunities and nation's absorptive capacity.

viii. To build and enhance the institutional capacity to assess, plan, review, update and implement the PSMP.

1.3 Area of the Survey

The Himalayan Kingdom of Bhutan is a landlocked country, which is bordered by China in the north and India to the south, east and west. It lies between latitudes 26.7°N and 28.4°N and longitudes 88.7°E and 92.2°E covering an area of 38,394km^2. Its landscape ranges from 100 masl in the sub-tropical plains in the south to 7,500 masl in the northern sub-alpine region. The average rainfall varies between 500mm and 2,000mm in the north to 2,000mm to 5,000mm in the south. The rivers carry large flows during the monsoon season while snow-fed flows during the dry season are significant. The river system is divided into five sub-basins. The principal rivers from west to east are the Amochhu, the Wangchhu, the Punatsangchhu/Sankosh and the Manas. All of the rivers drain into the River Brahmaputra.

By virtue of its geographical location, the country is blessed with abundant hydropower potential. Hydropower has been the country's main engine of growth and the main source of revenue over the last three decades since the commissioning of the first mega project in 1986. It has driven economic growth and greatly boosted progress in meeting many of the country's social-economic development objectives contributing about 13% of GDP, 35% of exports and approximately 27% of national revenue (NSB, 2015). Considering the huge potential, developments of hydropower projects has been identified as one of the five economic jewels of the country.
The potential of hydropower was reassessed covering the entire country.

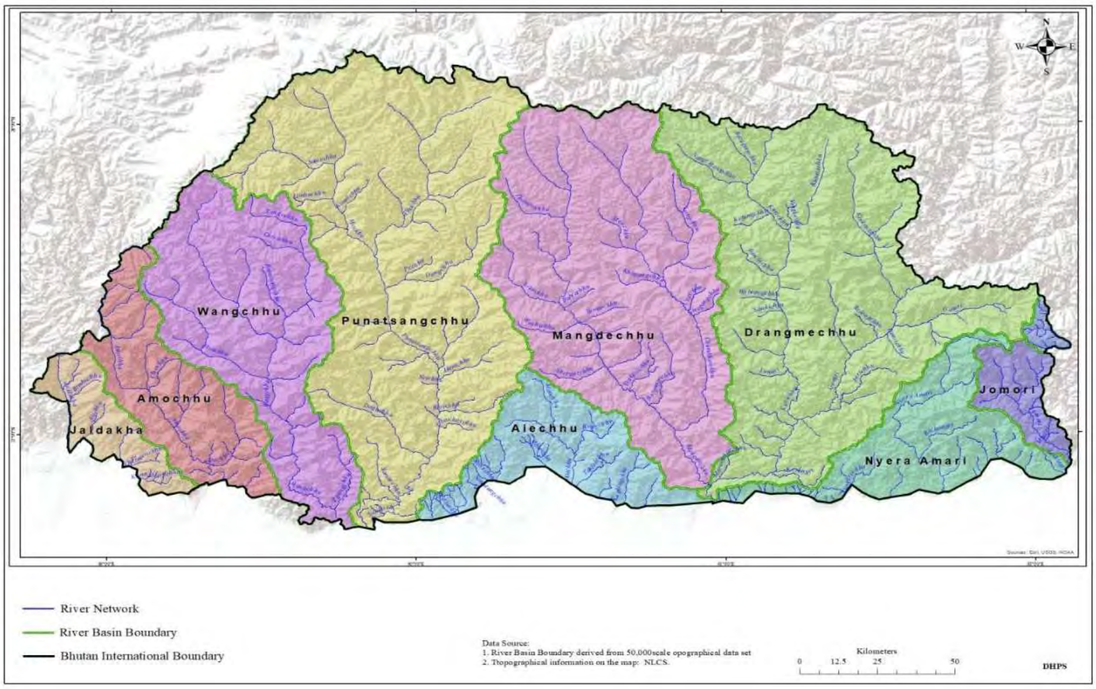


Figure 1-1 Area of the Survey

1.4 Participating Power Sector Agencies

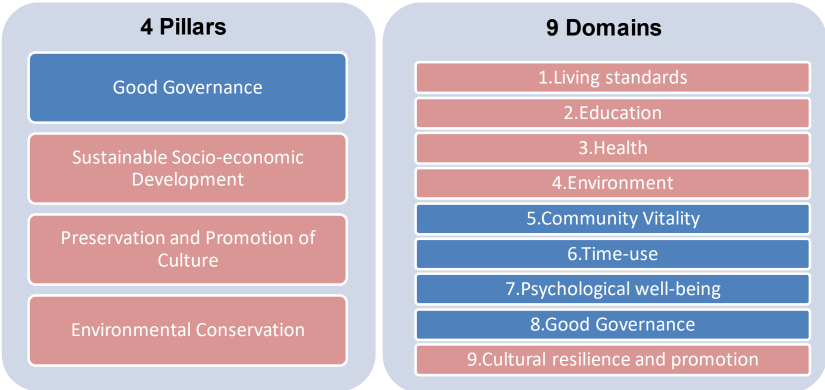
- DHPS, MoEA: Department of Hydropower & Power Systems
- DRE, MoEA: Department of Renewable Energy
- BEA: Bhutan Electricity Authority,
- BPC: Bhutan Power Corporation Ltd., and
- DGPC: Druk Green Power Corporation Ltd.

Chapter 2. Energy Policy in Bhutan

2.1 National Policy

(1) Gross National Happiness (GNH)

RGoB has set GNH as a fundamental policy for national development. It consists of four Pillars and nine domains. Of these, three Pillars (Sustainable Socioeconomic Development, Preservation and Promotion of Culture, and Environmental Conservation) and five domains (1. Living standards, 2. Education, 3. Health, 4. Environment and 9. Cultural resilience and promotion) are concepts that this research should take into account. It is necessary to consider these pillars and domains as items to be adopted when evaluating potential hydroelectric power sites.



Note: Items in red are those presently adopted when DHPS evaluates potential hydroelectric power sites
(Source: JICA Survey Team)

Figure 2-1 Framework of Gross National Happiness

(2) A Vision for Peace, Prosperity and Happiness (Bhutan 2020)

"A Vision for Peace, Prosperity and Happiness" (hereinafter Bhutan 2020) was formulated in April 1999, for the first time in Bhutan, to indicate the country's long-term national direction up to 2020. While concrete plans were explicitly demonstrated in the Five Year Plan in sequence, Bhutan 2020 indicated the necessity of a long-term vision for the direction the nation should follow and the speed of development, in order to promote consistency among sectors and focus on prioritized national targets.

In Bhutan 2020, hydro power was recognized in the same competitive sector as the mineral resource processing industry (ferrosilicon, calcium carbide, cement, and so on), horticultural development, non-agricultural employment, rural industrialization, niche markets, small and home manufacturing and tourism. As for hydro power development, 400MW of total capacity was already in operation and 1,200MW was undergoing planning and construction at that time, and additional development of 2,000MW by the end of 2012 (the last year of the 10th Five-Year Plan) and 2,500MW by the end of 2017 (the last year of the 11th Five-Year Plan) were indicated as milestones according to the existing Hydropower Development Master Plan (1990 to 2010). Preparations are currently under way to formulate the next long-term vision.

(3) Five Year Plan (FYP)

In Bhutan, the Five Year Plan (hereinafter FYP) has been formulated since 1961 and is regarded as the most important national plan. In the 9th FYP period (2002-2007), approximately 9% of the GDP growth rate in the five-year average was achieved. During the 10th FYP period (2008-2012), in 2011, the GDP growth rate reached 11.77%. Furthermore, in the 11th FYP (2013-2018), a goal has been set to maintain a high GDP growth rate of 9 to 10% up to 2018. In all FYPs, reducing poverty was set as a higher ranking goal, followed by promotion of economic growth while addressing regional disparities. In particular, it can be said that power development as a national strategy has been playing a vital role, when considering the current situation with the expansion of power exports to India, by promoting large-scale hydropower development relying greatly on national income, together with the promotion of rural electrification. This practice has been supporting economic growth.

The 12th FYP (2018-2023) was approved in a joint Cabinet and GNHC meeting on December 7, 2018. The 12th FYP period commenced from November 1, 2018 and will end on October 31, 2023. In the 12th FYP, the construction of four hydropower stations is scheduled to be completed, and the capacity of hydropower generation enhanced from 1,606MW to 4,664MW. Hydropower is set to contribute in two areas, Economic diversification and Water security, among sixteen National Key Results Areas (hereinafter NKRA).

(4) Economic Development Policy 2016 (EDP 2016)

Economic Development Policy 2016 (hereinafter EDP 2016) was formulated in June 2016, which set goals for economic development, including such targets as the achievement of 100% self-sustaining economic development and a high employment rate level (97.5%) by 2020, covering a very wide range of fields, including energy, industry, trade, tourism, mining, construction, education, health, information, agriculture, transportation, water source management, etc. Strategic priority areas listed in the EDP involve promotion of the "Five Jewels," which were five sectors regarded as core growth areas from the potential and social influence points of view: hydropower, agriculture, home and small manufacturing, tourism and mining.

Hydropower was the primary source of earning, which reached 19.1% of national income in 2014 to 2015, and was set as a strategic national resource in order to achieve sustainable financial independence. From the standpoint of economic development policy, EDP 2016 suggested making best efforts to achieve at least 5,000 MW of hydropower development by 2020. Furthermore, EDP 2016 set the goal of Bhutan becoming a knowledge center for hydropower development and related services both in the region and globally.

(5) Project for Formulation of Comprehensive Development Plan in Bhutan 2030

On September 30, 2016, JICA signed a Record of Discussions (hereinafter R/D) to start a technical cooperation project regarding the formulation of Comprehensive Development Plan in Bhutan 2030 with the Gross National Happiness Commission (hereinafter GNHC), in the presence of the Ministry of Works & Human Settlement (hereinafter MoWHS).

While Bhutan is engaged with its development policy, having set some goals that aim for development that is in a properly balanced state between farming areas and urban cities, in recent years the mostly young population has tended greatly to migrate from the farming areas in the east or south to the urban cities in the west, like the capital, Thimphu, and the international gate city Paro. Therefore, in the farming areas, the collapse of local communities, with expanding fallow lands and a lack of persons to provide public services due to the decreasing young population, is becoming a social issue. On the other hand, industries other than agriculture are not fully developed yet in Bhutan, so the number of regular employees is insufficient in the urban cities and social issues related to youth unemployment have arisen. In order to solve the issues associated with the imbalance of population distribution at the national level, a comprehensive development plan at the national level is required.

This Project is aiming to formulate a Comprehensive Development Plan in Bhutan, targeting 2030, and to help maximize GNH by promoting a plan that is well-balanced between urban cities and rural areas. The Project was being implemented with a cooperative research period between January 2017 and May 2019. The research activities include understanding the current status in the research areas and analyzing the issues related to development. Formulation of the development vision, development strategy, and the Comprehensive Development Plan were carried out. The development guide by sector includes potential growth sectors such as hydroelectric generation, the mining industry, the tourism industry, and small scale industry.

Shifting to an all-electric society independent of oil by using hydropower, which is the main industry in Bhutan, has contributed to sustainable development in an effective manner. In Bhutan, CO_2 emissions in the transportation sector are larger than in other sectors. Therefore, it is proposed that, in order to create a transportation system with advanced technologies, a drone-based freight transportation system is introduced and electric vehicles become commonly used. Furthermore, a roadmap, including quick charging stations, is described in order to promote the introduction of electric vehicles.

2.2 Energy Policy

(1) Power System Master Plan 2004 (PSMP2004)

Power System Master Plan 2004 (hereinafter PSMP2004) was part of the Water Resources Management Plan and an update to the Power System Master Plan 1993-4, Bhutan, formulated by Norconsult AS, with financial support from Norway. It was issued as a Ministerial Order.

(2) Bhutan Sustainable Hydropower Development Policy 2008 (BSHDP 2008)

Bhutan Sustainable Hydropower Development Policy 2008 (hereinafter BSHDP 2008) was issued as a Government Order on June 26, 2008. The main purpose of BSHDP was to increase the government's revenue by developing hydropower, and to promote hydropower by utilizing the Inter Governmental Model (hereinafter IG Model) jointly developed by India and Bhutan, and the Diversifying financial procurement and development model, including private investment. Though not explicitly mentioned as such, it was considered to be a policy regarding private sector participation, stipulated in Article 49 of the Electricity Act of Bhutan in 2001. It mainly focused on Private Finance Initiatives (PFI), anticipating Build, Own, Operate and Transfer (BOOT). As indicated in EDP 2016, the policy is currently being revised to strengthen government involvement by abolishing IPP (100% private investment, which was allowed in BSHDP 2008) and adopting PPP or other systems instead.

(3) National Transmission Grid Master Plan for Bhutan 2012 (NTGMP 2012)

The National Transmission Grid Master Plan for Bhutan 2012 (hereinafter NTGMP 2012) was prepared by the Central Electricity Authority (hereinafter CEA) of India as a Consultant. In PSMP 2004, the development goal was about 4GW along with Vision 2020, and the national goal was to realize 10GW of hydropower development by 2020. With the transition of these power development goals, it was necessary to revise the national transmission grid development plan, so RGoB engaged the CEA as a consultant to formulate the NTGMP in December 2009. Specifically, NTGMP 2012 suggested a transmission grid development plan by 2020 along with a 10GW power development plan, and the plan by 2030 with the assumption that all 24GW of potential power stations would be developed.

In addition to changes in the plans so far, and reflecting delays in the current construction plans, the NTGMP 2012 was updated to NTGMP 2018. The NTGMP 2018 indicates a transmission grid development plan with five-yearly snapshots up to 2040, and the plan beyond 2040.

(4) Domestic Electricity Tariff Policy 2016 (DETP 2016)

The Domestic Electricity Tariff Policy 2016 (DETP 2016) was formulated and issued as a Government Order in March 2016. As a fundamental policy for domestic tariff calculations, tariffs on generation, transmission and distribution are on the Cost plus model basis, and the cost includes operation and maintenance (O&M) costs, capital and financial costs, depreciation, approval and license application fees, various taxes, power losses and power purchase costs. DETP 2016 also provides guidance on how to treat Royalty Energy, Grants, Subsidies etc. other than the abovementioned domestic tariff calculations. It also determines the basic cycle of tariff revisions to be at three year intervals.

(5) Tariff Determination Regulation 2016 (TDR 2016)

Based on DETP 2016, Tariff Determination Regulation 2016 (hereinafter TDR 2016) was formulated by BEA, and issued as a Regulatory Order in April 2016. TDR 2016 is only applicable to domestic generation, transmission, distribution and power system operation - not to power imports and exports, nor power trading by PPA. TDR 2016 indicates specific formulae according to the cost calculation policy stipulated in DETP 2016, and determines the procedure for tariff applications by business operators.

(6) Bhutan Energy Data Directory 2015

The Bhutan Energy Data Directory 2015 analyzes the energy supply, the energy demand and the energy balance up to 2030, via a sectorial approach, based on a Business-as-usual scenario and Energy efficient scenario. As the energy data directory mainly revolves around the energy demand and supply in the priority sectors, it also takes into consideration the scattered, but developing usage and potential of renewables like solar, wind and waste. The Department of Renewable Energy has updated the Energy Data Directory 2005 with financial support from the Norwegian Government under the Energy+ Partnership Program administered by the Asian Development Bank.

(7) Rural Electrification Master Plan 2005

Rural Electrification Master Plan 2005 was formulated by international engineering consultants Nippon Koei, with support from JICA and implemented a Rural Electrification (loan aid, 2007-2012) and Rural Electrification Promotion Project (Phase I and Phase II) (2008-2014) in order to promote rural electrification.

(8) Alternative Renewable Energy Policy 2013 (AREP 2013)

The Alternative Renewable Energy Policy (hereinafter AREP 2013) was regarded as the Renewable Energy Policy indicated in BSHDP 2008. AREP 2013 mainly covers the following areas:

- Stand-alone power systems
- Dispersed power systems
- Renewable Energy (RE) connected to the grid
- Hybrid petroleum-alternative fuel combined with biofuel and power

AREP 2013 also sets the development goal of at least 20MW via renewable power other than small hydro by 2025. The breakdown is as follows:

- [Generation sector] photovoltaic power, wind power and biomass: 5MW each
- [Energy sector] biomass and solar thermal: 3MW each, and
- [Transportation sector] petroleum-alternative 1,000kL (equivalent to 110GWh); petroleum alternative fuel usage by 20% of public cars and 10% of privately-owned cars.

In addition, AREP 2013 prescribes the development mechanism for hydropower of less than 25MW, and the enactment of the Feed-in Tariff (FIT) by BEA.

(9) Renewable Energy Master Plan 2016 (REMP 2016)

Renewable Energy Master Plan 2016 (hereinafter REMP 2016) was formulated as part of Renewable Energy Resource Assessment Report (hereinafter RERAR) by DRE with assistance from ADB. RERAR covered the calculation stages up to the Theoretical Potential of renewable energy and Restricted Development Potential, but did not cover the evaluation stages up to Economic Potential and Useable Potential necessary to be implemented thereafter. With respect to hydropower potential, the Theoretical Potential was calculated with an evaluation which uses the head and the flow for every 2km of all of the rivers, and the Restricted Development Potential was calculated by excluding restricted potential considering environmental aspects etc.

(10) Renewable Energy Resource Assessment Report

The Renewable Energy Resource Assessment Report was completed in October 2016. As Bhutan has abundant hydropower resources, the power source is dominated by large-scale hydropower. In the case that Bhutan only relies on hydropower as its power source, however, there can be an energy security risk influenced by seasonal and climate change as the energy generated by hydropower depends on river flow. In order to address this issue, it is necessary to accelerate the development of large-scale hydropower, as well as to establish diversified power sources. This Report refers to potential evaluation for hydropower in Bhutan (less than 25MW), wind power, photovoltaic power, solar thermal hot-water-supply and biomass generation.

(11) Hydropower Development Strategy Report

A hydropower committee was set up by the Government of Bhutan to develop a strategy policy in May 2017, and this formulated the Hydropower Development Strategy Report. Bhutan has limited natural resources, but it is expected that a lot of hydropower plants will be developed because the country has abundant hydro potential. However, large and mega projects are faced with serious technical problems, extended delays and huge cost overruns. Under these circumstances, in order to proceed with the forthcoming hydropower development in a strategic way, it describes the many lessons which Bhutan has learned through hydropower development over 40 years, such as the importance of hydropower development to the country, information on the energy markets in India, Bangladesh, Nepal, etc., and the background to the development with India.

2.3 Organization of Energy sector and Power sector

The government organizations and major private companies in Bhutan related to the energy sector, and the roles played by each organization are described in this section. The Department of Power under the then Ministry of Trade and Industry was in charge of all tasks regarding the power sector before June 2002. The Ministry of Trade and Industry was renamed as the Ministry of Economic Affairs and the functions and roles of the previous Department of Power were divided in three – the Department of Energy, which took over policy and planning; Bhutan Power Corporation Limited (BPC), which inherited transmission and distribution business; and Bhutan Electricity Authority (BEA), which took over regulation duties for power business - reflecting the Electricity Act legislation in 2001. As for generation business, three power stations, Chhukha, Basochhu and Kurichhu, were operated, which were already split up at the time. These separate companies were merged into one newly-set up generation, operation and maintenance company, Druk Green Power Corporation Limited (DGPC), in January 2008. A summary of the related organizations is given below.

2.3.1 Government Organizations

(1) Ministry of Economic Affairs (MoEA)

The Ministry of Economic Affairs (MoEA) is the competent authority in charge of the energy and power sector, and the Minister of Economic Affairs has the following powers and roles according to the Electricity Act in 2001:

i) to determine fundamental policies, goals and strategies regarding the power industry,
ii) to approve plans for power system development,
iii) to determine electricity tariffs and to formulate fundamental policies on power supply,
iv) to formulate policies on the standards of customer service and power suppliers,
v) to formulate policies on the promotion of energy and power supply for the poor and the vulnerable,
vi) to approve license fees,
vii) to approve the business plans and budget of BEA,
viii) to formulate policies to address power shortages,
ix) to approve the code of conduct and regulations of BEA,
x) to formulate policies on private participation,
xi) to authorize compulsory expropriation of land and/or water necessary to implement business with regard to business licensees, and
xii) to implement other tasks as stipulated in the Electricity Act 2001.

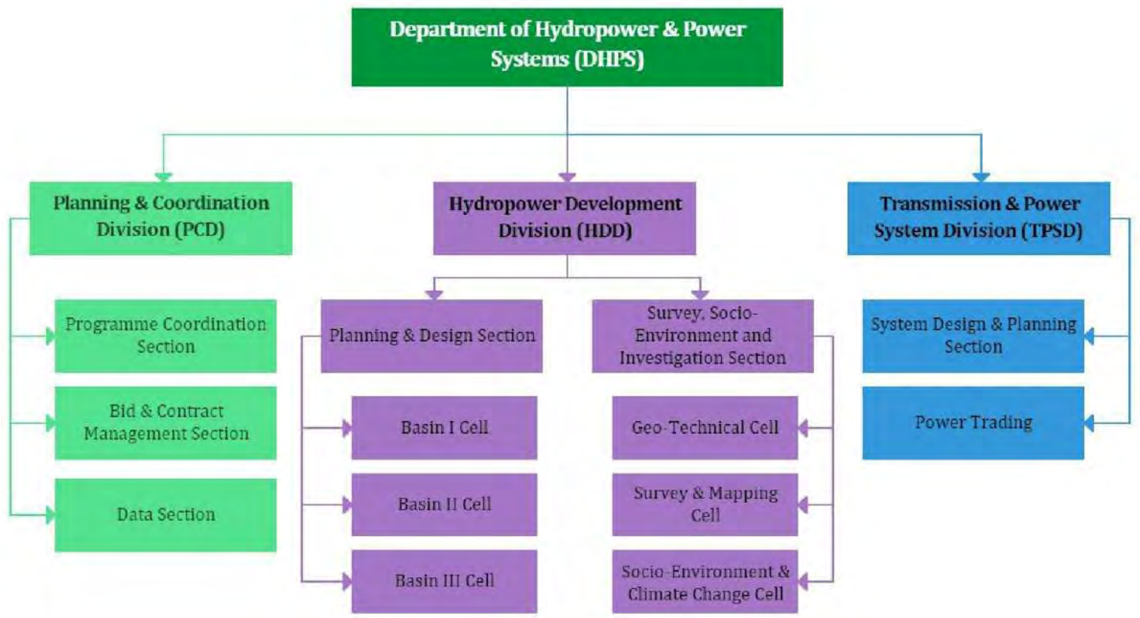
There are currently eight Departments in MoEA where DHPS and DRE are in charge of power administration.

(a) Department of Hydropower & Power Systems (DHPS)

The Department of Hydropower & Power Systems (DHPS) under the MoEA is responsible for developing the policies and plans for the development of hydropower and associated power systems. The functions of the Department are to:

- Be the Apex body for implementation of this policy. Formulate national policies, plans, programmes and guidelines related to sustainable development, efficient utilization and management of Hydropower and power systems in the country;
- Serve as the Central Coordination Agency and the Focal point of the Royal Government on all matters related to Hydropower and power systems;
- Responsible for planning of security of electricity supply, national transmission grid network and cross-border electricity trading;
- Oversee, monitor and evaluate the implementation of plans, programmes and projects related to hydropower, transmission and cross-border electricity trading;
- Provide techno-economic and budgetary clearance on all major projects and programmes related to hydropower, transmission and cross-border electricity trading before implementation;
- Be responsible for all bilateral and multilateral issues on hydropower, transmission and cross-border electricity trading; and
- Sign and enforce Concession Agreements (CA), over-sight over Power Purchase Agreements (PPA) and negotiate export tariffs for bilateral/multilateral projects;

Figure 2-2 shows DHPS' organizational structure.



(Source: DHPS Webpage)

Figure 2-2 DHPS Organizational Structure

(b) Department of Renewable Energy (DRE)

The Department of Renewable Energy (hereinafter DRE) is responsible for authorizing power companies to develop rural electrification plans, small-scale/mini/micro hydropower (less than 25MW), and non-conventional renewable energy resources (including expansion and modification). DRE is also in charge of formulating the framework and policies for the feed-in tariff.

(2) Bhutan Electricity Authority (BEA)

Bhutan Electricity Authority (BEA) was established in July 2002 according to the Electricity Act 2001. The operations and roles of BEA are stipulated in Articles 7 to 17 of the Electricity Act 2001, in which the following four items are described as major roles:

- to formulate and implement regulations, codes of conduct and standards regarding technology, safety and business operations of the power sector,
- to formulate general principles and procedures for tariff calculation, subsidies for domestic tariffs, and financial regulations,
- to issue and oversee licenses, and
- to formulate the procedure for dispute settlement when implementing power-related law.

According to the Electricity Act 2001, BSHDP 2008 stipulated that project companies are to acquire construction and generation licenses (except for less than 500kW projects) from BEA. The Electricity Act 2001 set a limit on the validity of the licenses to no more than thirty years in all cases.

(3) Ministry of Agriculture and Forests (MoAF)

The predecessor of the Ministry of Agriculture and Forests (hereinafter MoAF) was set up in 1985, in order to properly manage natural resources and food. In organizational restructuring in 2009, the forest division under the Department of Forests was integrated and the Department of Forest and Park Services (hereinafter DoFPS) was newly established under MoAF. The main feature of ecosystem conservation in Bhutan is the existence of nature reserves, which cover 51.44% of the country. Reserves are classified into four categories: National Park, Wildlife Sanctuary, Strict Nature Reserve and Biological Corridor. The zoning within a reserve is determined according to the Zonation Guideline formulated in 2013. A new zoning policy has recently been announced, so work to readjust the boundaries of nature reserves is being carried out.

(4) Ministry of Finance (MoF)

The Ministry of Finance (hereinafter MoF) monitors the profitability of hydropower developments, the balance of international payments and the influence on the debt, and monitors the situation to avoid instability. RMAB is in charge of foreign debt, and the MoF is responsible for domestic debt. The calculation of GDP is essentially based on estimation via extrapolation of past trends. As long as profitability is secured on the project, there are no regulations on the upper limit of the hydropower debt, while non-hydro external debt shall not exceed 35% of GDP during Five Year period. In the case of hydropower external debt, 40% of the Debt Service Ratio is the upper limit.

(5) National Environment Commission (NEC)

The National Environment Commission (hereinafter NEC) is mandated to look after all issues related to the environment in Bhutan. The Commission also monitors the impact of development on the environment and aims to put in place the necessary controls, regulations and incentives for the private/public sectors to achieve sustainable development through the judicious use of natural resources. The coordination of inter-sectorial programs, and the implementation of policies and legislation with regard to the environment are other important mandates of the Commission.

(6) Gross National Happiness Commission (GNHC)

In 2007, in recognition of Bhutan's unique development philosophy of Gross National Happiness, the Planning Commission was renamed as the Gross National Happiness Commission (hereinafter GNHC). The GNHC is responsible for ensuring that national development promoted the happiness of all Bhutanese. The following items are described as major roles:

- to guide long-term sustainable socio-economic development and strategies
- to spearhead five year and annual planning and guide public policy formulation
- to ensure that GNH principles are mainstreamed into plans and policies in cognizance of regional and international commitments
- to mobilize adequate resources on a timely basis and ensure equitable and efficient allocation

- to monitor, facilitate, and coordinate implementation of policies, plans and programs for effective delivery
- to evaluate polices, plans and programs on a timely basis and provide feedback and undertake corrective action.

2.3.2 Companies Related to Power Sector

Bhutan Power Corporation Limited (BPC) and Druk Green Power Corporation Limited (DGPC) are the two main power utilities in Bhutan. Both are fully owned by Druk Holding and Investment Limited (DHI), Government holding company.

(1) Bhutan Power Corporation Ltd. (BPC)

BPC was established in July 2002 as a result of power sector restructuring according to the Electricity Act 2001. BPC covers transmission, distribution and small scale generation of less than 5MW such as small hydro and diesel generation, as well as power system operation. The revenue profile mainly depends on two pillars, sales of electric power and construction of transmission and distribution facilities required by generation companies. Revenue from the power transportation service is not particularly noteworthy.

(2) Druk Green Power Corporation Ltd. (DGPC)

DGPC is a 100% government owned hydropower operation and maintenance company, and was established on January 1, 2008 in the form of an absorption-type merger, whereby three existing hydropower companies, Chhukha Hydro Power Corporation Limited, Kurichhu Hydro Power Corporation Limited and Basochhu Hydro Power Corporation Limited, merged into DGPC. Aside from this, DGPC operates and maintains hydropower stations that are 100% owned by the Bhutan Government (including the above-mentioned three hydropower stations, as well as Tala hydropower station). DGPC jointly invests in PPP and JV project companies according to instructions from the government and it owns hydropower companies as subsidiaries, such as 59% of DHPC (which owns the in-operation Dagachhu hydropower), 100% of THyE (which owns the under-construction Nikachhu project) and 50% of KHyE (which owns the Kholongchhu project). DGPC also owns 51% of a company that undertakes maintenance for hydropower equipment, Bhutan Hydro Service Limited (hereinafter BHSL), which was jointly established with a French company, Alstom Hydro Holding, in September 2014.

(3) Dagachhu Hydro Power Corporation Limited (DHPC)

Dagachhu Hydro Power Corporation Limited (hereinafter DHPC) is the project company. It operates Dagachhu hydropower, the first PPP project in Bhutan. DHPC is 59% owned by DGPC, 15% owned by the National Pension and Provident Fund of Bhutan (hereinafter NPPF) and 26% owned by Indian conglomerate, Tata Power Company.

(4) Other Hydropower Project Implementing Bodies

Other than the abovementioned power companies, there are Special Purpose Vehicles (hereinafter SPV), established in order to develop and implement the projects based on BSHDP 2008. These SPVs are provided with construction licenses from BEA. The corporate status of the SPV depends on the development model. In the case that the Bhutan Government implements a direct project via an Inter-Government model with the Indian Government, the SPV forms an “Authority”. Project implementing bodies using other models, such as the JV model, become a “limited company” according to the Corporate Act 2000.

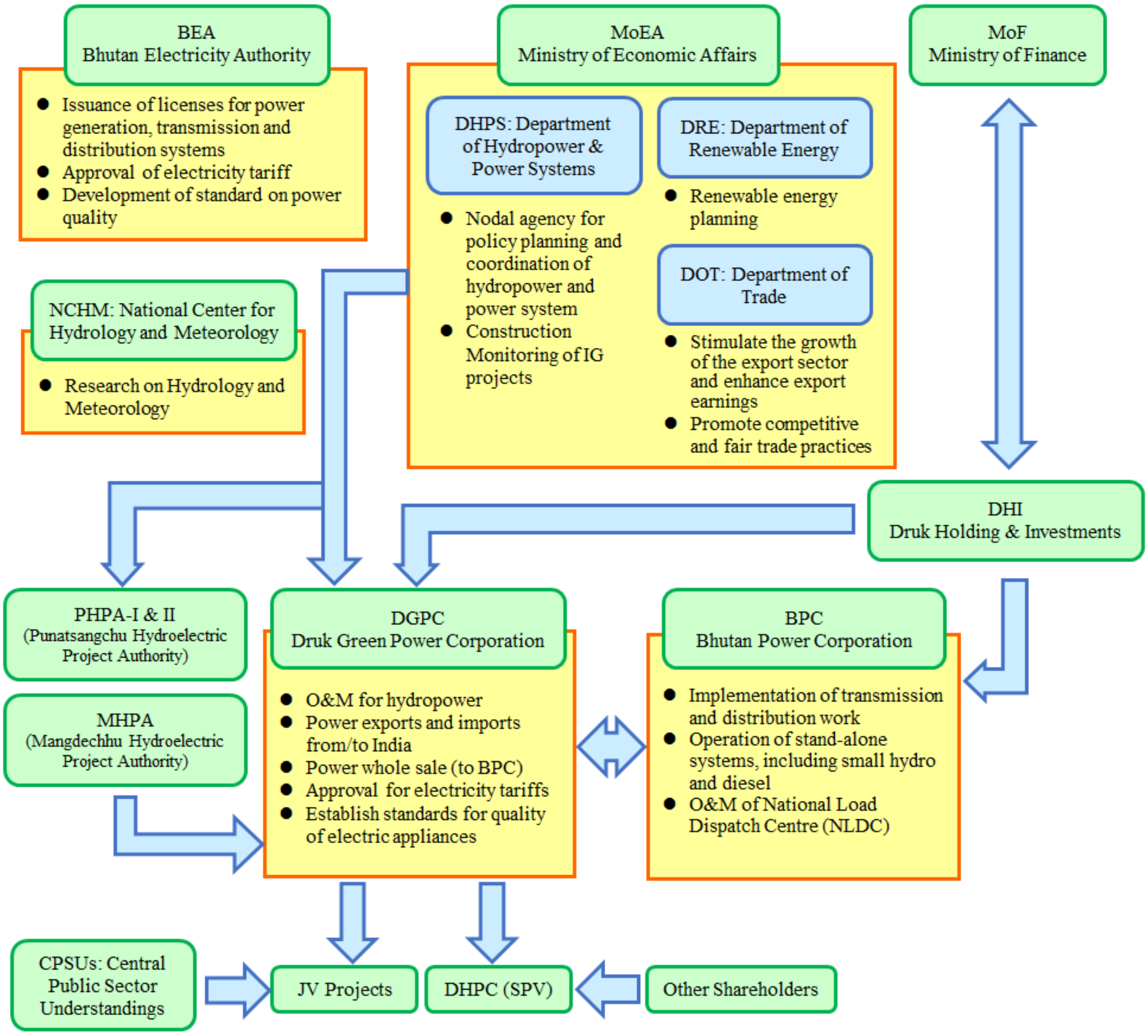
2.4 Organizational Roles in the Power Sector

(1) Current Situation in the Power Sector

The Electricity Act of Bhutan was amended in July 2001 to effectively and efficiently implement the promotion of rural electrification and hydropower development. The Electricity Act enables the restructuring of the power sector, splitting the Department of Power (hereinafter DOP), under the Ministry of Trade and Industry (hereinafter MTI), into three newly established organizations: the Department of Energy (hereinafter DOE), the Bhutan Energy Authority (hereinafter BEA), and Bhutan Power Corporation (hereinafter BPC). Major hydropower stations were also publicly incorporated in July 2002.

The DoE was responsible for the formulation of policies, planning and coordination of activities for the energy sector. In addition, the DoE was responsible for implementing the rural electrification program and development of new export-oriented hydropower projects. BEA is the regulatory authority in charge of developing licensing for generation and tariff-setting.

In December 2011, DOE, under the MoEA, split into three Departments: the Department of Hydropower & Power Systems (hereinafter DHPS), the Department of Hydro-Met Services (hereinafter DHMS), and the Department of Renewable Energy (hereinafter DRE). Currently, DHMS is an independent organization, the National Centre for Hydrology and Meteorology (hereinafter NCHM).
The organization chart for the power sector and accompanying roles are shown in Figure 2-3.



(Source: JICA Survey Team, based on information from MoEA, BPC webpage etc.)

Figure 2-3 Organizational Structure in Power Sector

(2) Roles of Power Facilities for Construction, Operation and Maintenance

DHPS formulates the overall development plans for hydropower and transmission systems. DGPC and the generation companies that DGPC invests in are in charge of the construction, operation and maintenance of all the individual hydropower facilities. BPC is in charge of the construction, operation and maintenance of all the individual transmission facilities.

Chapter 3. Viewpoints and Targets of Power System Master Plan

3.1 Current Master Plan

3.1.1 Hydropower Development Master Plan 1990-2010

The first power development plan in Bhutan was the Hydropower Development Master Plan 1990-2010 (HDMP), formulated by Norconsult AS in Norway with the support of the UNDP and the Norwegian government, in 1993. In response to a request from the government of Bhutan, a 20-year hydropower development plan was developed to investigate the possibility of exporting Bhutan's abundant hydropower potential. Under the HDMP, the investigation was undertaken in the following manner, with extremely limited, basic information at that time.

- Identify 91 potential sites via desk study on catchment area and head
- Extract 33 promising sites from the estimated results on annual power generation and development costs
- Conduct a field survey for these 33 sites, confirm the head, and ascertain the topography and geological conditions
- Conduct rough designs for 25 sites and calculate installed capacity, annual power generation, and development costs

3.1.2 PSMP 2004

Meteorological and hydrological information was developed in PSMP 2004. From the 91 potential sites specified by the HDMP, initial screening was conducted on 78 sites, excluding those that had already advanced to the next development stage, such as pre-FS, FS etc., narrowing them down to 20 sites. The 20 sites were then ranked via a Multi Criteria Analysis (MCA).

Table 3-1 Initial Screening in PSMP 2004

Screening stage	Cut-off point	Criteria	No. Remaining
(Pipeline projects had been removed in advance)			78
1st	Price index	Projects in price range above three times' the cheapest were removed	47
2nd	River flow	Price indices were updated according to new (increased) mean river flow	47
3rd	Price index	Repetition of 1st screening using new price indices	47
4th	Installed capacity	Removal of less than 150MW projects	20
5th	Project location	Information on project location with respect to National Parks/Protected Areas	20
6th	River flow	Update of river flow information based on the hydrological analyses	20
7th	Transmission lines	Additional costs of transmission lines and appurtenant equipment	20
8th	River basin	(+) Multiple (cascade) development (-) Interference with existing projects	20
9th	Project location	Projects interfering with existing projects, located inside a Protected Area/Corridor or 40% costlier than the cheapest were left out.	20

(Source: JICA Survey Team-created based on PSMP 2004)

For the remaining 20 sites, development priorities were decided by applying the following MCA.

Table 3-2 Evaluation Items and Weights of MCA in PSMP 2004

No.	Criteria		Sub-criteria	Weights			
1	Social and Environmental	Social	Improved access	22%	50%	30%	**3.30%**
2			Rural electrification	17%			**2.55%**
3			Employment benefits	10%			**1.50%**
4			Fishery potential	3%			**0.45%**
5			Tourism	8%			**1.20%**
6			Balanced regional development	40%			**6.00%**
--			Sub-total	100%			**15.00%**
7		Environmental	Intrusion into protected areas	35%	50%		**5.25%**
8			Loss of primary forest	40%			**6.00%**
9			Dewatering impacts	10%			**1.50%**
10			Access road erosion	10%			**1.50%**
11			Fish mitigation	5%			**0.75%**
--			Sub-total	100%			**15.00%**
12	Technical and Economic	Technical	Hydrological quality	22%	40%	70%	**6.16%**
13			Geological risk	25%			**7.00%**
14			Dam cost risk	15%			**4.20%**
15			GLOF risk	6%			**1.68%**
16			Site accessibility	10%			**2.80%**
17			Transmission line risk	18%			**5.04%**
18			Reservoir sedimentation	4%			**1.12%**
--			Sub-total	100%			**28.00%**
19		Economic	Size of project	0%	60%		**0.00%**
20			Economic merits	80%			**33.60%**
21			Financing ability	20%			**8.40%**
--			Sub-total	100%			**42.00%**
Overall							**100.0%**

(Source: JICA Survey Team-created based on PSMP 2004)

MCA was used within the context of overall objective of improving the socio-economic welfare of the people through sustainable hydropower. It allows the planners to compare diferent projects with varying characteristics and impacts in order to screen projects at various stages. The above criteria includes, those that influence each other and those that are dependent, and also those that determine abandonment of the development due to only one item. This is an effective method that considers the priorities of projects from a diversified viewpoint in order to proceed to the next development stage. As described in Chapter 7, this table has been partially reviewed and is still being used.

Based on the development goals indicated by Vision 2020, conceptual design work was implemented as a priority project to develop the top seven sites from among the 20 priority sites by 2022. In addition, this was set as a development plan until 2022, including the corresponding power transmission system development plan.
The short listed sites in PSMP 2004 is shown below. Hydropower development so far has been undertaken according to this short list, and the four projects of Punatsangchhu I, Mangdechhu, Punatsangchhu II and Nikachhu are under construction as of August 2018.

Table 3-3 Short Listed Sites in PSMP 2004

Sl No	Project Name	River	Gross Head (m)	Capacity (MW)	Energy (GWh)	EUCE* (US¢/kWh)
1	Punatsangchhu I	Punatsangchhu	286	1,000	4,770	2.86
2	Mangdechhu	Mangdechhu	719	670	2,909	3.23
3	Punatsangchhu II	Punatsangchhu	267	990	4,667	2.97
4	Chamkharchhu I	Chamkharchhu	527	670	3,207	2.97
5	Chamkharchhu II	Chamkharchhu	487	570	2,713	2.48
6	Kholongchhu	Kholongchhu	378	485	2,209	2.64
7	Amochhu	Amochhu	288	500	2,210	3.62

* Expected Unit Cost of Electricity

(Source: JICA Survey Team-created based on PSMP 2004)

3.1.3 National Transmission Grid Master Plan: NTGMP

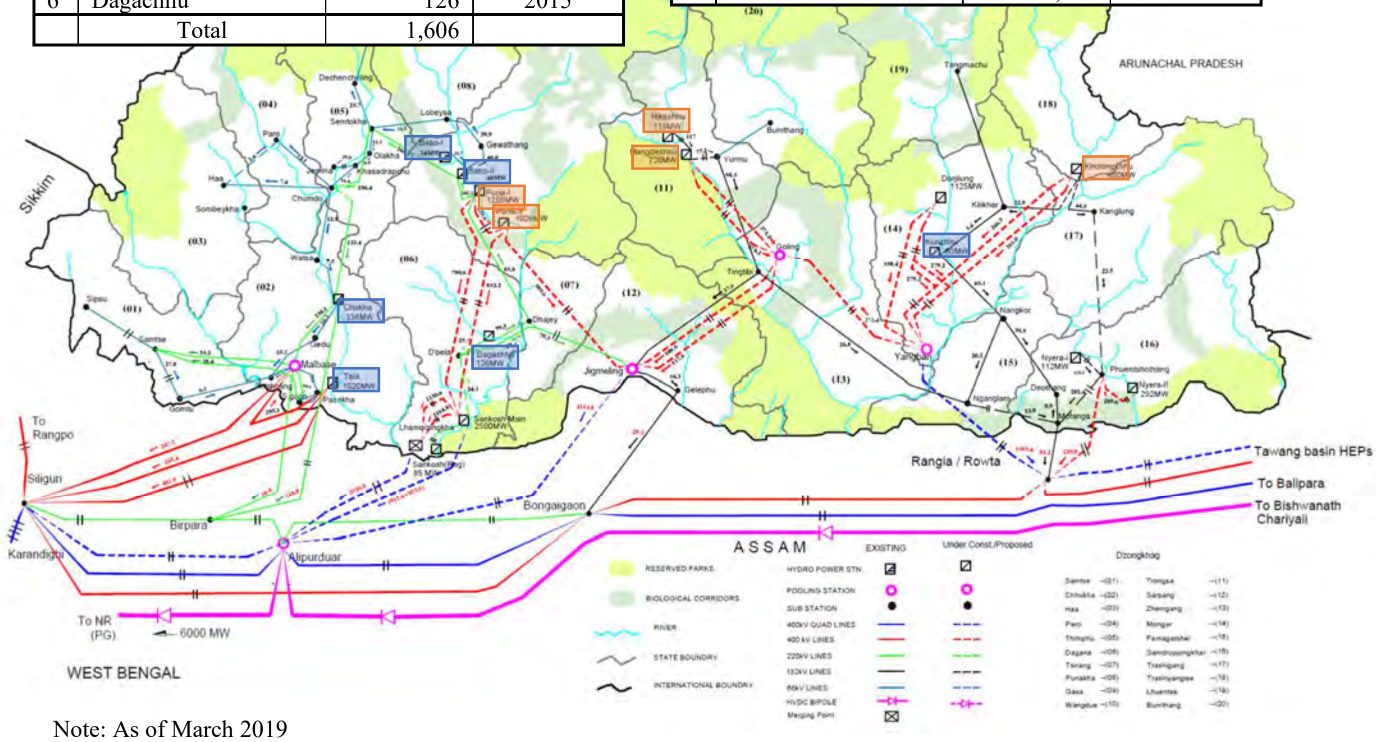
The current power system development plan is basically proceeding according to the National Transmission Grid Master Plan (NTGMP) up to 2030 that DHPS and the Indian Central Electricity Authority (CEA) jointly formulated in 2012. This plan was prepared based on the following concepts.

- transmit the electricity generated by hydropower stations to India efficiently
- strengthen domestic systems

DHPS reviews NTGMP as necessary. The basic concept is to set up five Pooling Stations (PS) in the southern part of Bhutan, aggregate the power from hydropower into the PS once and then send it to the Indian system. DHPS has not changed this concept, and is reviewing the locations of the PS and the transmission line route to them. In addition, DHPS independently implemented a review task incorporating changes (such as delays in the start of operation of the hydropower plants) with the cooperation of CEA, and formulated a new NTGMP 2018 in June 2018. The transmission network plan for 2030 in NTGMP 2018 is shown below.

	Name of Power station (Existing)	Installed capacity (MW)	Commercial operation year
1.	Chhukha	336	1986-88
2	Kurichhu	60	2001
3	Basochhu-I	24	2002
4	Basochhu-II	40	2004
5	Tala	1,020	2006-07
6	Dagachhu	126	2015
	Total	1,606	

	Name of Power station (Under construction)	Installed capacity (MW)	Commercial operation year
1.	Punatsangchhu-I	1,200	2023
2	Punatsangchhu-II	1,020	2022
3	Mangdechhu	720	2019
4	Nikachhu	118	2021
5	Kholongchhu	600	2023
	Total	3,658	



Note: As of March 2019

(Source: NTGMP 2018, additional notes by JICA Survey Team)

Figure 3-1 Transmission Network Plan for 2030

3.2 Way Forward

3.2.1 Power Configuration

It is necessary to consider the following key points to formulate a comprehensive electricity sector master plan. However, since some of them have a trade-off relationship with each other, it is determined which point is given priority, taking into consideration the nation's particular circumstances such as the national energy policy and energy potential.

- Economic efficiency (Reduction of power supply costs (generation costs + transmission costs))
- Power supply reliability (Allowable annual power shortage hours, power shortage electric energy, etc.)
- Energy security (Stable supply, Supply cost stability)
- Environmental and social considerations (Environmental evaluation criteria for each development project, Green House Gas emission volumes)

The power configuration to be aimed for in Bhutan was examined based on the above.

(1) Present power configuration

The power configuration in 2017 is shown below.

Table 3-4 Power Configuration in 2017

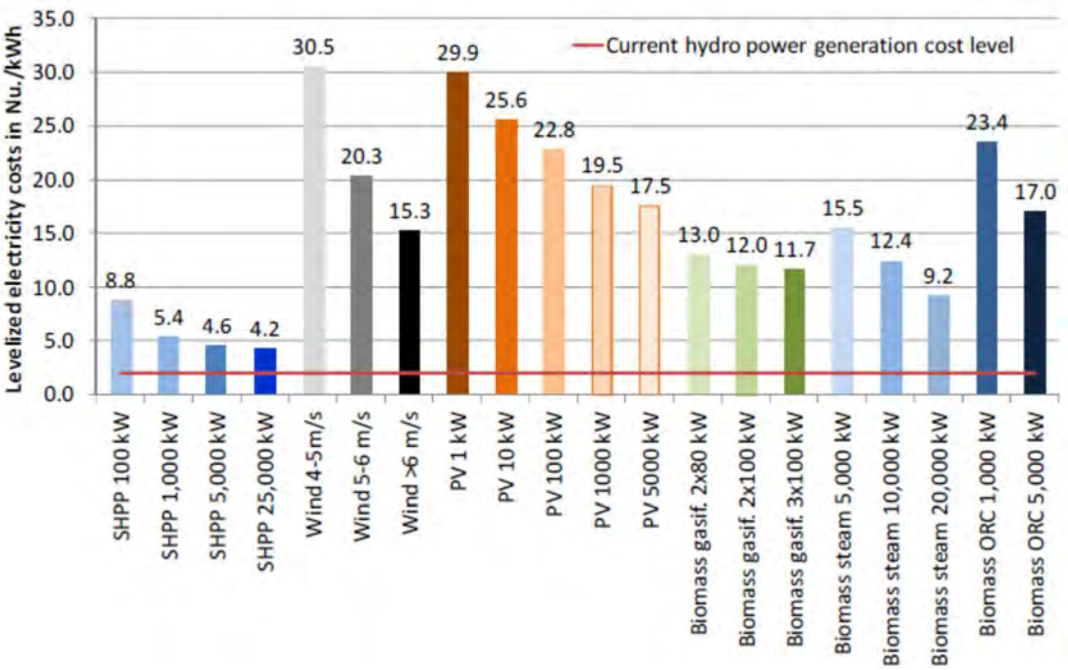
	Installed capacity (MW)		Electricity generation (GWh)	
Hydropower	1,606.0	99.0%	7,717.2	99.8%
Small hydro	8.1	0.5%	11.2	0.1%
Diesel generator	8.0	0.5%	0.3	0.0%
Wind power	0.6	0.0%	1.1	0.0%
Total	1,622.7	100.0%	7,729.8	100.0%

(Source: Power data 2017)

In Bhutan, there is great potential for hydropower plants, and looking at the power supply configuration in 2017, 99.0% of the installed capacity and 99.8% of the generated electricity are supplied by a large hydropower station. 28% of the generated electricity is supplied to domestic demand, and the rest is exported to India.

(2) Generation costs of various renewable energies

The generation costs of the various renewable energies described in the Renewable Energy Master Plan created by DRE in October 2016 are shown below.



(Source: Renewable Energy Master Plan, October 2016, DRE)

Figure 3-2 Generation Costs of various Renewable Energies

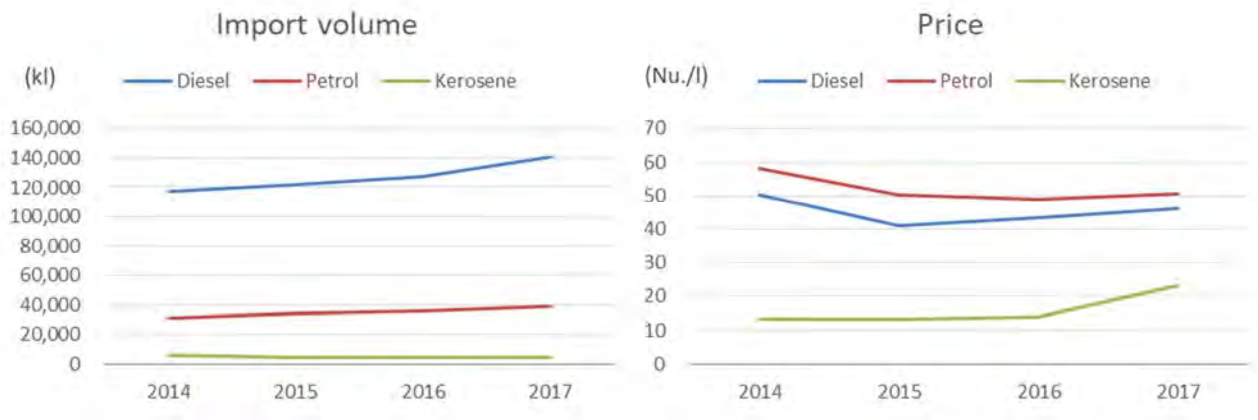
Compared to Nu. 2.0/kWh, the generation cost of a large hydropower plant, the generation costs of all renewable energies are more than double and those are five times or more excluding small hydropower.

The generation cost of renewable energy is expected to decline in the future, but considering circumstances such as Bhutan's topography, as shown below, it is not possible to expect much development volume.

Solar	Because of the very mountainous landscape, flat land is very scarce and the amount of forest is very large, so there is very little unused land where large solar power could be installed. Also, valuable unused flat land is highly likely to be used in the future for other uses such as industrial parks. Installation on the roofs of buildings would be expected, but the population is about 700,000, and there are not so many buildings.
Wind	Almost all the land is mountainous and, due to restrictions on the transport of blades, it is not possible to install power generating facilities with large unit capacity (about 500kW maximum). In areas where the altitude is high, the density of the air is low, and the energy obtained is reduced even at the same wind speed, so there are few economical sites.
Biomass	Much of the country's land is designated as protected forests, but about 10% of the total forest area is designated as areas that can be used for commercial purposes, and it is used to provide material for firewood and furniture while carrying out logging and afforestation. These products are mostly effectively used, except for sawdust during processing. Agricultural residues are effectively used as energy resources in each household.

(3) Generation cost of thermal power plant

Bhutan produces about 100,000 tons of coal annually, but there are no resources of petroleum or natural gas, and all petroleum fuels are imported from India. Import data for petroleum fuels are shown below.



(Source: JICA Survey Team-created based on data provided by DoT and MoEA)

Figure 3-3 Import Data for Petroleum Fuels

Imports of Diesel and Petrol are increasing every year. The price is about Nu. 50/*l* for Petrol and Nu. 45/*l* for Diesel.

The fuel cost in the case of installing a Diesel generator at a thermal power plant is calculated as follows.

Table 3-5 Fuel Cost for Diesel Generator

Item	Value
Heat rate of Diesel oil	38.2 MJ/*l*
Thermal efficiency of Diesel generator	44%
Fuel price of Diesel oil	Nu. 45/*l*
Fuel cost for Diesel generator	Nu. 9.6/kWh

(Source: JICA Survey Team)

The cost of a thermal power plant is Nu. 9.6/kWh even for only fuel costs, which is very high compared with the power generation cost of a large scale hydropower plant.

(4) Power configuration to be aimed for

In principle, power plants are developed with the aim of supplying the domestic electricity demand and, in response to an increase in electricity demand, new power plants are developed. The power supply configuration is decided considering the operability and economy of various power sources, in order to supply stable and inexpensive electric power to all customers in accordance with the demand shape, which changes from moment to moment.

In the case of Bhutan, the power system is already interconnected with the Indian system, and the amount of electricity exported to India is larger than the electricity supplied to the domestic demand. In addition, it is assumed that the hydropower resources are abundant, the hydropower potential is 30 GW or more (the development amount as of August 2018 is 1.6 GW) and the development costs are low, so hydropower is superior to other power resources. The Government of Bhutan regards hydropower as a valuable resource in the country, and the development of hydropower plants is positioned as an effective means of acquiring foreign currency.

Development of medium- or large-scale hydropower plants with excellent economic efficiency is required as power sources for export.

In Bhutan, distribution lines have already been extended, and 99%[1] of households can be supplied from distribution lines. Therefore, areas where power must be supplied by an isolated system using small-scale hydropower or solar power are limited to locations such as very high altitude areas surrounded by protected areas, where it is extremely difficult to extend the distribution lines.
In this way, based on both the domestic power supply situation and the situation regarding power sales to neighboring countries, Bhutan promotes the development of medium- or large-scale hydropower as the national policy.

Considering the particular nature of Bhutan, it is preferable that the future power configuration is covered nearly 100% by medium- or large-scale hydropower (25MW or more), as per the current situation. For this PSMP study, a study was conducted with the aim of identifying potential sites for hydropower resources and determining their development priority.

3.2.2 Evaluation Consideration for Priority Sites

(1) Evaluation method for potential sites

Since, the development of hydropower is considered one of the main contributor to the economy it is desirable to give priority to sites with excellent economic efficiency when selecting development priority sites. However, in this survey, the priority sites are decided by evaluating not only the economic aspect, but also via a risk assessment of the project, the impact on the natural and social environments, and the merits of the regional development. The multi-criteria analysis (MCA) method, which evaluates potential sites, has been used since PSMP 2004 as the main planning tool for selecting potential sites. In the current study, the evaluation criteria and corresponding weights previously used were verified and updated through numerous consultation with relevant stakeholders.

(2) Environmental considerations

As part of the Master Plan (MP) preparation, the Strategic Environmental Assessment (SEA) has been carried out to provide necessary information for selecting candidate sites and determining the development of priority sites from the natural and social environmental aspects. The evaluation items and the weighting used in the MCA method and the development priorities of each potential site obtained via the MCA method were modified based on opinions from experts, environmental administrative agencies, and citizens' representatives. The opinions submitted in the SHM and SEA are accordingly considered in the SEA Report.

Based on the results of this survey, feasibility studies (FS) for high priority sites are carried out and the locations and scale of major facilities (such as the intake dam, waterway, powerhouse, switchyard, and power transmission lines) are determined in the next step. In general, when developing an individual site, an environmental impact assessment (EIA) is implemented prior to the start of the project and the plan is revised based on opinions from experts, environmental administrative agencies and representatives of citizens. However, when implementing the EIA, there are issues such as the fact that there is little room for large plan changes and that the evaluation of cumulative impacts in the same river basin is not reflected. For this reason, when carrying out FS and before finalizing the locations and scale of major facilities, an SEA should be conducted that includes a comparison of alternative plans, and the locations and scale of the major facilities should be revised by listening to the opinions of experts, environmental administrative agencies and representatives of citizens as necessary.

(3) Projects excluded from this survey

The following projects which are already under construction, preparation of Detailed Project Report (DPR) completed and plants under operation (1,606 MW), are excluded from the scope of this survey.

[1] ELEVENTH FIVE YEAR PLAN, 2013-2018 Final Report (https://rtm.gnhc.gov.bt/wp-content/uploads/2019/01/Terminal-Report_11FYP_GNHC.pdf, P73)

Table 3-6 Sites to be excluded from the Scope of this Survey

No.	Project	River	District	Capacity (MW)	COD at NTGMP2018
1	Punatsangchhu I	Punatsangchhu	Wangdue Phodrang	1,200	2021 - 2025
2	Mangdechhu	Mangdechhu	Trongsa	720	2018 - 2020
3	Punatsangchhu II	Punatsangchhu	Wangdue Phodrang	1,020	2018 - 2020
4	Bunakha	Wangchhu	Chhukha	180	2031 - 2035
5	Sankosh Reservoir	Punatsangchhu	Dagana	2,500	2026 - 2030
	Sankosh RD			85	2026 - 2030
6	Chamkharchhu I	Mangdechhu	Zhemgang	770	2031 - 2035
7	Kuri-Gongri	Drangmechhu	Mongar	2,640	2031 - 2035
8	Kholongchhu	Drangmechhu	Trashi Yangtse	600	2021 - 2025
9	Wangchhu	Wangchhu	Chhukha	570	2031 - 2035
10	Amochhu	Amochhu	Samtse	540	2040 and beyond
11	Nikachhu	Nikachhu	Trongsa	118	2018 - 2020
12	Nyera Amari I	Nyera Amachhu	Samdrup Jongkhar	112	2026 - 2030
	Nyera Amari II			292	2026 - 2030
13	Dorjilung	Kurichhu	Mongar	1,125	2026 - 2030
	Total			12,472	

(Source: JICA Survey Team-created based on discussion with DHPS)

3.2.3 Hydropower Development Plan

According to NTGMP 2018 (refer to Table 3-6), formulated in June 2018, the development of sites excluded from the scope of this survey is expected to take up to 2035. The development volume is from 2,000 MW to 4,000 MW in 5 years. Considering the development plan above, the timing of the start of operations for the sites within the scope of this survey will basically be after 2036.

Hydropower development has a huge impact on the national finances. According to the data from 2017, debt related to hydropower development is about 80% of GDP. Therefore, considering the impact of hydropower development on the macro-economy of the country, the survey has taken into account such effects while formulating the MP.

Chapter 4. Power Demand Forecast

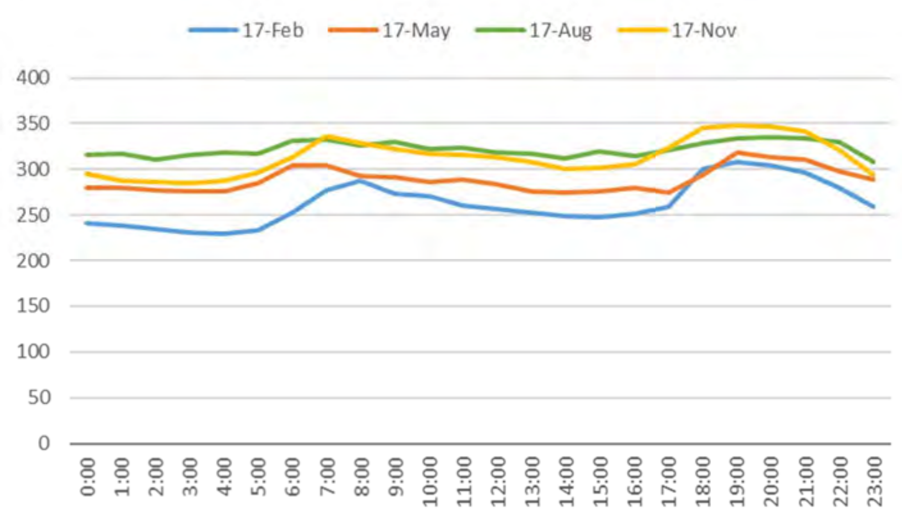
Currently, the electricity generated in Bhutan is supplied to domestic customers in Bhutan first and surplus power is exported. In the future, this trend will increase along with hydropower development, and it is important to evaluate not only the domestic demand forecast but also the possibility of electricity sales to India including neighboring countries in the electric power demand.

4.1 Power Demand Forecast in Bhutan

4.1.1 Power Supply and Demand Balance

(1) Current power demand status

Monthly average domestic power demands per hour in February 2017 (winter), May 2017 (Spring), August 2017 (summer), and November 2017 (Autumn) are shown below.



(Source: Quarterly Report, BPSO)

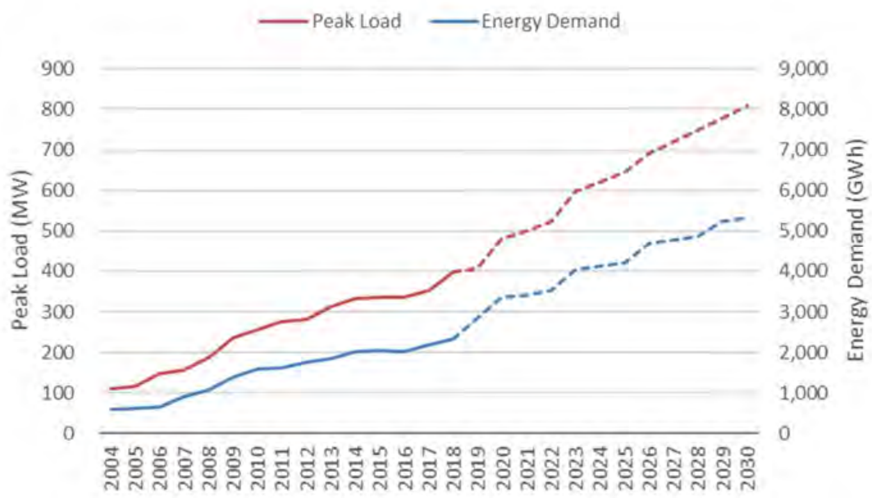
Figure 4-1 Power Demands per Hour in each Season

Peak demand for electricity has occurred twice in the morning and evening, but there is little drop in demand even at midnight.

(2) Demand forecasts

In general, power development is undertaken for the purpose of satisfying domestic power demand, so domestic power demand forecasting is a very important theme when formulating a power system MP. However, Bhutan is already interconnected to India, and the amount of electricity exported to India is larger than the electricity supplied to the domestic demand. Moreover, the RGoB considers hydropower a valuable domestic resource, and the development of hydropower plants is positioned as an effective means of acquiring foreign currency. In addition to supplying domestic demand, the power generated by power plants that will be developed in the future will be exported to neighboring countries. Considering the special characteristics of Bhutan, domestic power demand forecasting is a positioning for reference in this MP. Therefore, the values estimated by DHPS were used for the domestic power demand forecast in this MP and the validity of the values were evaluated.

Domestic power demand forecasts are shown below.



(Source: Power Data 2018, DHPS)

Figure 4-2 Domestic Power Demand Forecasts

The maximum power demand was 399MW in 2018, but it is assumed that this will increase to 808MW in 2030. The annual electricity energy was 2,328GWh in 2018, but it is assumed that this will increase to 5,317GWh in 2030. The annual growth rate for 12 years until 2030 is estimated to be 7.1% on average. The annual load factor was 66.6% in the actual data from 2018, but it is assumed that this will gradually increase in the future, reaching 75.1% in 2030.

Growth in demand is attributable to an increase in demand in four industrial parks that are planned to be built in conjunction with the start of operation of the Punatsangchhu-I&II hydropower electric plants (HEPs) and Mangdechhu HEP, in addition to the general demand increase.

Since supply capacity in winter is small at the present time and it is not possible to supply electricity throughout the year, Bhutan is forced to refrain from creating new demand by attracting large-scale and energy intensive factories. However, when a surplus of supply capacity occurs in winter, a stable supply of electricity throughout the year becomes possible, so further increases in demand can be expected by aggressively proceeding with developments for new demand.

The increase in electricity demand in the last 10 years is shown below.

Table 4-1 Electricity Demand

(Unit: GWh)

	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	Growth rate
LV	214	227	248	284	318	333	351	369	396	415	439	7.5%
LV Bulk	45	47	55	56	60	69	67	60	65	67	72	4.7%
MV Industries	80	89	108	110	124	111	91	102	111	114	122	4.3%
HV Industries	741	1,008	1,159	1,171	1,267	1,328	1,495	1,526	1,437	1,590	1,696	8.6%
Total energy sales	1,080	1,372	1,571	1,620	1,770	1,841	2,005	2,057	2,009	2,186	2,328	8.0%

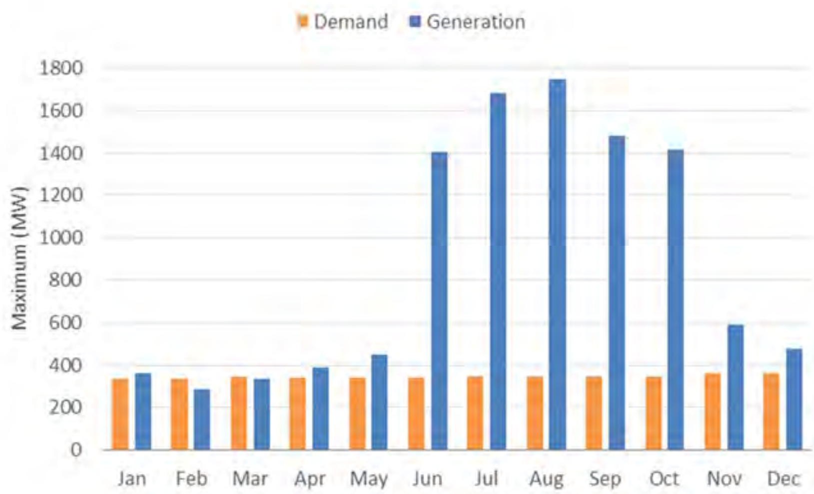
(Source: Power Data, BPC)

Considering that the 10-year growth rate from 2008 to 2018 was 8.0%, the average annual growth rate of 7.1% in the demand forecast up to 2030 is generally reasonable. However, the growth rate for the five years from 2013 to 2018 is 4.8%, and based on recent trends, the demand forecast up to 2030 is considered to be slightly overestimated. There is great expectation for an increase in bulk customers

(HV Industries), which account for more than 70% of the overall demand, in order to realize this demand forecast. In consideration of this, it is necessary to actively promote the creation of new demand by attracting large-scale factories.

(3) Demand and supply balance

The relationship between domestic power demand and power generation for each month in 2017 is shown below.

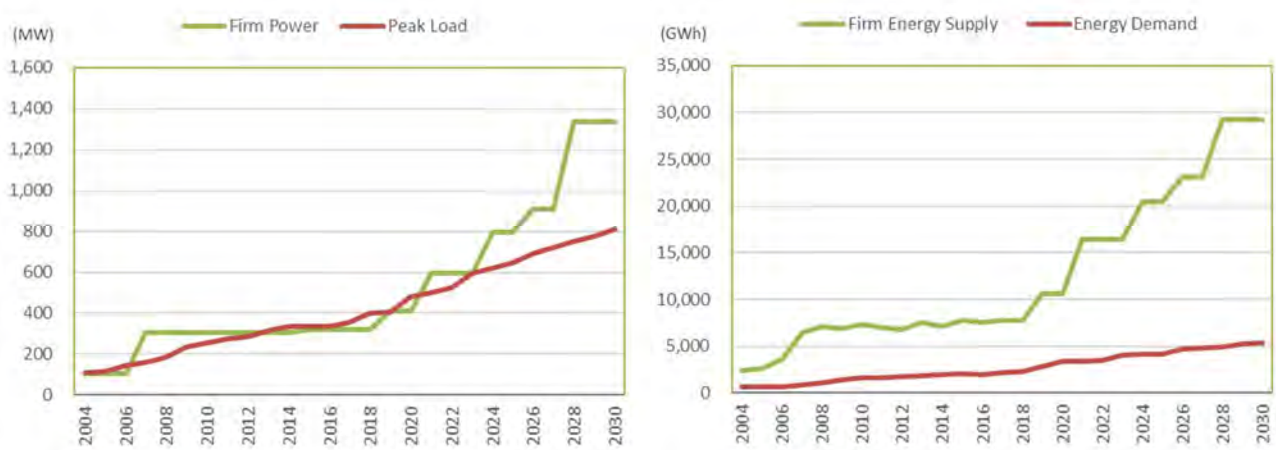


(Source: Annual Report 2017, BPSO)

Figure 4-3 Relationship between Domestic Demand and Generation in each Month

Hydropower supply capacity is lowest in February, at about 20% of the generation in July and August when it is at maximum. However, the maximum value of electricity demand is almost constant in each month. In February and March, when electricity demand reaches the maximum, capacity is insufficient for the domestic supply, and is compensated for by power imports from India.

The relationship between the electricity demand and the firm capacity of hydroelectric power plants is shown below.



(Source: Power Data 2018, DHPS)

Figure 4-4 Relation between Demand and Firm Capacity of Hydroelectric Power Plants

In general, the amount of river water in winter (dry season) in Bhutan will drop to less than 20% of that in the summer (rainy season), so the supply capacity of hydropower plants will drop dramatically in the winter. Supply power that can be generated even in winter is called “Firm Power”, which means that it can be supplied at any time throughout the year.

Looking at the relationship between the maximum electric power demand generated in winter and the hydropower plant supply capacity in winter (Firm Power), from the start of operation of Tala hydropower plant (winter supply capacity 199 MW) in 2007 until the year 2012, Supply capacity exceeded demand even in winter when supply capacity decreased. However, because there has been no major hydropower development since Tala Hydropower began operating, supply capacity in winter has been insufficient since 2012 with the increase in peak demand, and it is covered by electricity imports from India. This tendency is expected to be solved when Mangdechhu HEP (winter supply capacity 90 MW) begins operating in 2019, and Punatsangchhu II HEP (winter supply capacity 164 MW) begins in 2022, when it is expected that a large amount of surplus power will be generated even in the winter.

In terms of the relationship between the power generation and the demand, on an annual basis, there has always been power surplus since 2007, and surplus electricity is exported to India. In terms of the actual results in 2018, the annual electric energy demand was 2,328GWh, while the generated electric energy was 6,960GWh, and 65.8% of the generated electric energy was exported to India. This tendency will become more prominent after 2019, when the export ratio is assumed to exceed 80%.

(4) Transmission and distribution loss

The transmission and distribution loss in 2016 is as shown below. It is a very low level of around 1.1%. By further reducing transmission and distribution losses, it would become possible to sell more power to neighboring countries. However, this would require the introduction of equipment measures such as higher voltages and/or thicker wires, and the amount of loss that could be reduced would not be very great compared to the additional costs, meaning that it would be uneconomical.

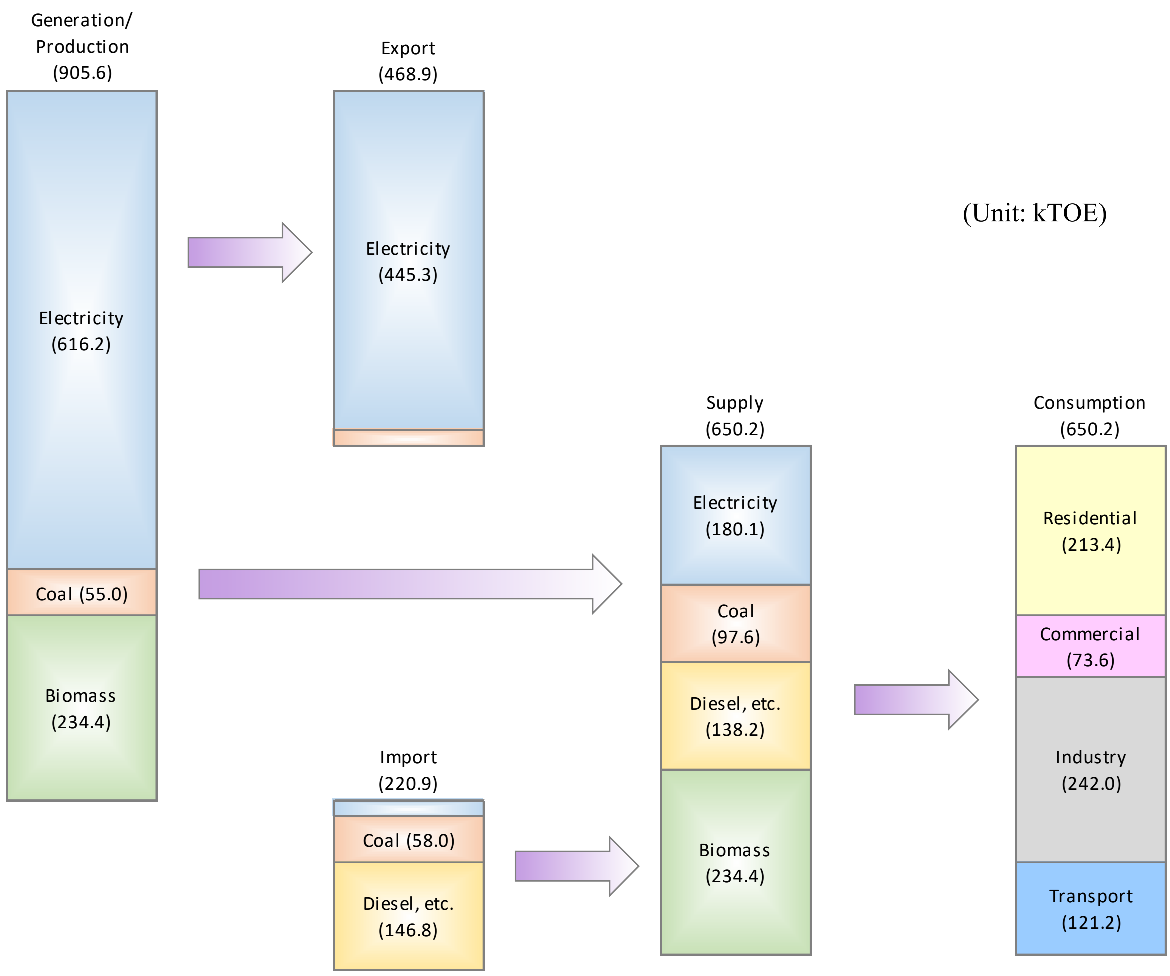
Table 4-2 Transmission and Distribution Losses

	Input (GWh)	Loss (GWh)	Loss rate (%)
Low, Middle Voltage	614.1	42.6	6.9%
High Voltage	1,440.3	2.9	0.2%
Disco	2,054.4	45.5	2.2%
Purchases from Genco	2,084.7		
Wheeling	5,779.3		
Transco	7,864.0	44.0	0.6%
Total	7,864.0	89.5	1.1%

(Source: Created by JICA Survey Team based on Power Data 2017, BPC)

4.1.2 Energy Balance

The Department of Renewable Energy released "Bhutan Energy Data Directory 2015" in 2016. The energy balance in 2014 is calculated in this document. The results are shown below.



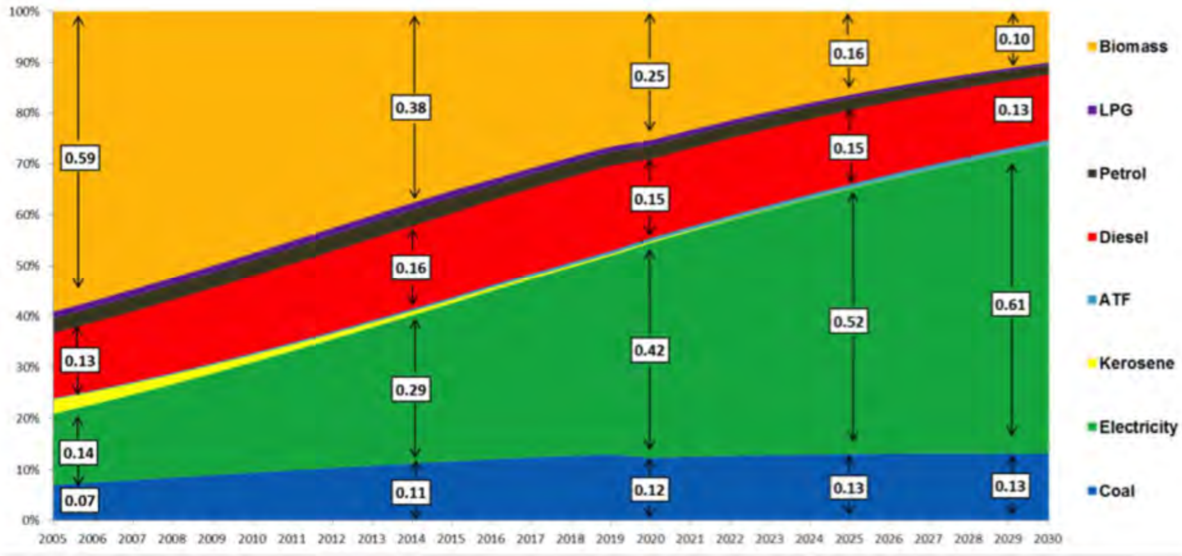
Note: Diesel, etc. includes Petro, Kerosene, LPG.
Commercial includes Others.
The totals do not match because there are losses (especially transmission losses).

(Source: created by JICA Survey Team based on the "Bhutan Energy Data Directory 2015")

Figure 4-5 Energy Balance (2014)

According to the breakdown of total domestic energy production (905.6 kTOE), electricity is 68% and biomass is 26%, and all biomass is used for domestic use, but 72% of power generation electricity is exported. Of the total supply (650.2 kTOE), 34% is covered by imports.

In the same report, two scenarios are presented for an energy balance up to 2030, of which the Energy Efficient Scenario is shown below.



(Source: Bhutan Energy Data Directory 2015)

Figure 4-6 Future Energy Balance (Energy Efficient Scenario)

In the Energy Efficient Scenario, the shift to electricity, which is easy-to-use and cheap energy, will progress in the future, and it is assumed that the share of electricity will significantly increase, to 61% while that of biomass will sharply decline in 2030. Though it is affected by future technological developments, the proportion of electricity in primary energy is expected to increase further, if it is possible that the electricity generated by hydropower plants is used to produce hydrogen, which is used as an energy source in various applications (transport via fuel cell cars, hot water by cogeneration, heat source at plants, air conditioning, cooking etc.).

4.2 Overview of Power Situation in India

4.2.1 Power Generation Facilities

The configuration of the power generation facilities on March 31, 2018 is shown below. Coal-fired thermal power is 57% of the total generation capacity, but the composition ratio of renewable energy (RES) such as solar power, wind power, small hydropower and biomass power generation has also increased to 20%. The composition ratio of hydropower and gas-fired thermal power, which are capable of relatively fast output adjustment according to frequency fluctuation, is 20%.

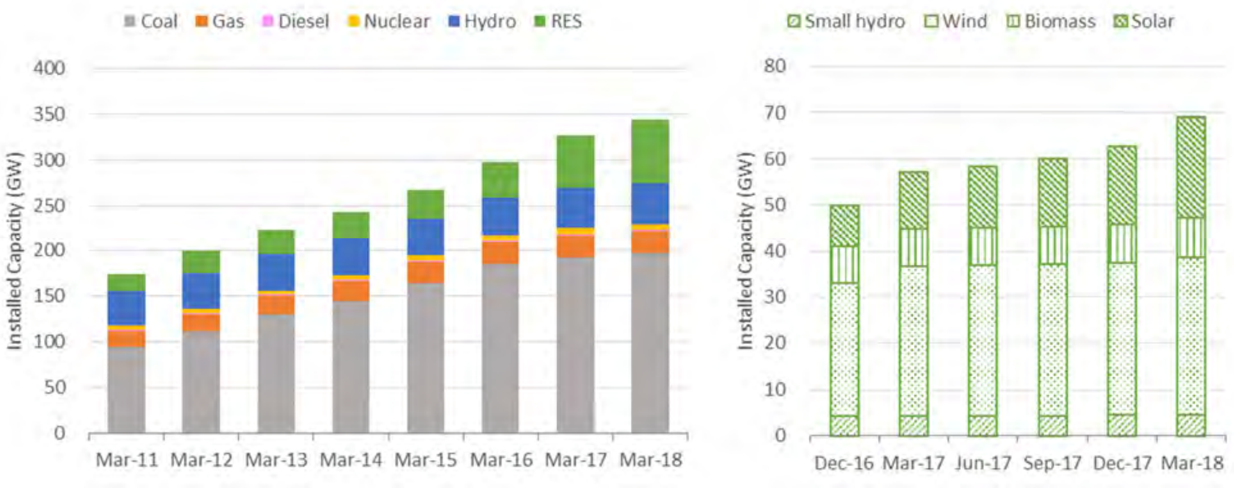
Table 4-3 Configuration of Power Generation Facilities

(Unit: GW)

Region	Coal	Gas	Diesel	Thermal Total	Nuclear	Hydro	RES	Total
Northern	52.9	5.8	0.0	58.7	1.6	19.8	12.9	93.0
Western	70.6	10.8	0.0	81.4	1.8	7.4	20.4	111.1
Southern	45.8	6.5	0.8	53.0	3.3	11.8	34.4	102.5
Eastern	27.3	0.1	0.0	27.4	0.0	4.9	1.0	33.4
North-East	0.5	1.7	0.1	2.3	0.0	1.3	0.3	4.0
ALL INDIA	197.2	24.9	0.8	222.9	6.8	45.3	69.0	344.0
	57%	7%	0%	65%	2%	13%	20%	100%

(Source: Monthly Report 2018.03, CEA)

Changes in the power generation capacity from 2011 to 2018 are shown below. Over the past seven years the total capacity has doubled, and the capacity of coal-fired thermal power has also almost doubled. The renewable energy capacity is rapidly increasing, and the increase in solar power is particularly remarkable. However, the composition ratio of facilities capable of relatively fast output adjustment (hydropower + gas-fired thermal power) has been gradually decreasing.



(Source: JICA Survey Team-created based on CEA website data)

Figure 4-7 Changes in Power Generation Capacity

In recent years, India has been focusing on the development of renewable energy, and plans to increase the installed capacity of 69 GW at the end of March 2018 to 175 GW by 2022 and 480 GW by 2030. On the other hand, for coal-fired thermal power plants, there is a policy not to construct new plants in the near future except for those currently under construction. For the existing coal fired power plants, there are plans to introduce highly efficient technologies in addition to increasing the capacity of existing plants which are due for replacement in order to deal with supply-side diversity.

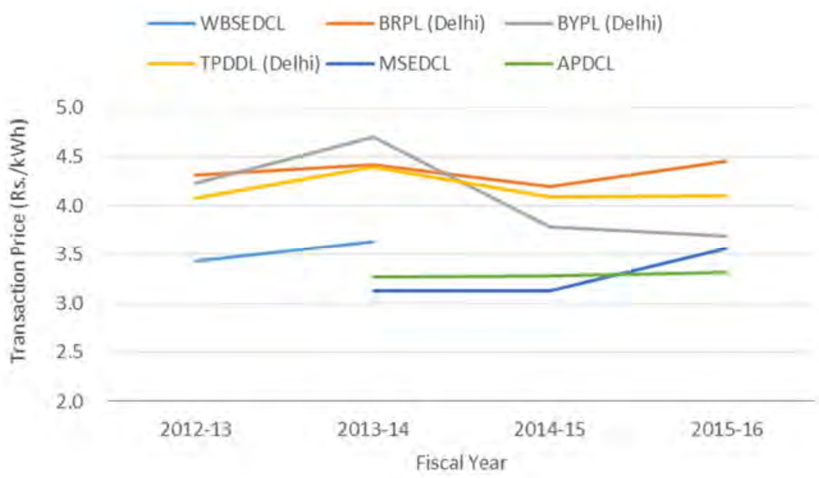
4.2.2 Power Transactions

The amount of electricity generated in India in the year (April 2017 to March 2018) is 1,308 TWh. Of this, thermal power accounts for 79% and renewable energy, 8%. About 90% of the electricity trading is via long-term contracts; the remaining 10% is via short-term contracts of less than 3 months.

(1) Long-term contracts

Transaction prices in long-term contracts are determined by bidding. Each distribution company invites bids from suppliers for the incremental demand that is needed that year. In response to that invitation, a power producer will participate in bidding by presenting its unit price for fixed costs and variable costs. The winner of a bid is the power producer who presented the lowest unit price, and a long-term contract is concluded between the distribution company and the power producer based on the unit price presented by the power producer.

The current average transaction price varies greatly depending on the distribution company, but it is estimated to be around Rs. 3.5-4.5/kWh.



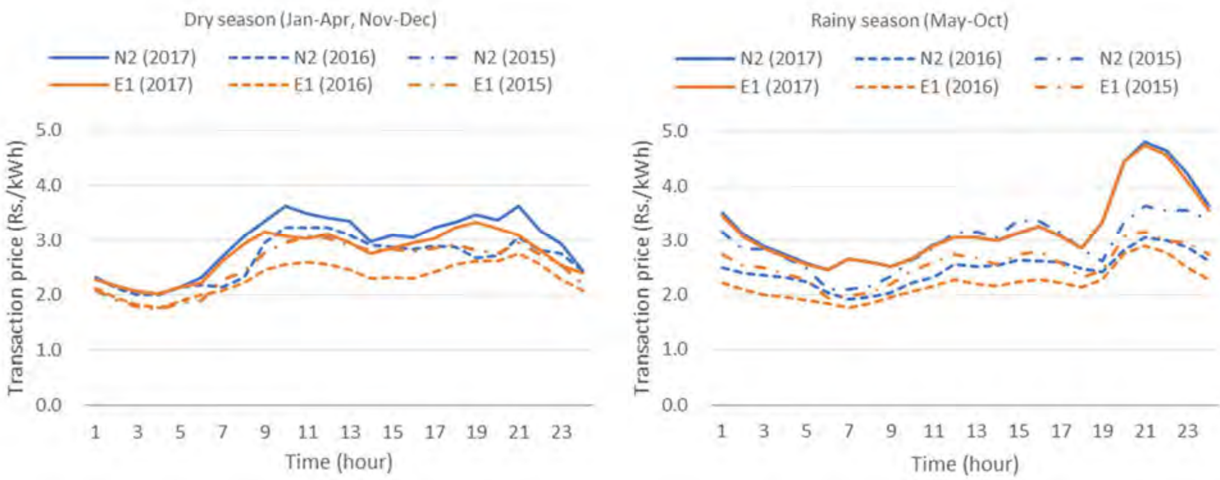
WBSEDCL: West Bengal State Electricity Distribution Company Limited, BRPL: BSES Rajdhani Power Limited,
BYPL: BSES Yamuna Power Limited, TPDDL: Tata Power Delhi Distribution Limited,
MSEDCL: Maharashtra State Electricity Distribution Company Limited, APDCL: Assam Power Distribution Company Limited

(Source: JICA Survey Team-created based on DEEP website data)

Figure 4-8 Average Transaction Prices in Long-Term Contracts

(2) Spot market

The spot market price fluctuates greatly depending on time and season. The transaction price situation over the three years from 2015 to 2017 in IEX implementing spot market transactions is shown below.



Note: N2 is the area including Delhi; E1 is the area including Kolkata

(Source: JICA Survey Team-created based on IEX website data)

Figure 4-9 Transaction Price Situation in IEX

The transaction price in 2017 tends to increase slightly compared with 2016 and 2015, and the average price in both N2 and E1 is around Rs. 3.0/kWh. In the rainy season it tends to be slightly higher during the evening peak, but similar trends are not seen during the dry season.

4.2.3 Ancillary Services

In India, the Deviation Settlement Mechanism (DSM) has been introduced as a means to increase the accuracy of the planned values of power producers and power distribution companies, and to provide incentives to match the real-time demand-supply balance. For Ancillary Services, RRAS (Reserves Regulation Ancillary Services) has operated since May 2016.

(1) Frequency adjustment situation

Frequency adjustment statistics for the overall Indian system from April 2017 to March 2018 are shown below.

Table 4-4 Frequency Adjustment Statistics for overall Indian System

Frequency distribution			Frequency adjustment results (every 10s)		
Below 49.9Hz	49.9 – 50.05	50.05Hz or higher	Maximum	Minimum	Average
10.55%	76.24%	13.21%	50.32Hz	49.62Hz	49.98Hz

(Source: POSOCO website)

Looking at the maximum and minimum values, the frequency results for the year are all within ±0.4Hz, meaning that very high quality electric power is supplied.

(2) Demand and supply balancing through DSM

(a) General power producers and distribution companies

Power producers (excluding renewable energy) and power distribution companies need to pay deviation charges to Reginal Load Despatch Centre (RLDC) according to the difference between the

planned value and the actual value every 15 minutes. The reference unit price for the deviation charge differs depending on the average system frequency every 15 minutes, and is set so that the unit price becomes higher as the frequency becomes lower - for example, Rs. 1.9884/kWh when the average frequency is 50.00 - 49.99Hz, and Rs. 8.2404/kWh when the average frequency is 49.70Hz or less.
When the average frequency is 50.10 to 49.70Hz, payment of the deviation charge is unnecessary as long as the deviation amount is within 12% of the planned value or within 150MW. When the average frequency is 50.10 to 49.70 Hz, the unit price for the deviation charge when there is a deviation amount of 150 MW or more and 12% or more of the planned value is as follows.

Table 4-5 Unit Prices for Deviation Charge

Deviation volume when planned value is 1,250MW or less	Deviation volume when planned value is more than 1,250MW	Unit price
> 12% but <= 15% of planned value	> 150MW but <= 200MW	20% of reference price
> 15% but <= 20% of planned value	> 200MW but <= 250MW	40% of reference price
More than 20% of planned value	More than 250MW	100% of reference price

(Source: Compendium of CERC Regulations, July 2016)

However, in the case of under-drawal by the buyer or over-injection by the seller when the average frequency is 50.10 Hz or more, and in the case of over-drawal by the buyer or under-injection by the seller when the average frequency is 49.70 Hz or less, it is necessary to pay a deviation charge regardless of the deviation volume.[2]

(b) Renewable energy

Renewable energy (wind power and solar power) follows another rule, as shown below.
For wind power and solar power producers, a charge is paid by multiplying the planned power generation amount presented by each producer every 15 minutes by the contract price. When the actual power generation deviates from the planned value, the deviation charge shown in the following table is traded between the regional DSM pool market and the power producer as a deviation charge.

Table 4-6 Deviation Charges (in the case of Renewable Energy)

Absolute error (Ratio to planned value)	Over-injection (Additional charge paid by regional DSM pool market)	Under-injection (Deviation charge to be paid to regional DSM pool market)
<= 15%	Contract price	Contract price
> 15% but <= 25%	90% of contract price	110% of contract price
> 25% but <= 35%	80% of contract price	120% of contract price
> 35%	70% of contract price	130% of contract price

(Source: Compendium of CERC Regulations, July 2016)

In other words, if the deviation amount is within 15%, there is no penalty, but if it exceeds 15%, a penalty is imposed according to the rate of excess. Therefore, renewable energy producers are also required to improve the prediction accuracy for power generation.

(3) Ancillary services (RRAS)

RRAS is operated by POSOCO (Power System Operation Corporation Limited), which operates NLDC and RLDC. POSOCO has been an independent Government organization since January 2017 (source: POSOCO Annual Report 2016-17).

2 When the average frequency is 50.10Hz or higher, the unit price for the deviation charge is Rs. 1.7800/kWh, the same as in the case of 50.01 to 50.00Hz.

(a) RRAS Rules

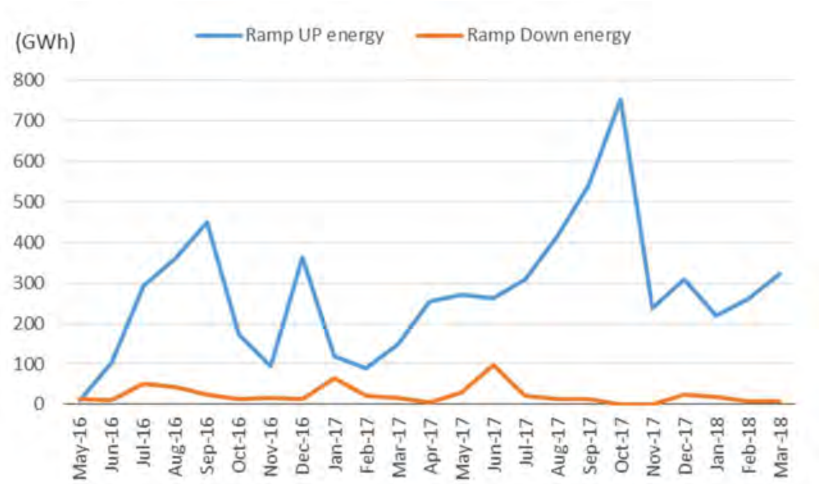
Power plants nominated to be an Ancillary Services Provider (ASP) present fixed costs, variable costs and variable capacity within 15 minutes to POSOCO every month.

When an imbalance of supply and demand is expected, RRAS instructs power plants predetermined as ASP to raise or lower the amount of electricity generation. In such case, the order of the instructions is based on the merit order determined by the price previously presented by each ASP. In other words, POSOCO instructs plants to increase output in ascending order of price, and decrease output in descending order of price.

When increasing output in response to such an instruction, fixed costs + variable costs + appropriate profit (mark-up) is paid to the ASP. The mark-up as of March 2018 is Rs. 0.5/kWh. When decreasing output, the ASP needs to return a charge corresponding to 75% of the variable costs to the DSM pool. That is, by reducing the amount of power generation, 25% of the variable costs related to the reduced power generation amount can be gained as compensation.

(b) Operation status of RRAS

The operation status of RRAS from May 2016 to March 2018 is as follows.

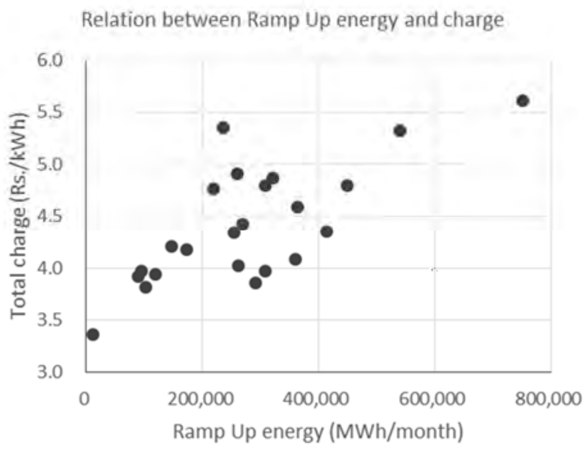


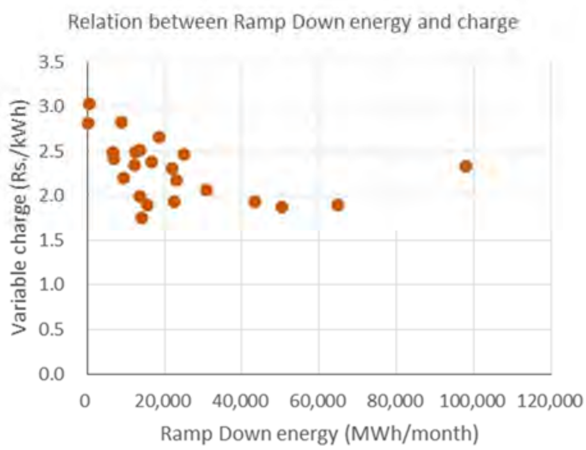
(Source: JICA Survey Team-created based on POSOCO website data)

Figure 4-10 Operation Status of RRAS

Looking at the operation status during this period, ramp up instructions were 276GWh/month on average (384MW per hour) and ramp down instructions were 23GWh/month on average (32MW per hour) across the whole of India. Ramp up instructions were much higher.

The relationship between the monthly instruction volume and the average unit price is shown below.





(Source: JICA Survey Team-created based on POSOCO website data)

Figure 4-11 Relationship between monthly Instruction Volume and Average Unit Price

In the case of a ramp up instruction, since the instructions are issued in ascending order of the sum price of fixed costs and variable expenses, the average unit price tends to rise as the instruction volume increases. The average unit price is around Rs. 4.6/kWh, including appropriate profit (mark-up). In the case of a ramp down instruction, instructions are issued in descending order of variable costs, so the average unit price tends to decrease as the instruction volume increases. The average unit price is around Rs. 2.2/kWh.

4.3 Power Trade

4.3.1 Possibility of Selling Electricity

Electric power generated by hydropower is produced by converting the flow rate of the river from the upstream into electricity. The calculation method for the amount of electricity that can be sold is shown below.

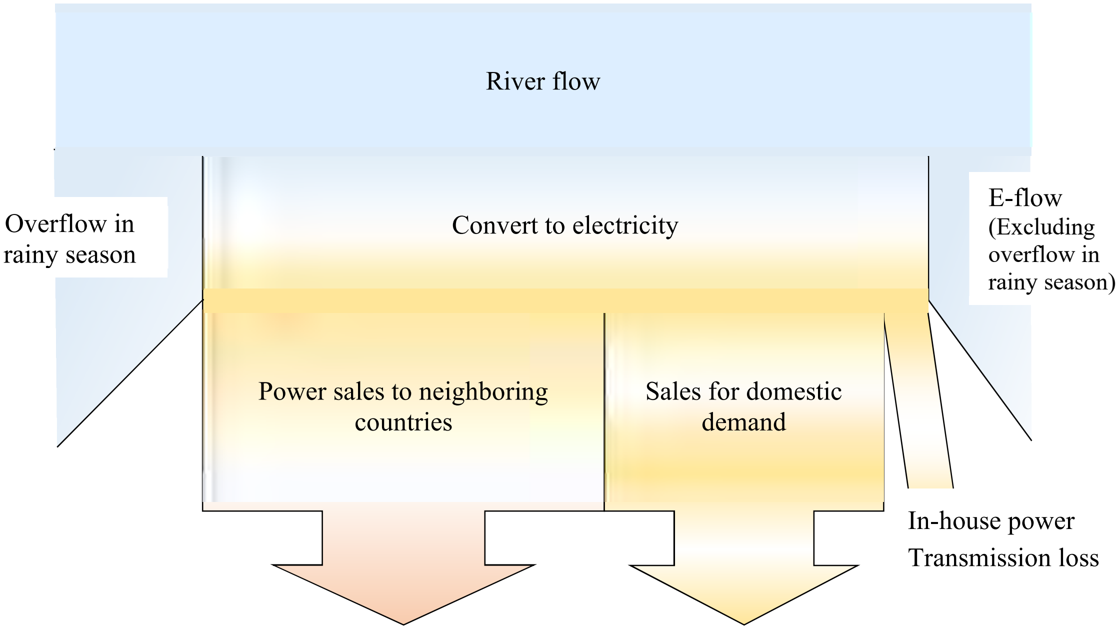


Figure 4-12 Calculation Method for the Amount of Electricity that can be sold

(1) E-flow

To maintain the downstream ecosystem, the minimum necessary quantity of flow is always discharged. Because this amount is released directly without passing through the turbine for power generation, it cannot be converted to electric power. However, if there is a power station at the dam-toe as in a dam-type power plant, the E-flow can also be converted to electric power.
The amount of E-flow shall be an amount corresponding to 10% of the minimum river flow rate (average flow rate in dry season) considering that the maintenance flow rate is recognized at 10% of the drought flow rate in the EIA of planned and under construction hydropower projects. In July, August, and September, the river flow rate is very high, exceeding the maximum amount of water required for the power plant which is released downstream. As this cannot be used for power generation, it is overflowed and discharged downstream. Since the overflow amount is larger than the amount corresponding to E-flow, there is no decrease in the amount of power generation.
In primary screening, the average flow in February was used as the minimum flow. However, in secondary screening, the average flow rate for lean months from December to March was used.

In this MP, at all project sites other than dam type sites, 10% of the drought flow rate is used for E-flow and economy is evaluated as the E-flow amount deducted from the electricity generated. When implementing a specific project, it is necessary to evaluate the impact on the ecosystem due to the decrease from the original river flow rate during the EIA.

(2) Overflow in rainy season

In the rainy season, there is a high possibility that a flow rate exceeding the power plant's maximum used water amount will flow from the upstream. In this case, if the water storage capacity of the dam reservoir is small, it is inevitable that an amount of water greater than the maximum amount of used water will be discharged directly downstream without passing through the water turbine. If the maximum amount of water used by the power plant is increased, the amount of overflow in the rainy season will decrease and the amount of electricity that can be sold will increase, but the construction costs will increase accordingly.

(3) In-house power and transmission loss

Part of the generated electricity is consumed due to the in-house power needed for operation and maintenance of the power plant, and transmission losses.

(4) Power sales to neighboring countries

Surplus power, after supplying domestic demand, will be sold outside the country. Power sales outside the country are basically conducted through Indian traders. The traders decide their buyers, which include neighboring countries such as Nepal and Bangladesh.

4.3.2 Power Sales for Domestic Demand

Electricity generated by hydropower stations will be sold for domestic electricity sales preferentially. If the firm power increases with the development of hydropower stations, the amount of power that can be supplied throughout the year increases, so even if domestic power demand increases, it can be supplied without importing power from India.

(1) Current electricity tariffs

Electricity tariffs in Bhutan are shown below. There are government subsidies for tariff categories other than High Voltage (66 kV and over), and electricity is considerably cheap.

Table 4-7 Electricity Tariffs in Bhutan

	Tariff Structure	Demand charge (Nu./kVA/month)	Energy charge (Nu./kWh)	Total (Nu./kWh)
LV	LV Block-I (Rural) 0 – 100 kWh	--	0	0
	LV Block-I (Others) 0 – 100 kWh	--	1.28	1.28
	LV Block-II (All) >100 – 300 kWh	--	2.68	2.68
	LV Block-III (All) >300 kWh	--	3.53	3.53
	Low Voltage (LV) Bulk	--	4.02	4.02
MV	Medium Voltage (MV)	300	2.16	2.93
HV	High Voltage (HV)	262	1.59	2.26

Note: 1st July 2018 to 30th June 2019
Demand charge is converted into unit price per kWh, assuming that the power factor is 90% and the monthly load factor is 60%

(Source: JICA Survey Team-created based on BPC website data)

For MV and HV customers, payment of a Demand charge is required in addition to the payment of Energy charges. If the power factor is 90% and the monthly load factor is 60%, converting the Demand charge into the unit price per kWh corresponds to a Demand charge of Nu. 0.77/kWh for MV and Nu. 0.67/kWh for HV.

The charge for wholesale electricity from DGPC to BPC is Nu. 1.59/kWh.

(2) Domestic sales unit price and possibility of attracting large customers

As of today, the main limiting factor in terms of the establishment of new industries is the availability of firm power. With the development of new hydropower projects, domestic demand is expected to increase at 6-7% in consonance with the GDP. Among the numerous advantages of creating domestic demand, one of the main benefits is the creation of employment opportunities by these new industries, driving economic growth by moving into the manufacturing and service sectors. Further, creation of domestic demand will ensure sustained growth in the economy. Therefore, selling power to the domestic market has immense benefits as compared to selling power directly to India.

When a large customer thinks about the location of a new factory, it decides by comprehensively judging many conditions. The conditions include sufficient customers being in the vicinity, materials necessary for production being cheaply available, good transportation of goods, cheap labor, the possibility of cheap procurement of water, electricity, gas, etc., tax incentives and so on. In particular, in electric power-intensive industries, it is absolutely vital that the electricity charges are low. With this in mind, it is necessary to set the available price to be attractive for large-scale, electric power-intensive customers, and to make the prices sufficiently cheaper than the electricity charges offered by neighboring power distribution companies.

The electricity charges offered by neighboring power distribution companies are shown below.

Table 4-8 Electricity Charges at neighboring Distribution Companies

	Tariff Structure	Demand charge (Rs./kVA/month)	Energy charge (Rs./kWh)	Total (Rs./kWh)
Assam	HT-II Industries above 150 kVA Opt-I	180	7.2	7.62
	HT-II Industries above 150 kVA Opt-II	300	6.5	7.19
Meghalaya	Industrial High Tension (IHT)	200	6.5	7.01
WB	Industries (132kV)	384	7.09	8.08

Note: Unit of Demand charge in Assam is Rs./kW/month
Demand charge is converted into unit price per kWh, assuming that the power factor is 90% and the monthly load factor is 60%

(Source: JICA Survey Team-created based on APDCL, MePDCL and WBPDCL website data)

The cheapest price is Rs. 7.01/kWh, in Meghalaya State, and the electricity price in Bhutan is much cheaper compared with electricity charges at neighboring distribution companies. As mentioned in the next section, even if electricity is sold at a price of Nu. 4.2/kWh[3], equal to the selling price to neighboring countries, because it is an attractive enough price for large-scale electricity customers.

4.3.3 Power Sales to Neighboring Countries

The current power transaction price in India is Rs. 3.5-4.5/kWh for long term contracts and Rs. 3.0/kWh in the spot market, as shown in 4.2.2.

(1) Point of Connection (PoC)

It is necessary to pay a connection charge (PoC) to India in order to connect to the Indian system, in principle, for power sales to foreign countries.

Table 4-9 PoC for Bhutan Generators to connect to the Indian System

	Paisa/kWh				
	Jul-Sep	Oct-Dec	Jan-Mar	Apr-Jun	Average
PoC Slab Rate	20.79	13.13	7.08	16.77	14.44
Reliability Support Charges Rate	3.79	3.37	3.60	3.74	3.63
Total	24.58	16.50	10.68	20.51	18.07

Note: from July 2017 to June 2018

(Source: JICA Survey Team-created based on CERC website data)

[3] The exchange rate of Rs. and Nu. is equivalent.

In addition, since selling electricity to foreign countries is basically done via traders in India, it is necessary to pay commission fees to these traders. The commission fee is 7 Paisa/kWh in the case of NVVN. An average of 25 Paisa/kWh is required to cover both these charges.

(2) Future forecasts for electricity charges and available price for demand outside the country

The IEA (International Energy Agency) announced the fuel price forecasts for three scenarios until 2040 in WEO 2017. Forecasted Prices for various Fuels are shown below.

Table 4-10 Forecasted Prices for various Fuels in WEO 2017

Real terms (USD 2016)	2016	New Policies		Current Policies		Sustainable Development	
		2025	2040	2025	2040	2025	2040
Crude oil (USD/barrel)	41	83	111	97	136	72	64
Natural gas (USD/MBtu)	7.0	10.3	10.6	10.8	11.5	8.6	9.0
Steam coal (USD/tonne)	80	87	91	90	101	78	77

Natural gas: Japan import price, Steam coal: for Coastal China (Source: WEO 2017, IEA)

New Policies	Voluntary emissions regulations are implemented in each country (central scenario: temperature rise 3.5 °C)
Current Policies	Do not incorporate large changes (temperature rise 6 °C)
Sustainable Development	Keep the atmospheric greenhouse gas concentration to 450 ppm to keep the temperature rise in 2100 less than 2 °C compared with the Industrial Revolution.

It is forecasted that real prices of all fuels in 2040 will rise above the 2016 prices in the “New Policies Scenario”, which is the central scenario. Price rises of around 1.7% annually for natural gas and around 0.5% annually for coal are expected.

The current power transaction price in India is on average about Rs. 4.0/kWh. As mentioned in the previous section, most of the power trading in India is electricity supplied from thermal power plants and it is thought that the transaction price will rise according to the rise in fuel prices. Assuming that the proportion of fuel costs is 70% of the electricity transaction price and the fuel cost will rise by 1.0% per annum for the next thirty years, the electricity transaction price will rise on average by about 12% over the 30 years. In other words, the average electricity trading fee for 30 years is assumed to be around Rs 4.5/kWh, and if electricity from Bhutan's hydropower can be provided at this price, it can compete equally with other power suppliers in India. Taking these points into consideration, the necessary expenses in India (Rs 0.3/kWh) are deducted, and it is estimated that an income of Nu. 4.2/kWh can be obtained when electricity generated by hydropower in Bhutan is sold for demand outside the country.

(3) Power sale to Bangladesh

In the Bangladesh power MP survey conducted by JICA in 2016, if the price is lower than the generation cost of domestic thermal power plant using imported coal and LNG, Bangladesh will consider purchasing power from abroad. A specific price for import power is 5.6Tk/kWh (corresponding to Nu. 4.6/kWh) in 2017 unit price.

4.4 Value of Firm Power

Firm power is output that can be supplied at any time throughout the year, and it is defined as output that can be supplied at a probability of 90% even in February, when the river flow rate is at its smallest. In Bhutan, river flow is generally the smallest in February, decreasing on average to about 10 to 20% of the maximum discharge water used by a power plant. In the case of run-of-river type hydropower, since the river flow is not stored it becomes the power plant's output as it is, so the Firm power is about 10% of the maximum output. On the other hand, for pondage type hydropower or reservoir type hydropower, Firm power can be increased by preferentially using water stored in a pond or reservoir during the required time periods.

(1) Value of Firm power

Supply capability that can be supplied throughout the year generally increases as Firm power increases, the value of Firm power is calculated as the extent to which the development of thermal power plants in neighbourhood can be postponed. In Bhutan, there is no such effect of development of thermal power plants.

In Bhutan, when domestic power demand increases, if sufficient Firm power is not secured, it will not be possible to supply electricity using only the country's supply capacity in the dry season, and it will have to rely on importing power from India. At such time, there is a possibility that if supply capacity is insufficient in India, imports from India cannot be guaranteed, resulting in a shortage of supply capacity and forced outages occurring in some areas. Therefore, securing the firm power within the country through Hyderpower resources will enhance employment opportunities and revitalize the domestic economy while guaranteeing the energy security. Since it is difficult to quantify these merits, the firm power is evaluated as the effect of postponing the development of thermal power plants in India.

The details of the thermal power plants targeted for postponement of development are shown below.

Table 4-11 Thermal Power Plants targeted for Postponement of Development

	Combined cycle (gas, oil-fired)	
Construction costs	1,108	USD/kW
O&M costs	10.10	USD/kW/year
Life-time	20	years
Annual expenses	9,775	Nu./kW/year[4]

(Source: JICA Survey Team-created based on Assumptions to the Annual Energy Outlook 2018, U.S. EIA)

The value at which Firm power increases will be evaluated as Nu. 9,775/kW, as an annual benefit.

(2) Calculation method for Firm power

In the case of a run-of-river type hydropower plant without a regulating pond or reservoir, output is calculated from the river flow that can be used with a probability of 90% even in February. However, if a hydropower plant has a regulating pond or reservoir it increases the usable flow via the following methods in consideration of the size of the water storage capacity and the magnitude of the electric power demand.

(a) Daily operation

8 hours of peak time and 16 hours of off-peak time in a day, creating an increase in output during the peak time so that the output during the off-peak time becomes 80% of the peak time output.

[4] Converted with Nu. 69.7/USD. Calculated as a life of 20 years and an interest rate of 10%, the capital recovery factor is 11.746%. The calculation formula of Annual expenses is (1,108 x 0.11746 + 10.1) x 69.7 = 9,775 Nu./kW/year.

(b) Weekly operation
5 days of weekdays and 2 days of holidays in a week, creating an increase in weekday output so that the average output on holidays becomes 80% of the average output of weekdays.

(c) Seasonal operation
The water stored in the rainy season is used evenly during the 5 months from December to April.

(3) Increase in Firm power at downstream power plants

If a power plant can be operated by using a regulating pond or reservoir to increase the discharge rate when the river flow rate is low, an increase in Firm power can be expected because the river flow rate also increases at the power plant downstream.

Even in areas where the river slope is steep and the flow is said to be fast enough, the average flow speed of a river is about 3 m/s. In other words, it is about 10 km/h, and if the power plants are about 50 km apart, the water released upstream reaches the downstream plant after about 5 hours have elapsed Therefore, even if peak operation is performed with the usage flow rate increased during the peak hours via daily operation, the river flow rate will increase in a time that does not meet the peak period at the power plant 50 km downstream. That is, Firm power increased via daily operation cannot be expected to increase Firm power at the power plant 50 km downstream. In consideration of this point, it is assumed that Firm power increased via daily operation increases only at power plants located just downstream. Conversely, since river flow increased via weekly operation or seasonal operation arrives at the downstream power plant on that day, it can be expected to increase Firm power at the downstream power plant.

Power plants that can be expected to increase Firm power shall be power plants scheduled to be developed by 2035 described in NTGMP 2018 (refer to Table 3-6), in addition to existing power plants.

4.5 Value of Providing Ancillary Services

Ancillary services include frequency control (primary, secondary, tertiary), system balancing (reserve capacity), power flow control, voltage control, transmission line congestion control and black start. Of these, only frequency control and system balancing are discussed in this report.

4.5.1 Treatment in Primary Screening

As shown in 4.2.3, the value of providing ancillary services is considered to be Rs. 0.5/kWh or more. At the moment, there is no market in India for ancillary services which can respond quickly like hydropower. In the future, based on the bid price presented by each business entity (service provider) that can provide ancillary services, the service provider will be instructed to increase output in ascending order of bid price, or decrease output in descending order of bid price. In other words, the value of Ancillary Services will compete with facilities that have similar functions, including pumped storage power plants (PSPP) and batteries. For this reason, it is very difficult to estimate a specific unit price at present.

When providing ancillary services, it is necessary to operate generators with output suppressed in preparation for a command to raise output when frequency drops. It is difficult to provide ancillary services during the rainy season, when the river flow rate is very high, as when the river flow rate is very high, operation with suppressed output will result in a decrease in power generation, which is not an economical operation. Also, in the dry season, since the amount of generated electricity becomes smaller and it is preferentially supplied to domestic demand, it is considered that the amount that could provide ancillary services would not be very large.

In the case of development of hydropower plants with reservoirs, value in providing ancillary services can be expected. However, considering that the volume that could be provided is not very large, and that the market is incomplete in the Indian system, a certain volume cannot be expected and it is difficult to calculate concrete unit prices. Therefore, the value of providing ancillary services was not considered in the benefit calculations in the primary screening.

4.5.2 Treatment in Secondary Screening

Since the primary screening was carried out to screen out sites with a lower development priority, the value of providing ancillary services was not considered. However, in the secondary screening, in order to properly evaluate the value of hydropower possessing a regulating pond, the value of providing ancillary services was considered under certain assumptions. In addition, since it is not possible to adjust the output at a run-of-river (ROR) type power plant, this value is not applicable.

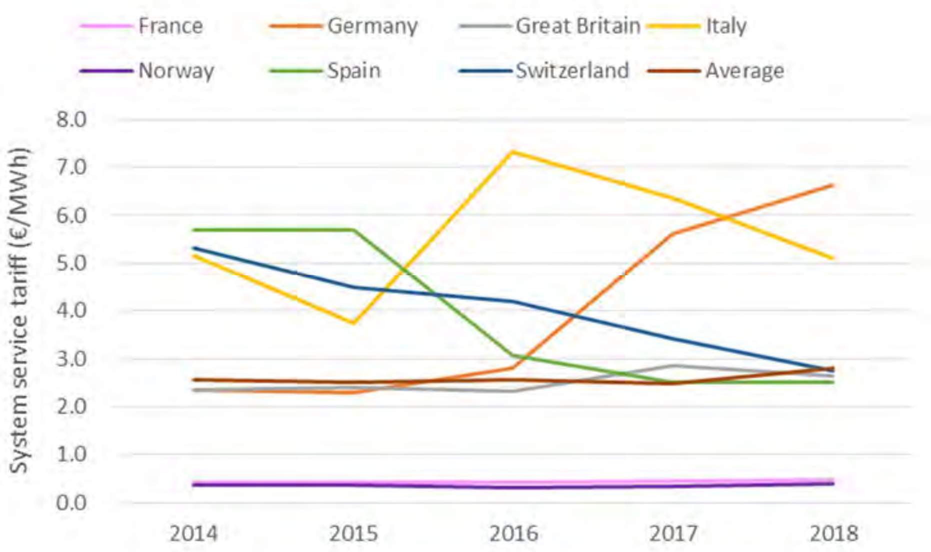
(1) Value of providing ancillary services

(a) Actual situation in India

The actual average unit price in the Indian market was about Rs. 4.6/kWh in the case of a ramp up instruction, and about Rs. 2.2/kWh in the case of a ramp down instruction. The average unit price in the case of a ramp up instruction includes fuel costs equivalent to Rs. 2.9/kWh, so excluding fuel costs required for expenses, the profit actually obtained by the ancillary service provider was about Rs. 1.7/kWh. Furthermore, an amount equivalent to 75% of the average unit price in the case of a ramp down instruction needs to be returned to the DSM pool (RLDC), so the profit actually obtained by the ancillary service provider was Rs. 0.55/kWh. These benefits are the profits obtained in cases where the instruction is actually issued from the RLDC. No compensation whatsoever can be obtained by only preparing and waiting to provide ancillary services.

(b) Actual situation in ENTSO-E

The transmission costs in each European country are compiled by ENTSO-E and the report "ENTSO-E Overview of transmission tariffs in Europe" is issued every year. Among these, the trends for "System service tariffs in major countries" are shown below.



(Source: JICA Survey Team based on "ENTSO-E Overview of transmission tariffs in Europe")

Figure 4-13 Trends of System Service Tariffs in major European Countries

This value is considered to be the expenses necessary for each country's System Operator to operate its own country's system stably. Although it varies from country to country, it is on average about Euro 2.5/MWh (Rs. 200/MWh[5]).

Since system services include frequency control (primary, secondary, tertiary), system balancing (reserve capacity), power flow control, voltage control, transmission line congestion control and black start, it is difficult to isolate only frequency control and system balancing. However, when 50% of the system service tariff is calculated as frequency control and system balancing, the expense required for both functions is Rs. 100/MWh. In other words, in order to maintain a stable system frequency, a cost of Rs. 100 per 1 MWh of demand is necessary. In order to supply high quality and stable electric power, frequency control capacity (including supply reserve) corresponding to about 3% of the demand is necessary. Therefore, the value of the frequency control capacity is considered to be Rs. 3,333/MWh (Rs. 3.3/kWh).

(c) Value of providing ancillary services to be used in this survey

The above two concepts differ greatly, with the actual value in India being Rs. 1.7/kWh and that in ENTSO-E being Rs. 3.3/kWh. The actual value in India requires a relatively slow response of within 15 minutes. It does not include frequency control (primary) and hot reserve. Hydropower can provide quick response for frequency control in seconds – more valuable than the actual value in India. Because Bhutan's hydropower can provide the same ancillary services required by ENTSO-E, the value of providing ancillary services to be used in this survey shall be Nu. 3.3/kWh (Rs. 3.3/kWh), which is the actual value in ENTSO-E.

(2) Available volume for providing ancillary services

The provision of ancillary services basically means that when the frequency of the system deviates from the standard value, the output of the power plant is changed automatically or in response to a command from the LDC. If the frequency of the system returns to the standard value, there is no need

[5] Convert at 1 Euro = 80 Rs.

to change the output. Therefore, if the capacity of the regulating pond can absorb an output change of about 15 minutes, it is possible to provide ancillary services.

When providing ancillary services, it is necessary to keep the output changeable in case the frequency of the system deviates from the standard value. In particular, it is necessary to operate generators with output suppressed in preparation for a command to raise output when frequency drops.

(a) Available volume in rainy season

It is difficult to provide ancillary services during the rainy season (July, August, and September), when the river flow rate is very high, as when the river flow rate is very high, operation with suppressed output will result in a decrease in power generation, which is not an economical operation.

(b) Available volume in dry season

Especially in February during the dry season, the river flow rate reaches its lowest, and Firm power is calculated based on this flow rate. During the peak period of February, generators are operated with output at Firm power as a priority operation to supply power to domestic demand, and further increases in output are impossible. Therefore, ancillary services cannot be provided during the peak period of February. However, in the off-peak time period, since operation is at an output of about 80% of Firm power, it is possible to provide ancillary services, and the changeable output range is ±20% of Firm power.

(c) Available volume in other seasons

In other seasons, it is considered possible to provide ancillary services. In order to do so, it is necessary to change the output in a short time, and the water volume discharged downstream from the power plant changes accordingly. If the output is changed too rapidly, the flow rate of the river downstream of the power plant will suddenly change, and the impact on the residents living downstream will become a concern. In consideration of this point, the changeable output width is set to ±20% of the maximum available output of each month. If there is a regulating pond that can adjust the flow rate just downstream, it is not necessary to consider the impact on the downstream, so the changeable output width is ±40% of the maximum available output of each month.

(d) Annual available volume for providing ancillary services

The above is summarized as follows.

Table 4-12 Annual Available Volume for Providing Ancillary Services

Month	Season	Available hours	Available volume
January	Dry season	744	20% of Firm power
February	Dry season	512	20% of Firm power
March	Dry season	744	20% of Firm power
April	Other season	720	20% of Available power
May	Other season	744	20% of Available power
June	Other season	720	20% of Available power
July	Rainy season	0	Not available
August	Rainy season	0	Not available
September	Rainy season	0	Not available
October	Other season	744	20% of Available power
November	Other season	720	20% of Available power
December	Dry season	744	20% of Firm power

(Source: JICA Survey Team)

4.6 Value of Greenhouse Gas (CO_2) Emission Reductions

A hydropower plant is a power generation system that does not generate CO_2 at all during power generation. Therefore, it is possible to reduce CO_2 emissions in neighboring countries by developing a hydropower plant in Bhutan and selling the power generated to neighboring countries.

According to the CO_2 Baseline Database for the Indian Power Sector, CEA (2016), the CO_2 emissions factor in 2016 in the power sector in India is 0.82 t-CO_2/MWh, due to the high proportion of coal-fired thermal power plants. In India, it is a policy to promote the development of renewable energy, and it is assumed that this emission factor will gradually decrease.

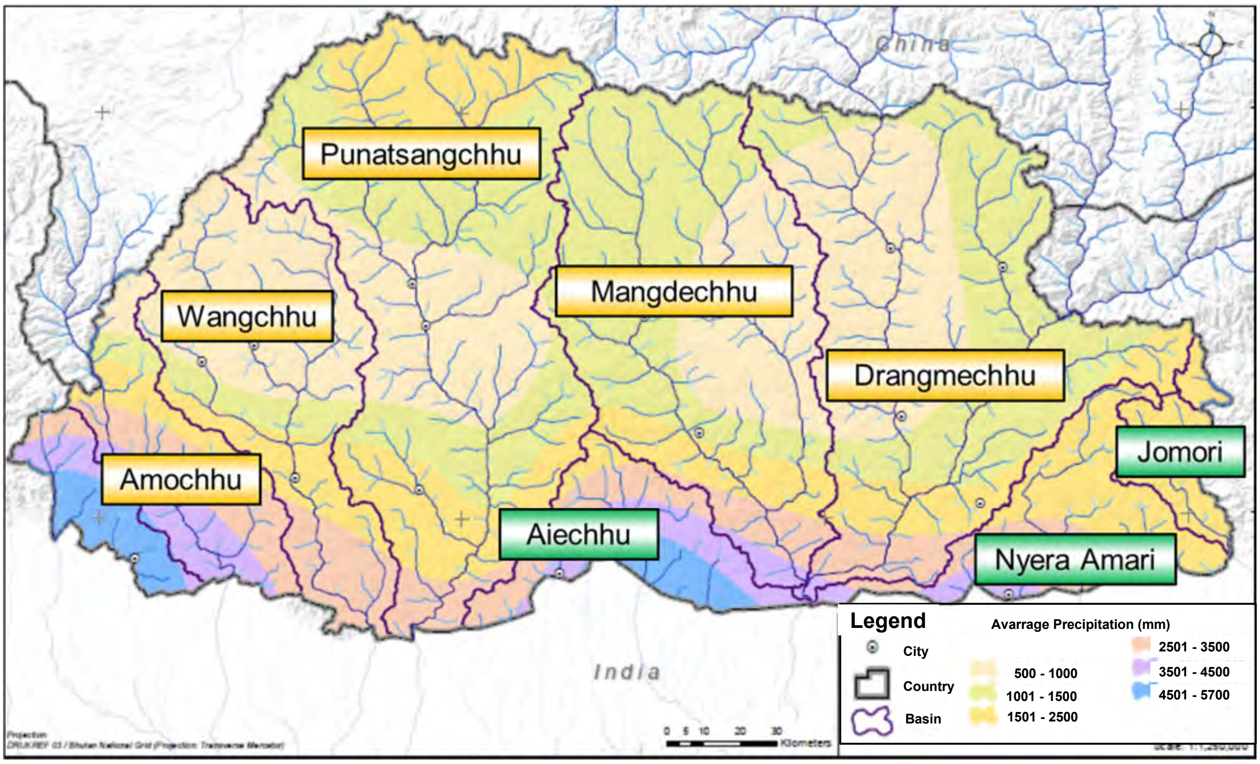
At present, there is no market actively trading CO_2 emissions in India, and it is difficult to estimate the current trading price, so this value is not calculated as a benefit in this survey.

Chapter 5. Basic Data and Conditions for PSMP 2040

5.1 Topography of Main River Basins

5.1.1 Target River Basins for Hydropower Potential Site Identification

The Kingdom of Bhutan has five main river basins (Amochhu, Wangchhu, Punatsangchhu, Mangdechhu, and Drangmechhu) and some small river basins. In consideration of mid to large scale hydropower development of more than 25MW, three small river basins (Aiechhu, Nyera Amari and Jomori) are also considered for this PSMP 2040 in addition to the five main river basins, as shown in Figure 5-1.



(Source: National Atlas of River Basins and Water Infrastructure in Bhutan, ADB, March 2016)

Figure 5-1 River Basins in Bhutan

5.1.2 River Profile and Catchment Area of Each River Basin

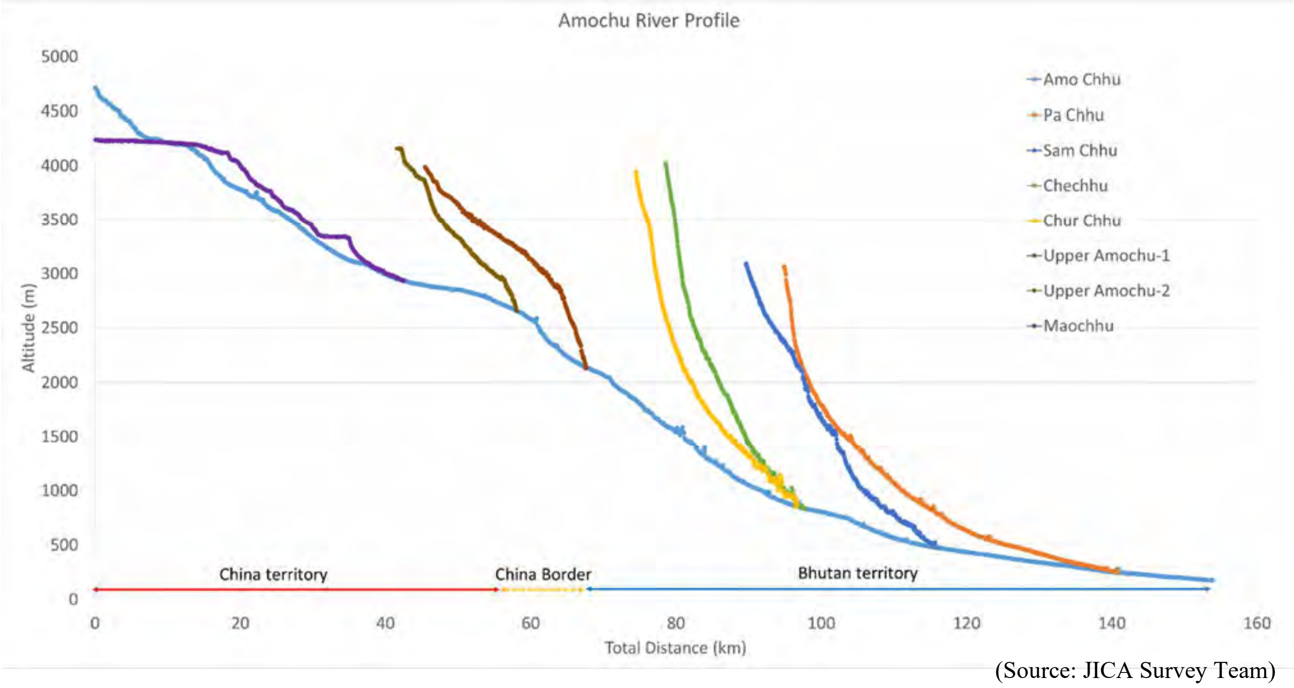
(1) Amochhu river basin

Amochhu originates from the base of Mount Shudu Tsenpa in the Tibet Autonomous Region, China where it is known as Machu. The length of river from source to outlet at the Bhutan-India border is around 150km and 60km of the upper section of the river flows through the Autonomous Region of Tibet, and the river traverses the Bhutan-China border for about 11 km. The river enters Haa Dzongkhag, Bhutan at an elevation of around 2200m. The river is known as Amochhu in Bhutan and Toorsa in West Bengal in India.

While the river slope one third upstream of the river in Bhutan is very steep at 1:20, one third downstream of the river shows a relatively gentle river slope of 1:80.

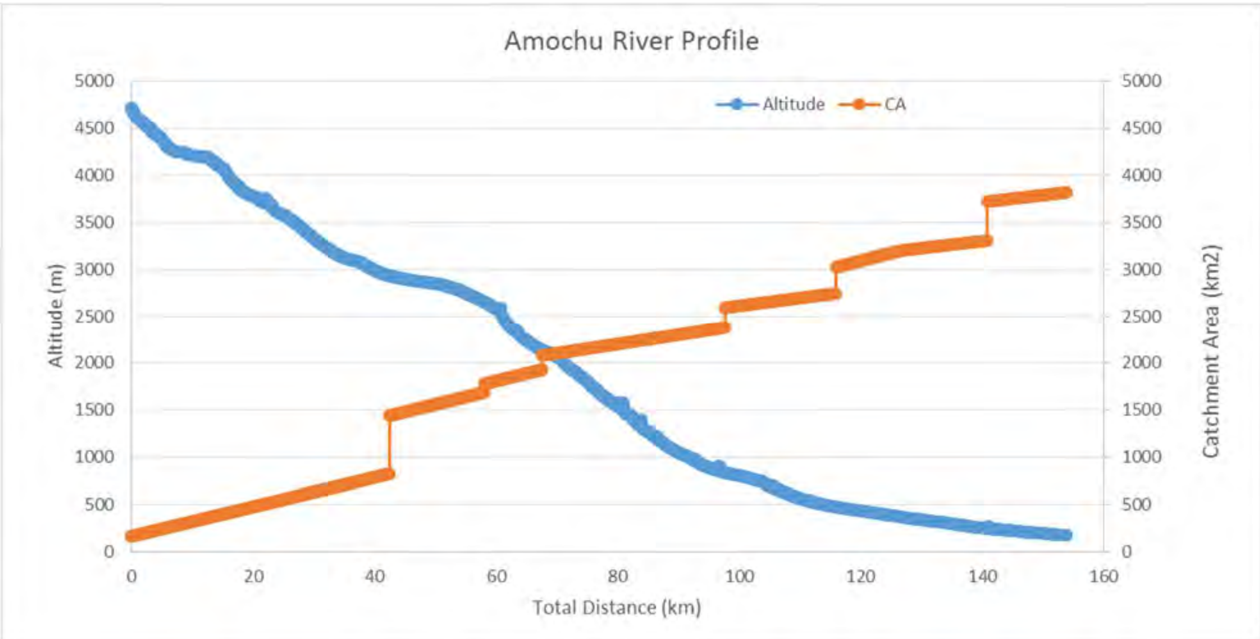
The catchment area of the Amochhu basin works out to around 3,927 sq. km of which 40% outside Bhutan.

The profiles of rivers within the basin are shown in Figure 5-2, and the relationship between the river profile of the main stream and its catchment area is shown in Figure 5-3.



(Source: JICA Survey Team)

Figure 5-2 River Profile of Amochhu Basin



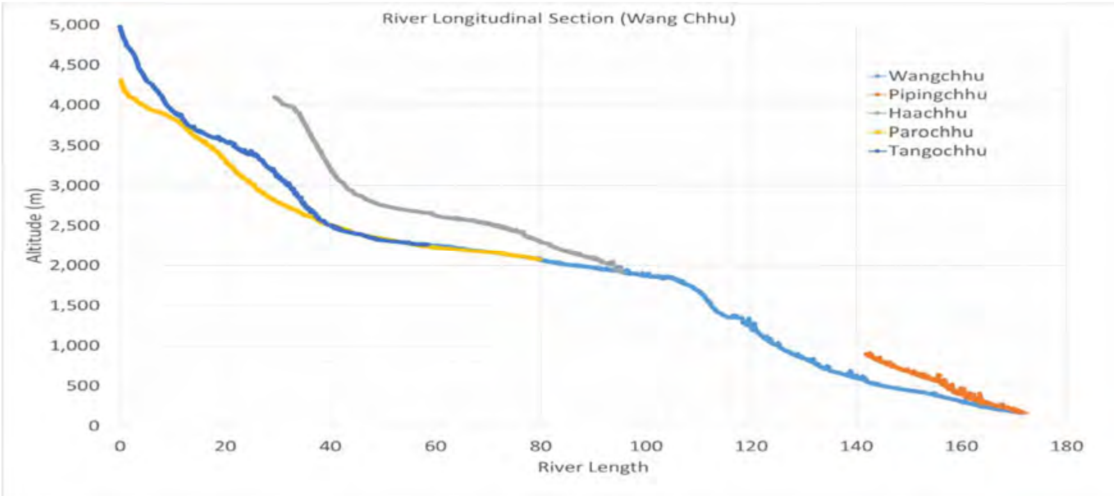
(Source: JICA Survey Team)

Figure 5-3 River Profile and Catchment Area of Amochhu Main River

(2) Wangchhu river basin

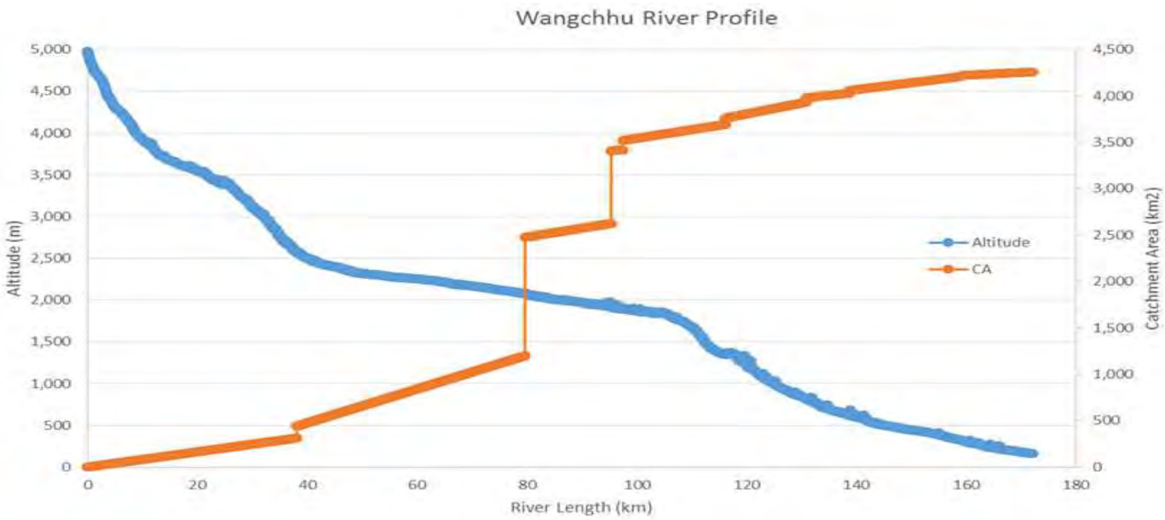
Wangchhu originates from the base of Mount Jomolhari (EL. 7,326m) at the Bhutan-China frontier and the length of the river from the source to the outlet at the Bhutan-India border is around 170km. While the river slope up to 40km upstream from the headstream is very steep at more than 1:20, one of the middle reaches between 40km and 100km (EL 2,500-1,800m) from the headstream is relatively gentle at 1:120. Further, the reach downstream of 110 km from the source exhibits a relatively steep river slope, at 1:40, which is suitable for hydropower development.

The catchment area of the Wangchhu basin delinated at the outlet near Indo-Bhutan is works out to about 4643 sq. km. The profiles of the rivers withn the basin are shown in Figure 5-4, and relationship between the river profile of the main stream and its catchment area is shown in Figure 5-5.



(Source: JICA Survey Team)

Figure 5-4 River Profile of Wangchhu Basin



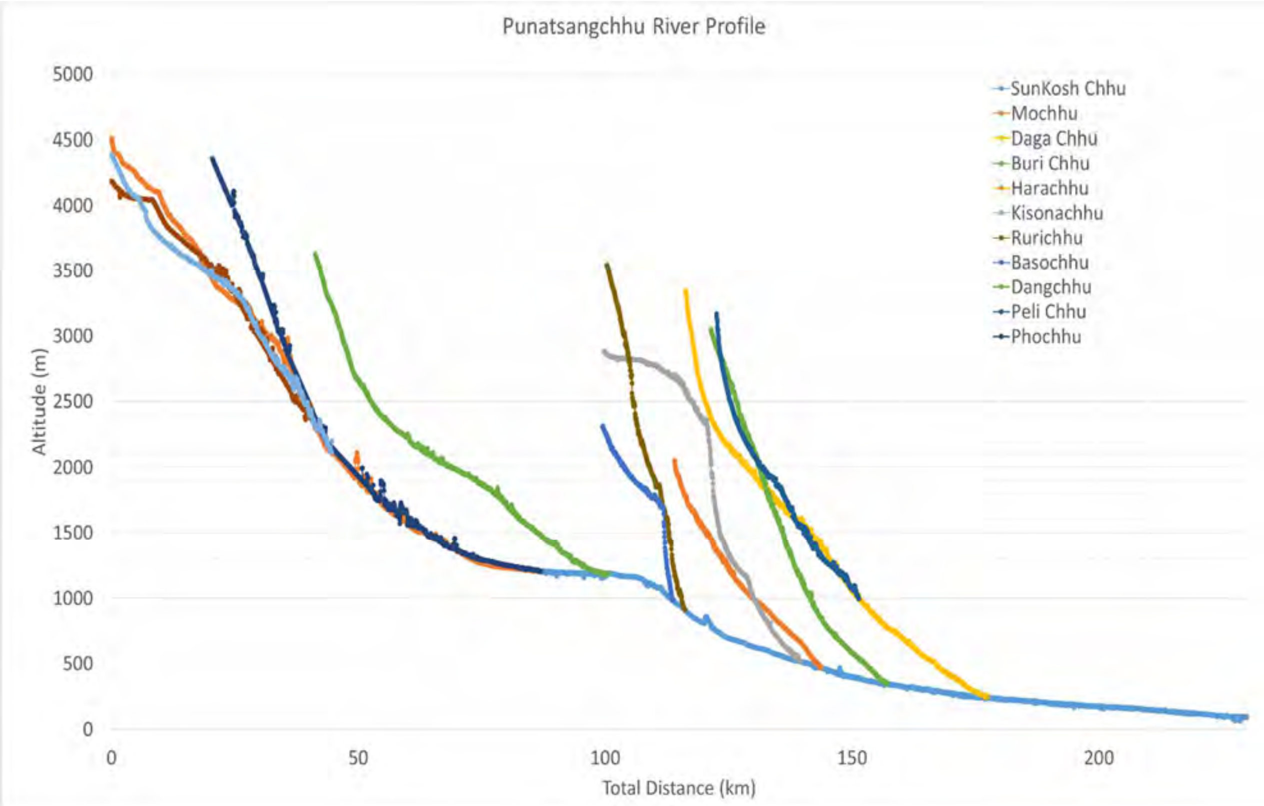
(Source: JICA Survey Team)

Figure 5-5 River Profile and Catchment Area of Wangchhu Main River

(3) Punatsangchhu river basin

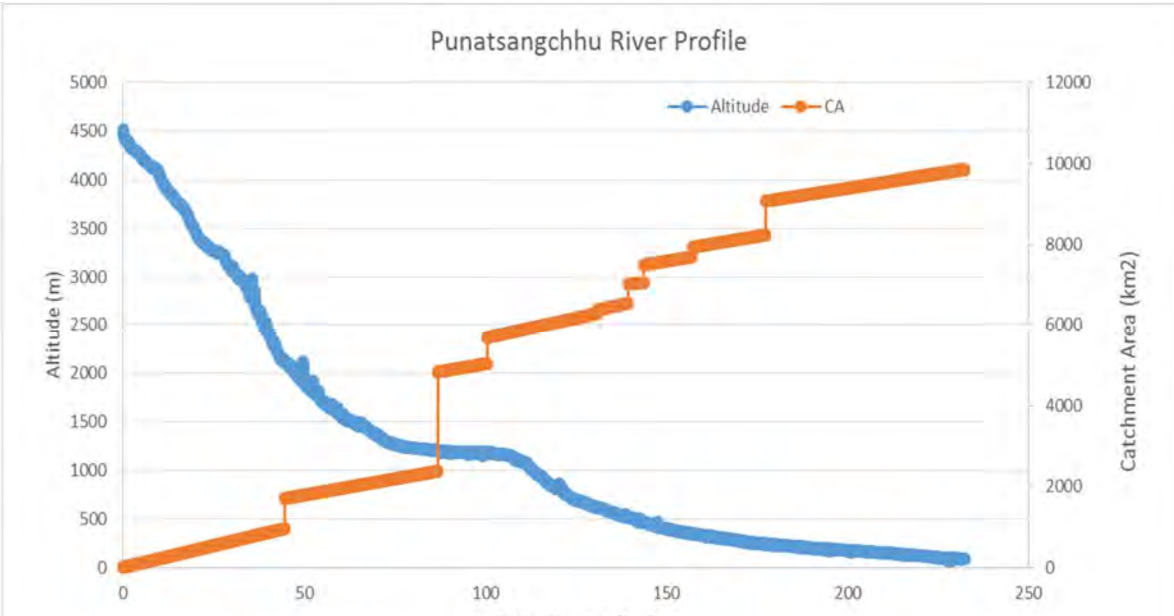
The length of Punatsangchhu from its source at the northern frontier to the outlet at the Indo-Bhutan border is about 230 km. While the river slope up to 70km upstream from the headstream is very steep at 1:20 to 1:25, the middle reach between 80km and 110km (EL 1,200m) from the headstream exhibits a gentle slope. Further, the river slope of the downstream reaching between 110km and 140km from the headstream is relatively steep at 1:50; the river slope then becomes gentle again towards the Indo-Bhutan border.

The catchment area of Punatsangchhu increases from 2,400 sq. km to 4,800 sq. km at the confluence of Phochhu and Mochhu. The total catchment area of Punatsangchhu delinated at the outlet at the Indo-Bhutan border is around 9,747 sq. km. The profiles of the rivers within the basin are shown in Figure 5-6, and the relationship between the river profile of the main stream and its catchment area is shown in Figure 5-7.



(Source: JICA Survey Team)

Figure 5-6 River Profile of Punatsangchhu Basin



(Source: JICA Survey Team)

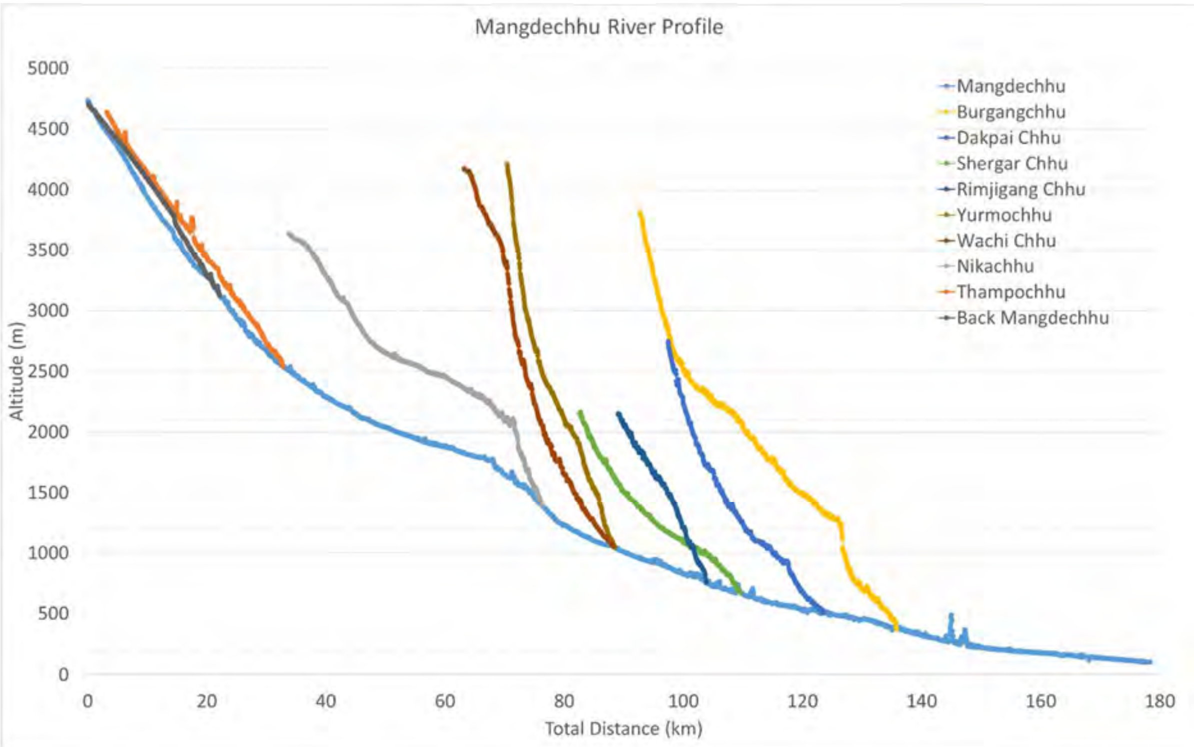
Figure 5-7 River Profile and Catchment Area of Punatsangchhu Main River

(4) Mangdechhu river basin

Mangdechhu originates from the base of Mount Gangkar Puensum (EL. 7,570m) at the northern frontier and flows through the center of Bhutan. The length of the river measured from the source to the outlet at the India-Bhutan border is around 180km. Although the river slope changes after 70km downstream from the headstream, the slope of the river is generally steep at 1:40 on average.

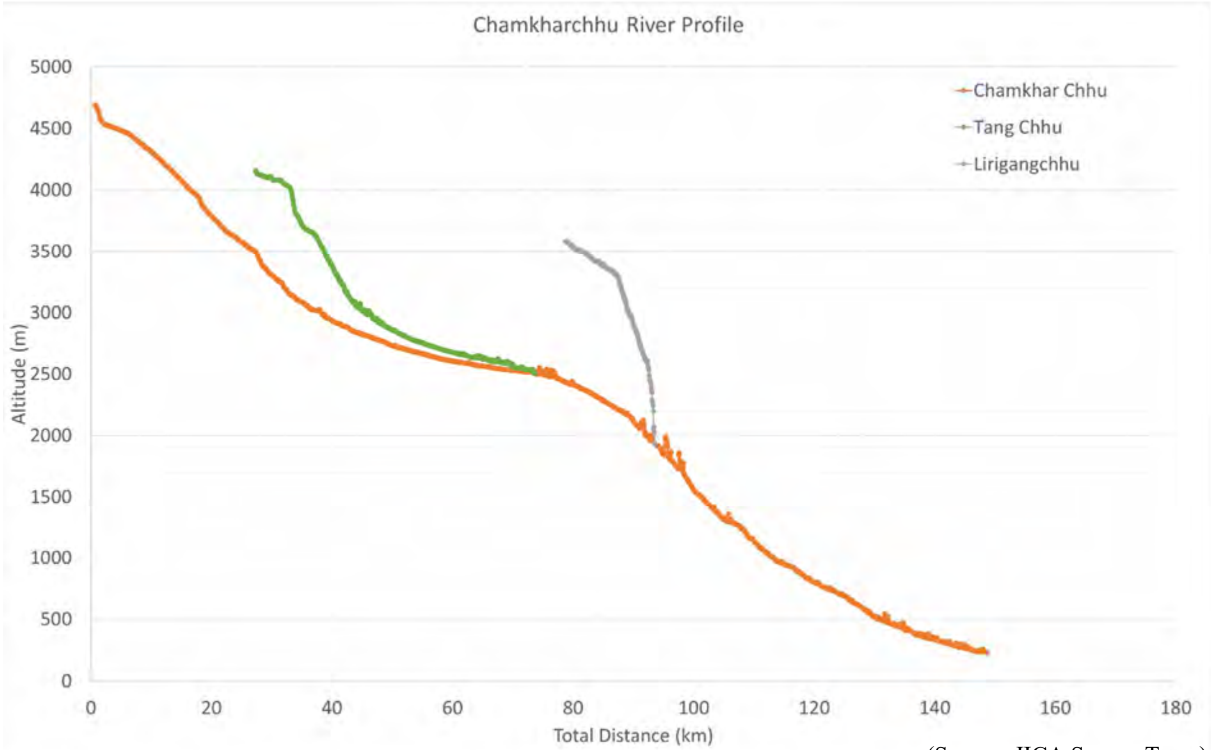
The largest tributary, Chamkharchhu joins Mangdechhu on the left at an elevation of about 270m and the slope is 1:33 on average, which is steeper than the main stream.

The catchment area of Mangdechhu increases from 3,800 sq. km to 6,800 sq. km at the confluence of Mangdechhu and Chamkharchhu. The catchment area of Mangdechhu at its outlet at the confluence with Manas is around 7,300 sq. km. The profiles of rivers within the basin are shown in Figure 5-8 and Figure 5-9, and the relationship between the river profile of each main stream and its catchment area is shown in Figure 5-10 and Figure 5-11.



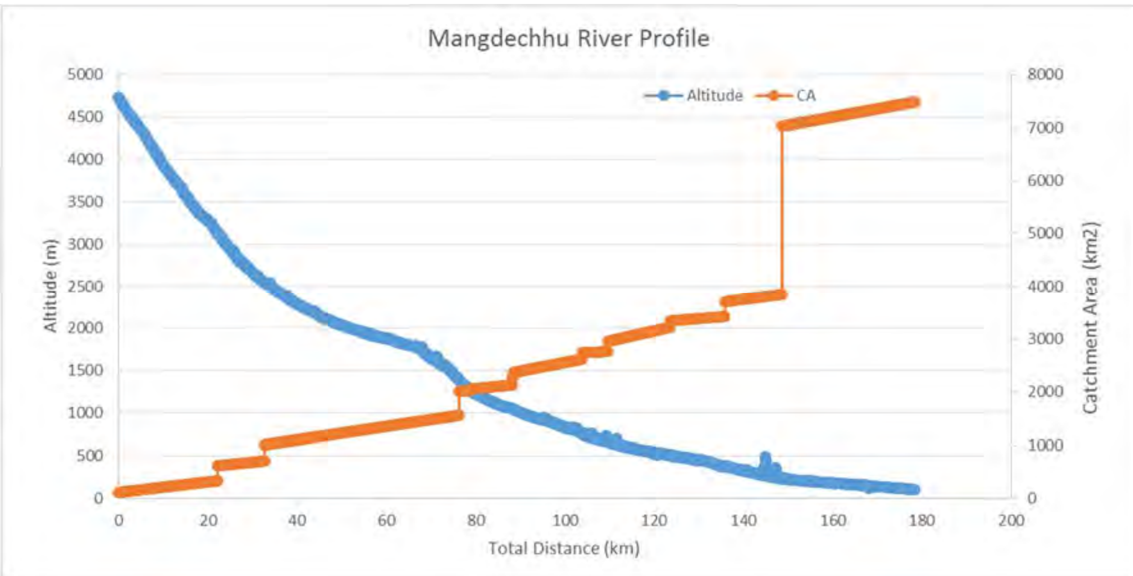
(Source: JICA Survey Team)

Figure 5-8 River Profile of Mangdechhu Basin



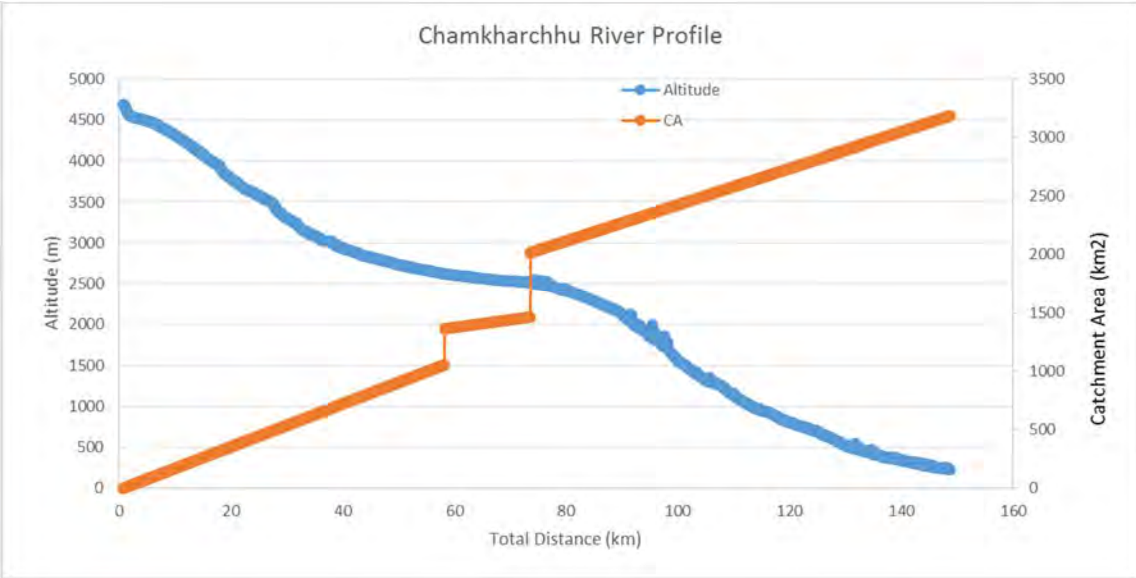
(Source: JICA Survey Team)

Figure 5-9 River Profile of Chamkharchhu Basin



(Source: JICA Survey Team)

Figure 5-10 River Profile and Catchment Area of Mangdechhu Main River



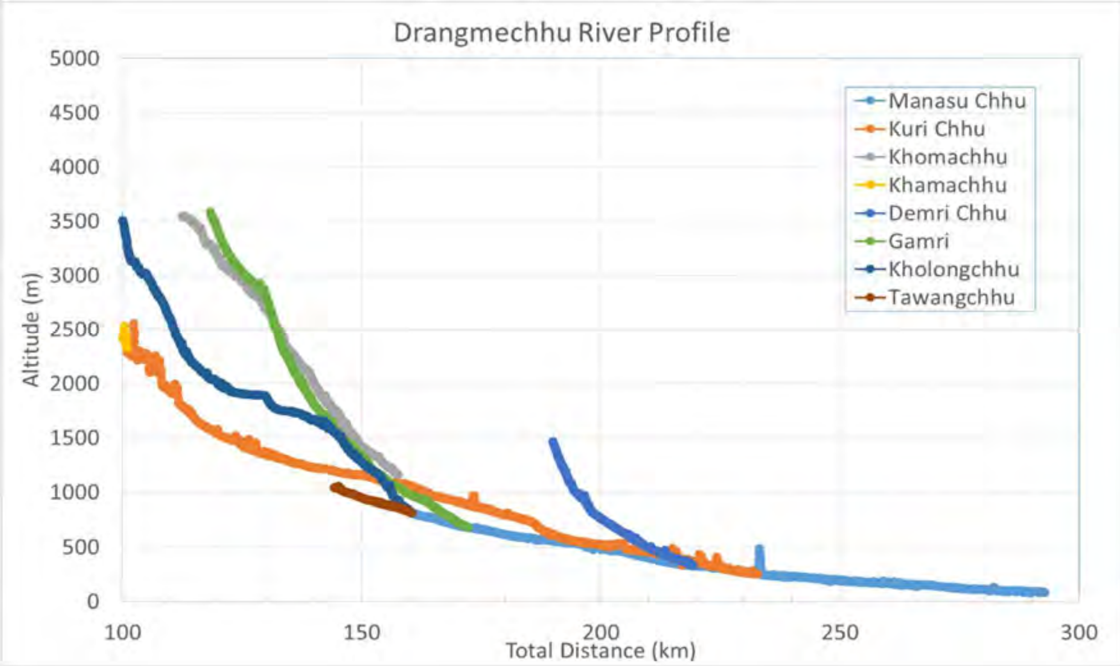
(Source: JICA Survey Team)

Figure 5-11 River Profile and Catchment Area of Chamkharchhu Main River

(5) Drangmechhu river basin (Manas river basin)

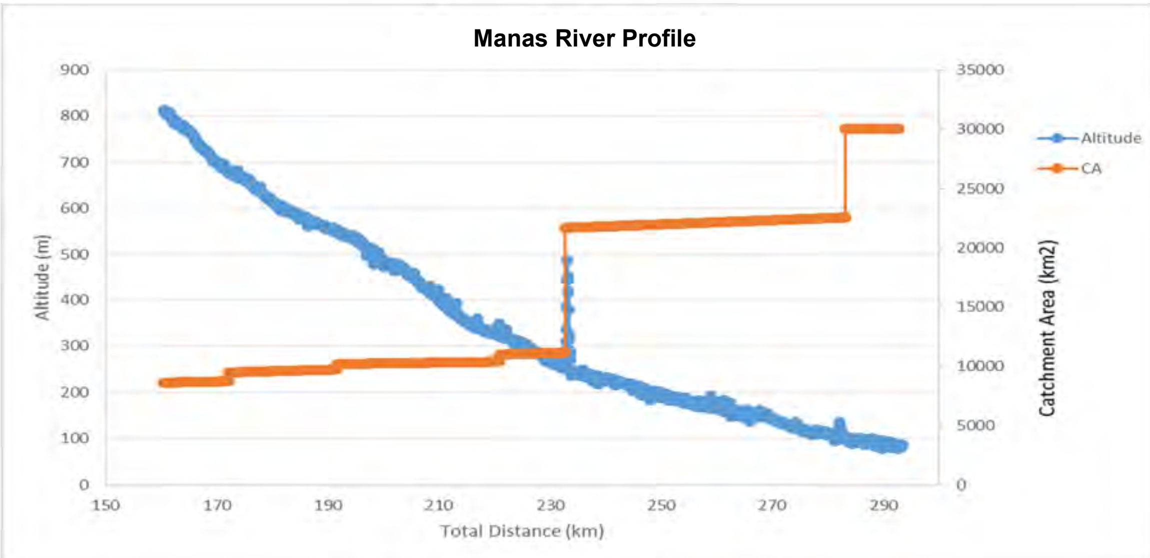
Drangmechhu (Manas) is the biggest river system in Bhutan. The basin is drained by two major rivers, Kurichhu and Gongri. The Kurichhu and Gongri river systems are transboundary rivers which have their sources originating in China. Gongri confluences with Kurichhu and thereafter is known as Drangmechhu. About 60% of the total Kurichhu catchment and 64% of the total Gongri catchment lie outside Bhutan. The Drangmechhu traverses through the southern foothills, where it is known as Manas, and is joined by Mangdechhu on the right at an elevation of about 150masl. The river drains into India about 9km downstream of the confluence of Drangmechhu and Mangdechhu. The average river slope in Bhutan is relatively gentle, at approximately 1:180, but the tributaries have much steeper slopes.

The catchment area of Drangmechhu at the confluence of Kurichhu and Gongri is about 22,000 sq. km becoming approximately 30,000 sq. km at the confluence with Mangdechhu. The profiles of the rivers within the Drangmechhu basin are shown in Figure 5-12, and the relationship between the river profile of each main stream and its catchment area is shown in Figure 5-13 and Figure 5-14.



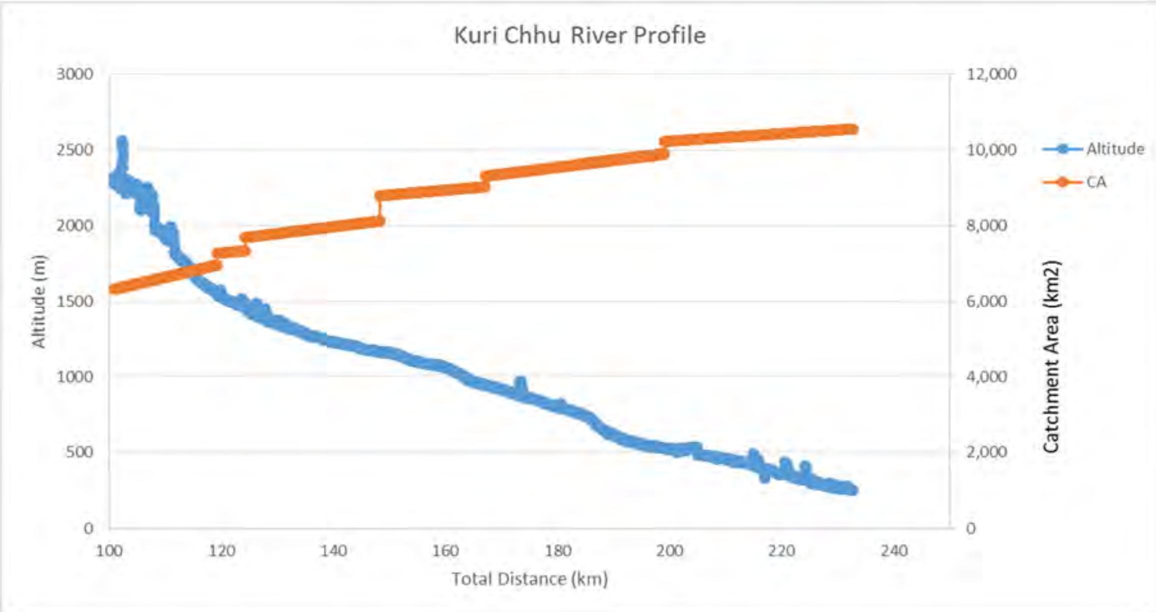
(Source: JICA Survey Team)

Figure 5-12   River Profile of Drangmechhu Basin



(Source: JICA Survey Team)

Figure 5-13   River Profile and Catchment Area of Manas Main River



(Source: JICA Survey Team)

Figure 5-14 River Profile and Catchment Area of Kurichhu Main River

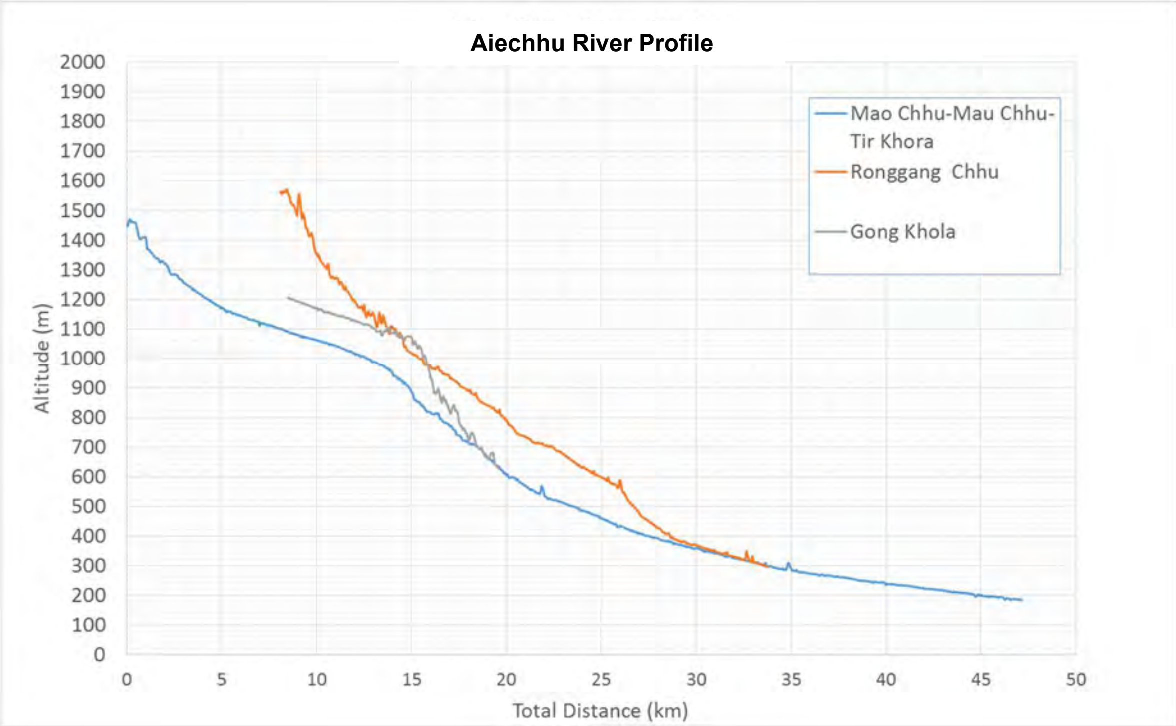
(6) Aiechhu, Nyera Amari and Jomori Basins

Aiechhu river basin originates at an EL 3,000m class mountain ridge in South Central Bhutan, and it is a relatively small river basin with a length of approximately 50km up to the Indian border. Its river slope is 1:40 on average, and its catchment area is 830km^2 at the Indian border.

Nyera Amari river basin originates at an EL 4,000m class mountain ridge in South East Bhutan, and it is a relatively small river basin with a length of approximately 110km up to the Indian border. Its river slope is 1:30 on average, and its catchment area is 1,100km^2 at the Indian border.

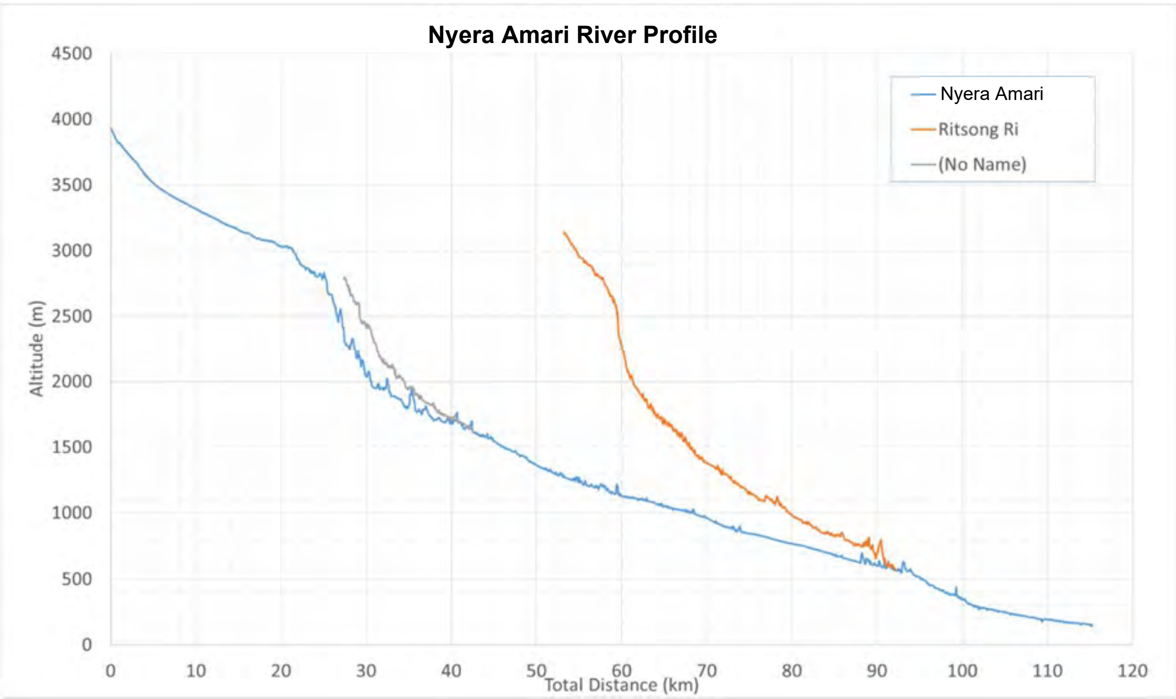
Jomori river basin also originates at an EL 4,000m class mountain ridge in South East Bhutan, and it is a relatively small river basin with a length of approximately 70km up to the Indian border. Its river slope is 1:20-25 on average, and its catchment area is 720km^2 at the Indian border.

The river profiles of Aiechhu, Nyera Amari and Jomori river basin are shown in Figure 5-15, Figure 5-16 and Figure 5-17.



(Source: JICA Survey Team)

Figure 5-15 River Profile of Aiechhu Basin



(Source: JICA Survey Team)

Figure 5-16 River Profile of Nyera Amari Basin

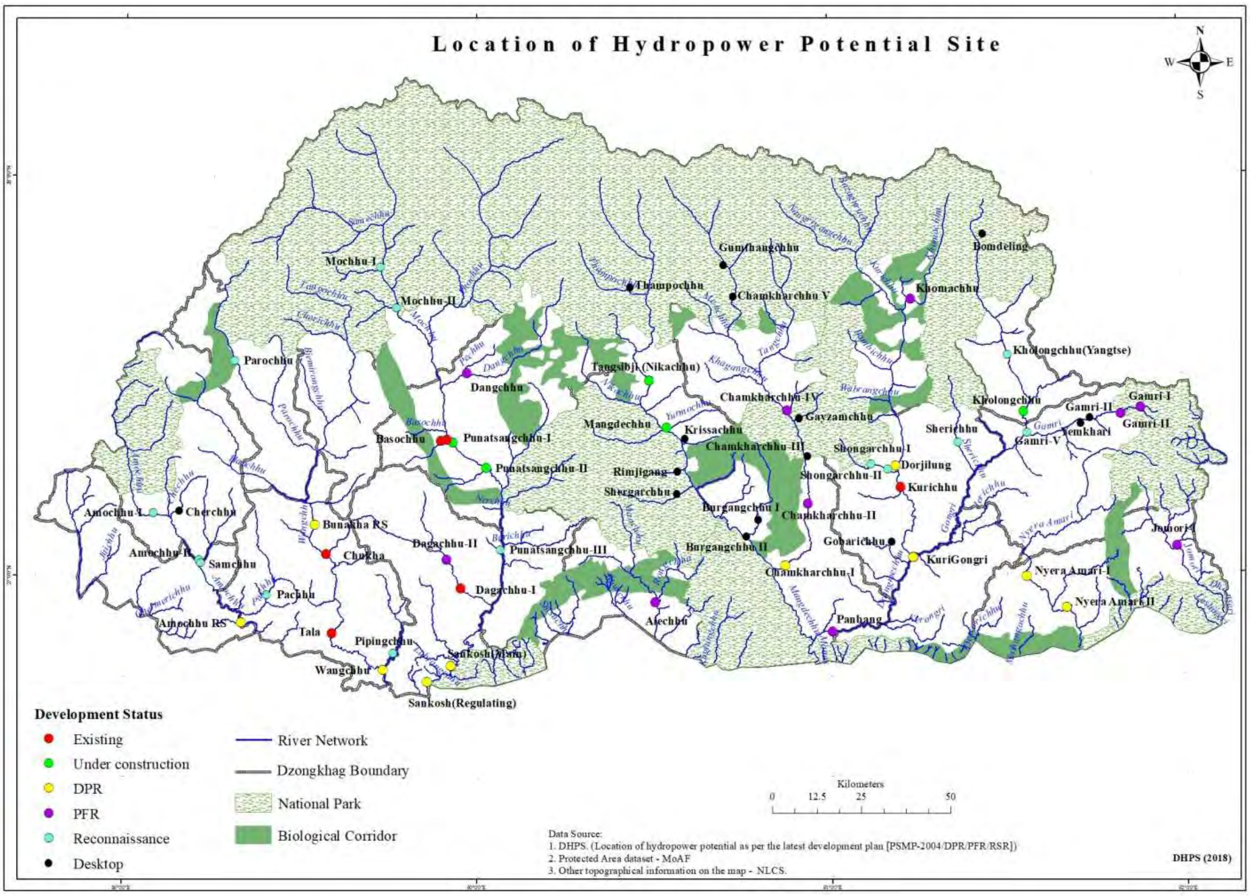
(Source: JICA Survey Team)

Figure 5-17 River Profile of Jomori Basin

5.1.3 Potential Hydropower Sites in PSMP 2004

The Power System Master Plan (PSMP-2004) estimated the overall hydropower potential of Bhutan at about 30,000MW with the energy production of about 120,000GWh as shown in Figure 5-18. Out of the total potential, 70 RoR and 6 reservoir schemes with their capacities greater than 10MW were envisaged and projects having a capacity greater than 25MW fall under the purview of DHPS. While most of these projects have been studied at various levels, few are under construction phase and six (6) hydropower plants under operation, the installed capacity of the country has reached at 1,606MW.

The updated location map of the hydropower potential sites as of 2018 is shown in Figure 5-18.



(Source: DHPS)

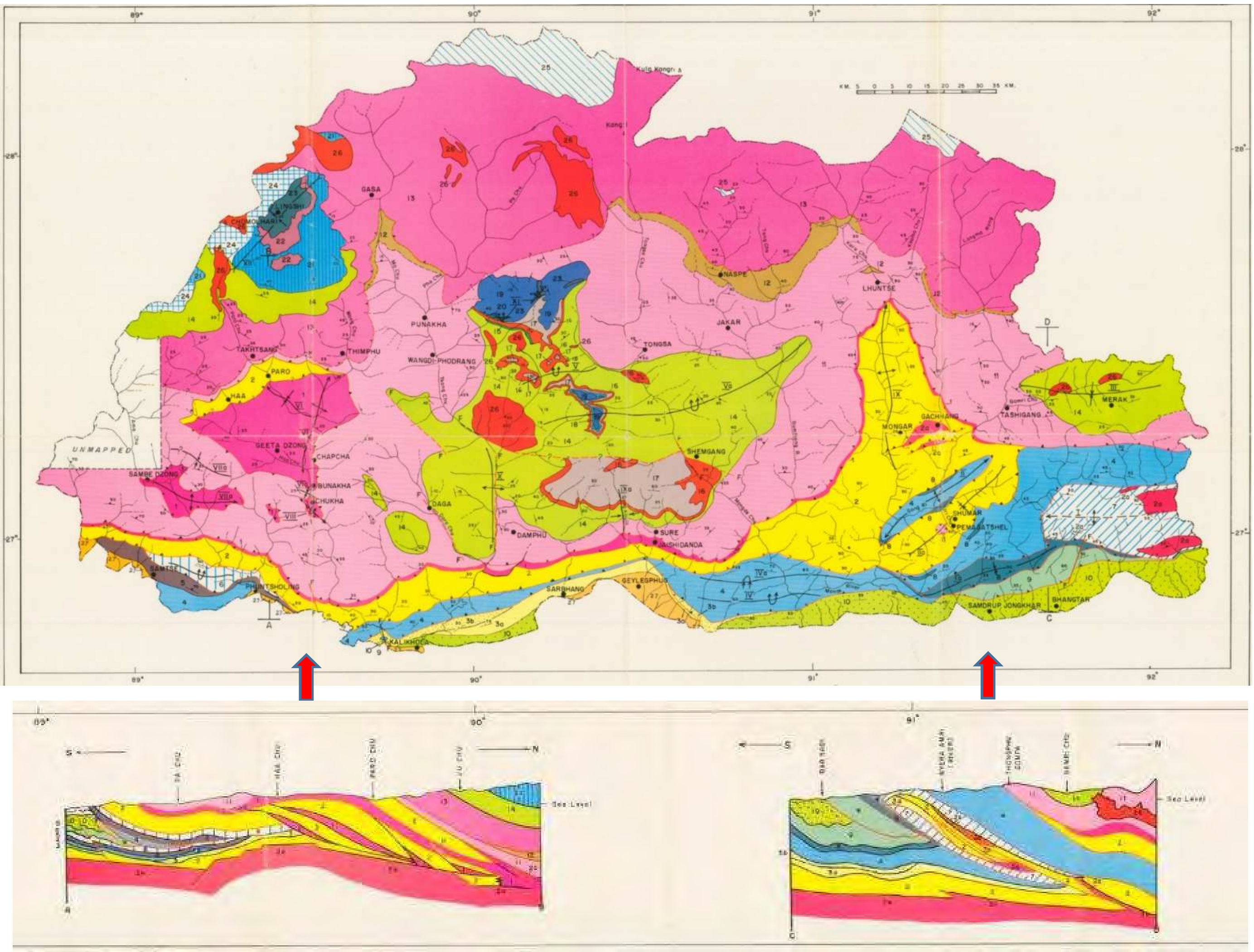
Figure 5-18 Updated Location Map of Potential Sites as of 2018

5.2 General Geology

Detail Geology of Bhutan was unveiled with the publishment of 'Geology of Bhutan Himalaya' by A. Gansser et al. in 1983 as shown in Figure 5-19. With time, the study deepened and "The Bhytan Himalaya - A Geological Account", GSI publication in 1995 written by O.N Bhargava has been commonly used for many development sites. Figure 5-20 and Figure 5-21 shows the plan view, and cross-sectional views in the South-North direction, Western (A-B) and Eastern (C-D) locations, with their legends.

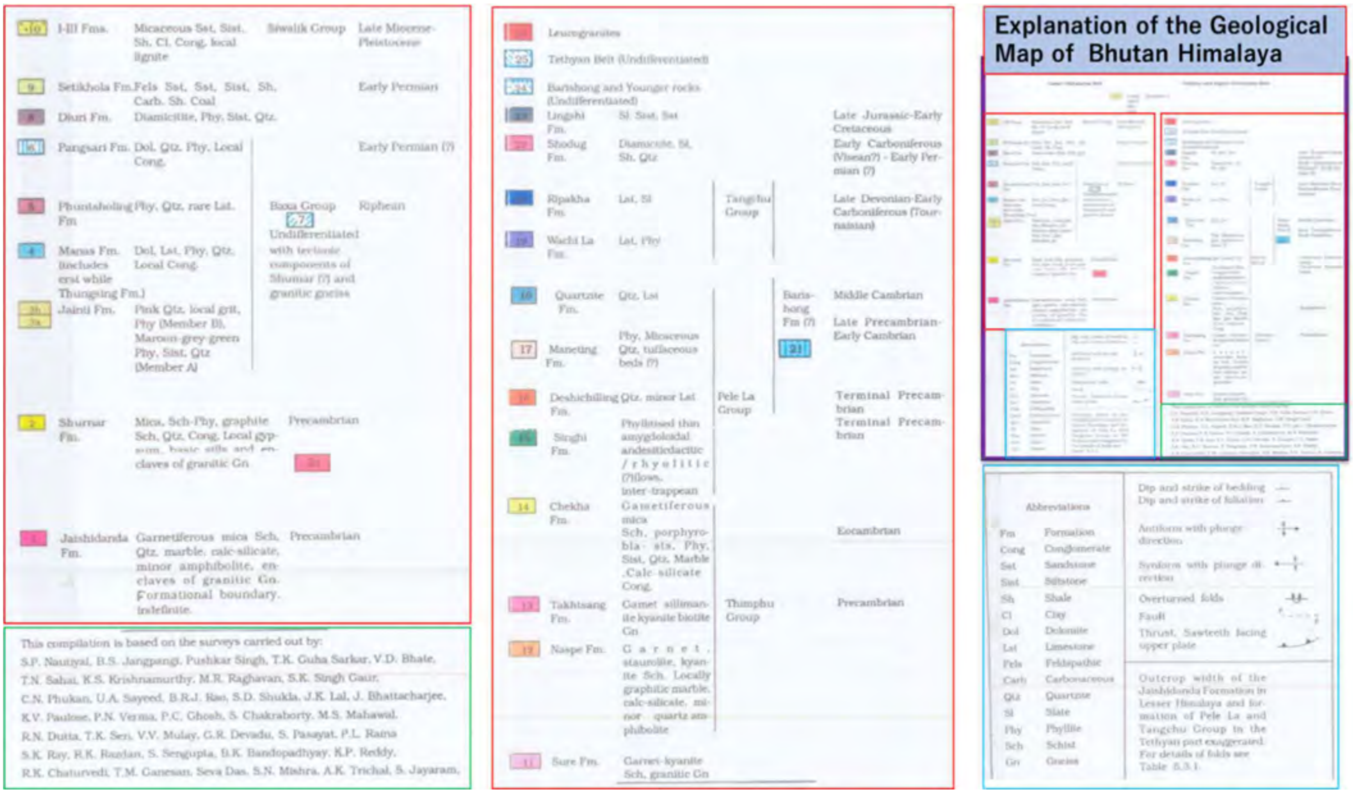
(Source : JICA Survey Team compiled based on A.Gansser, (1983))

Figure 5-19 Geological Plan of Bhutan by A. Gansser, 1983



(Source: Bhargava, 1995)

Figure 5-20 Geological Plan of Bhutan by Bhargava, 1995



(Source: JICA Survey Team compiled based on Bhargava, 1995)

Figure 5-21 Geological Plan of Bhutan by Bhargava, 1995 (Legends)

The Neogene Siwalik Group, which is the dotted yellow zone, is located at the south end of the country. Some formations belonging to the Baxa Group, which are colored yellow, are convoluted under low-grade Paleoproterozoic to Permian sedimentary rocks of the Lesser Himalayan Series (LHS). The Neoproterozoic Greater Himalaya Series (GHS), which is colored pink, comprising Leucogranite and high-grade metasedimentary gneisses, is covered by the Tethyan Sedimentary Series (TSS), which is colored dark pink.

The following table (Table 5-1) is a tectono-stratigraphic order of Bhutan based on Bhargava's work. These lithologic groups and formations are separated by mostly north-dipped thrusts. Those strata are very complicated, with the younger stratum folded into the lower part of the older stratum with thrust faults interposed.
Remarkable exfoliative and strength-anisotropic characteristics are recorded in the rocks close to the major structural faults and in most pelite-originated metamorphic strata related to the above-mentioned complicated geological structure.

Table 5-1 Tectono-stratigraphic order of superposition in Bhutan Himalaya

Tethyan succession	Conglomerate, shale, siltstone, sandstone, limestone, volcanics
	----- Unconformity -----
Thimphu Group	Gneiss, migmatite, amphibolite and high grade metasediments
	----- Thimphu Thrust -----
Jaishidanda Formation	Biotite-garnet-staurolite schist with tectonic slivers of granite gneiss
	----- Jaishidanda Thrust -----
Shumar Formation	Quartzite, phyllite and chlorite-mica schist, Barsong limestone, a few tectonic slivers of granite gneiss in lower part
	----- Shumar Thrust -----
Diuri Formation	Diamictite, phyllite, quartzite
	----- Unconformity? – locally tectonised -----
Baxa Group	Gritty feldspathic quartzite, limestone, dolomite, quartzite, conglomerate, slate, phyllite, tectonic scales of Permian Setikhola Formation
	----- Baxa Thrust -----
Damuda Subgroup	Sandstone, siltstone, shale, coal beds
	----- Main Boundary Thrust -----
Siwalik Group	Sandstone, siltstone, shale, clay, conglomerate
	----- Fault -----
Quaternary succession	Sand, conglomerate, silt, clay

(Source: JICA Survey Team compiled from the Bhutan Himalaya: a geological Account (Bhargava, 1995))

The latest geological map edited by Long et al. in 2011 is currently used in Bhutan. Long et al. comprehensively compiled previous, useful geological information. The accumulation of fine geological data shows more ground than the other conventional geological maps and it is highly accurate, as shown in Figure 5-22 and Figure 5-23.

The geologic zone in Bhutan comprises four main geo-tectonic units and they contact three major thrusts which point toward the north. The geotectonic units (from South to North) are 1. Neogene Sub-Himalayan zone composed of Siwalik Group, 2. Lesser Himalayan Zone mainly composed of Proterozoic meta-sedimentary rocks, 3. Greater Himalayan Zone consisting of higher Himalaya gneisses, and 4. Tethyan Himalayan Zone consisting of Tethyan sedimentary rocks. The boundary between the Sub-Himalayan Zone and the Lesser Himalayan Zone is the main boundary thrust (MBT) fault. The main central thrust (MCT) fault is between the lesser Himalayan Zone and the Greater Himalayan Zone. The South Tibetan detachment (STDs, normal fault) is between the Greater Himalayan Zone and the Tethyian Himalayan Zone at the north end.

1. Neogene Sub-Himalayan zone composed of Siwalik Group
The Siwalik Group is composed of three members - upper, middle and lower. Since it was deposited in two coarsening up megacycles consisting of sandstone clay alternations in the lower portion passing gradually into coarse sandstones and/or conglomerates towards the top, the upper member is the courcest and the lower member is the finest.

2. Lesser Himalayan Zone mainly composed of Proterozoic meta-sedimentary rocks
The Lesser Himalayan Zone consists of the Paro Formation, Daling-Shumar Group, Baxa Group, Jaishidanda Formation, Diuri Formation, and Gondwana succession.
The Paro Formation consists of high-grade metasedimentary and calcareous rocks, including calc-silicate rocks, marble, quartzite, quartz-garnet-staurolite-kyanite schist which subordinate feldspathic schist and bodies of two mica granite-composition orthogneiss.

The Daling-Shumar Group is distributed in the northernmost part of the Lesser Himalayan Zone, and is in contact with the Greater Himalayan Zone by MCT. It is mainly composed of platy quartzite and phyllite, and mica-schist is distributed in the vicinity of MCT. In the upper part of the lower Daling-Shumar Group, limestone is accompanied with platy quartzite. The Baxa Group is widely distributed in the south (structural lower order) of the Daling-Shumar Group. In the Baxa Group, stratigraphically the upper is composed of the Pangsari Formation, Manas Formation, and Phuentsholing Formation in order of older age. The Pangsari Formation consists of thin-bedded to laminated, locally talcose phyllite interbedded with medium-to thick-bedded dolostone and marble, and fine-to medium-grained, thin-bedded quartzite.

The Manas Formation has medium-to thick-bedded, medium-to coarse-grained, locally-conglomeratic quartzite exhibiting common trough cross-bedding, interbedded with thin-bedded to thinly-laminated phyllite, and medium-gray dolostone. The Phuentsholing Formation consists of finely-laminated slate and phyllite, interbedded with thin-to medium-bedded limestone, thin-bedded fine- to medium-grained quartzite, and creamy gray dolostone.

The Jaishidanda Formation is composed of biotite-rich, locally garnet-bearing schist, interbedded with biotite lamination-bearing, lithic clast-rich quartzite.

The Diuri Formation has pebble-to cobble, slate-matrix diamictite.

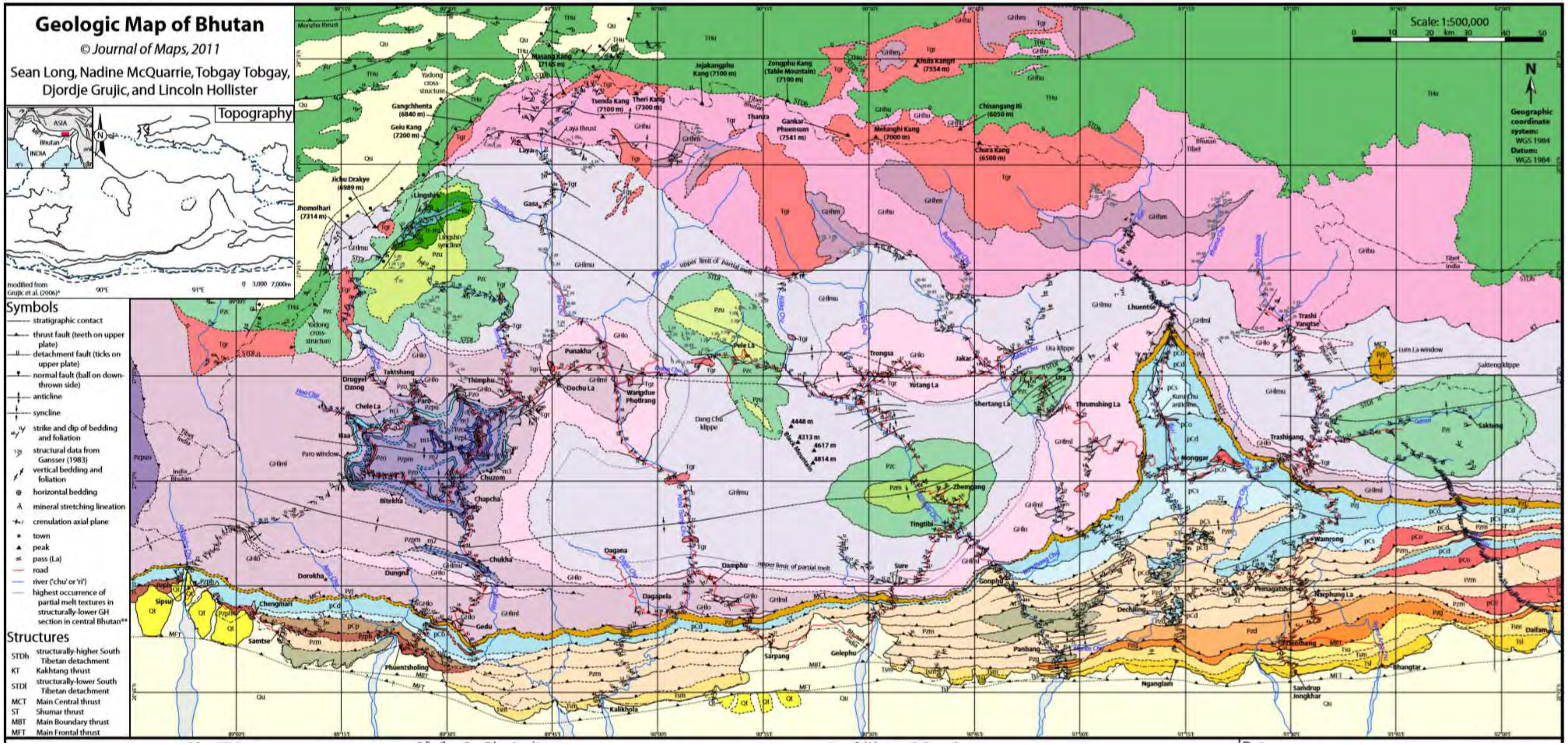
The Gondwana succession is composed of medium-grained, feldspathic, lithic-rich sandstone interbedded with thin-to medium-bedded, carbonaceous siltstone, shale, slate, and argillite, and rare coal beds.

3. Greater Himalayan Zone consisting of higher Himalaya gneisses

The Greater Himalayan Zone is structurally divided into two, with the lower above the MCT and below the Kakhtang Thrust (KT) and higher above the KT section. The former overlies the Paro Formation, and the rock is paragneiss interlayered with quartzite, both of which contain partial melt textures. The latter is composed of migmatitic orthogneiss and metasedimentary rocks, including schist, paragneiss, quartzite, and marble, and intruded by Miocene Leucogranite.

4. Tethyan Himalayan Zone consisting of Tethyan sedimentary rocks

Rocks of the Tethyan Himalayan Zone are preserved above the Greater Himalayan section in synforms. The basal Tethyan Himalayan rocks, referred to as Chekha Formation, consist of quartzite, shale, siltstone, sandstone, and conglomeratic quartzite. These are overlain by Maneting Formation phyllite and fossiliferous limestone of Late Cambrian age. Undifferentiated (Paleozoic-Eocene) rocks such as limestone, sandstone, shale, and locally marble, quartzite, slate, and phyllite are above the structurally higher South Tibetan detachment (STDh).



(Source: http://www.pitt.edu/~nmcq/Long_etal_2011_JOM_Bhutan_Map_1-500k.pdf#search=%27long+et+al%2C+bhutan%27)

Figure 5-22 Latest Geological Plan of Bhutan by Long, 2011

(Source: http://www.pitt.edu/~nmcq/Long_etal_2011_JOM_Bhutan_Map_1-500k.pdf#search=%27long+et+al%2C+bhutan%27)

Figure 5-23 Latest Geological Plan of Bhutan by Long, 2011 (Legends)

Table 5-2 Geological Units and Lithologic features of Bhutan

Geological Units				Lithologic features
Quaternary sediment		Qt	River terraces	Uplifted remnants of older alluvial terraces in southwest and south-central parts of map area.
		Qu	Undifferentiated	Unconsolidated sediment deposited in braided stream, alluvial fan, and floodplain environments across southernmost Bhutan and northernmost India. Also includes undifferentiated sediment of Tibetan Plateau.
Sub-Himalayan Zone	Siwalik Group (Miocene-Pliocene)	Tsu	Upper member	Medium- to coarse-grained conglomeratic sandstone and pebble-to cobble- and locally boulder- (up to 1-2 m in diameter) conglomerate, interbedded with tan siltstone.
		Tsm	Middle member	Tan to gray, medium- to coarse-grained sandstone and pebble- to cobble-conglomeratic sandstone.
		Tsl	Lower member	Gray to green, massive-weathering siltstone and shale, interbedded with tan to gray, fine-grained, lithic-rich sandstone.
Lesser Himalayan Zone		Pzg	Gondwana succession (Permian)	Gray, medium-grained, feldspathic, lithic-rich sandstone interbedded with dark-gray to black, thin- to medium-bedded, carbonaceous siltstone, shale, slate, and argillite, and rare black coal beds.
		Pzd	Diuri Formation (Permian)	Green-gray, pebble- to cobble-, slate-matrix diamictite. Conglomerate at base along Kuri.
		Pzj	Jaishidanda Formation (Neoproterozoic-Ordovician[?])	Gray, biotite-rich, locally garnet-bearing schist, interbedded with gray to tan, biotite lamination-bearing, lithic clast-rich quartzite . Upper greenschist to lower amphibolite facies.
	Baxa Group	Pzph	Phuentsholing Formation (Neoproterozoic[?] or younger)	Dark-gray to black, finely-laminated slate and phyllite, interbedded with thin- to medium-bedded, gray to tan limestone, thin-bedded, tan to dark-brown, fine- to medium-grained quartzite, and creamy gray dolostone.
		Pzm	Manas Formation (Neoproterozoic-Cambrian[?])	Gray to white, medium- to thick-bedded, medium- to coarse-grained, locally-conglomeratic quartzite exhibiting common trough cross-edding, interbedded with dark-gray to dark-green, thin-bedded to thinly-laminated phyllite, and medium-gray dolostone.
		pCp	Pangsari Formation (Mesoproterozoic[?]-Cambrian[?])	Dark-green to dark-gray, thin-bedded to laminated, locally talcose phyllite interbedded with white, pink, and green, medium- to thick-bedded dolostone and marble, and green, fine- to medium-grained, thinbedded quartzite.
	Daling-Shumar Group (Paleoproterozoic)	pCd	Daling Formation	Similar lithologies to Shumar Formation, but dominated by schist and phyllite. Quartzite is thin- to medium-bedded, and medium-gray limestone interbeds are rare. Lower contact is gradational with Shumar Formation.
		pCo	Orthogneiss	Concordant bodies of mylonitized, granitic orthogneiss at varying stratigraphic levels; interpreted as deformed Paleoproterozoic granite plutons that intruded Daling-Shumar Group.
		pCs	Shumar Formation	Light-gray to white, tan-weathering, very fine-grained, medium- to thick-bedded, cliff-forming quartzite. Interbeds of thinto thick-bedded, green, muscovite-biotite schist and phyllite with diagnostic sigmoidal quartz vein boudins become more common upsection.
	Paro Formation	Pzpun	Undifferentiated (age uncertain)	Metasedimentary rocks at west end of map area in Sikkim.
		Pzpu	Upper unit (Cambrian-Ordovician)	Tan to gray, very coarse-grained, thin- to medium-bedded, cliff-forming, biotite-rich quartzite, interbedded with biotite-muscovite-garnet schist. Marble marker bed is divided out.
		Pzpm	Middle unit (Cambrian-Ordovician)	Gray to tan, thin-bedded, fine-grained, micaceous quartzite, interbedded with biotite-garnet-muscovite schist , rare calc-silicate rocks, and marble. Contact with schist of lower unit is gradational. Two white to gray, mediumcrystalline marble marker beds are divided out.
		Pzo	Orthogneiss (Ordovician)	Concordant, foliated leucogranite and granitic orthogneiss bodies within middle and upper unit, interpreted as deformed Ordovician granite plutons. Kyanite- and sillimanite-bearing schist locally present in country rock adjacent to intrusions.
		Pzpl	Lower unit (Neoproterozoic[?]-Ordovician)	Muscovite-biotite-garnet-staurolite schist, with kyanite present within quartz veins . Quartzite interbeds become more common upsection.
Greater Himalayan Zone	Structurally-lower Greater Himalayan section	GHlmu	Upper metasedimentary unit (Neoproterozoic-Ordovician[?])	Variable metamorphic grade; dominantly amphibolite facies ,partial melt- and often kyanite-, sillimanite-, or staurolite-bearing paragneiss, schist, and quartzite in east and near base in west-central Bhutan, and melt-free, dominantly upper greenschist-facies quartzite and biotite-muscovite-garnet schist in central Bhutan. Upper limit of partial melt textures in central Bhutan is shown.
		GHlo	Orthogneiss unit (Cambrian-Ordovician)	Cliff-forming, massive-weathering, granite-composition orthogneiss; generally exhibits leucosomes and abundant feldspar augen . Paragneiss, schist, and quartzite intervals locally split out.Interpreted as deformed Cambrian-Ordovician granite plutons that intruded Greater Himalayan sedimentary protoliths thickens toward eastern Bhutan.
		GHlml	Lower metasedimentary unit (Neoproterozoic-Cambrian[?])	Dominantly amphibolite-facies metasedimentary rocks, including quartzite, and biotite-muscovite-garnet schist and paragneiss often exhibiting kyanite, sillimanite, or staurolite, and partial melt textures. Orthogneiss intervals locally split out.
	Structurally-higher Greater Himalayan section	Tgr	Leucogranite (Miocene)	Massive to foliated, syn-Himalayan leucogranite plutons. Leucogranite intrudes the structurally-higher and structurally-lower Greater Himalayan sections, as well as Tethyan Himalayan rocks near the STDI in the Lingshi region.
		GHhu	Undifferentiated (age uncertain)	Upper amphibolite-, granulite- , and locally eclogite-facies migmatitic orthogneiss and metasedimentary rocks, including schist, paragneiss, quartzite,and marble.
		GHhm	Metasedimentary rocks (age uncertain)	Migmatitic schist and paragneiss, and lesser quartzite and marble, locally divided out, based primarily on the mapping of Gansser.
Tethyan Himalayan Zone		THu	Undifferentiated (Paleozoic-Eocene)	Limestone, sandstone, shale, and locally marble, quartzite, slate, and phyllite above STDh in Tibet and parts of northernmost Bhutan
		Ku	Cretaceous, undifferentiated	Dark-gray to black, brown-weathering, carbonaceous shale, and brown sandstone. Equivalent to upper part of Lingshi Formation of Tangri and Pande.
		Tr-Jru	Triassic-Jurassic, undifferentiated	Dark-gray, tan weathering shale, and fine-grained sandstone. Forms diagnostic tan slopes.Equivalent to lower part of Lingshi Formation of Tangri and Pande.
		Pzu	Paleozoic, undifferentiated	In Lingshi region: medium-gray, cliff-forming, thin-bedded, silt lamination-rich, fossiliferous limestone equivalent to Barshong Formation (Early-Middle Cambrian) of Tangri and Pande, and brown, pebble-clast diamictite equivalent to Shodug Formation (Permian-Carboniferous) of Tangri and Pande. In Dang Chu klippe: Gray to brown,fine-grained quartz sandstone of Deschilling Formation (Late Cambrian), dark-gray shale of Maneting Formation (Late Cambrian), and gray, finegrained sandstone of Quartzite Formation (Late Cambrian) of Pele La Group , and Late Devonian-Early Carboniferous Wachi La and Ripakha Formations of overlying Tang Chu Group.
		Pzm	Maneting Formation (Ordovician or younger)	Dark-gray, graphitic, crenulated, finely-laminated, biotite-garnet phyllite.
		Pzc	Chekha Formation (Ordovician or younger)	Tan to gray, thick-bedded, fine- to medium-grained, cliff-forming, micaceous quartzite, interbedded with biotite-muscovite-garnet schist in eastern and central Bhutan. Interbedded with green to white, thin-bedded marble in Dang Chu klippe. Dominated by tan, cliff-forming marble, with lesser gray phyllite and dark-gray phyllitic quartzite in Lingshi region. Dominantly upper greenschist facies.

(Source: JICA Survey Team compiled from Long et al., 2011)

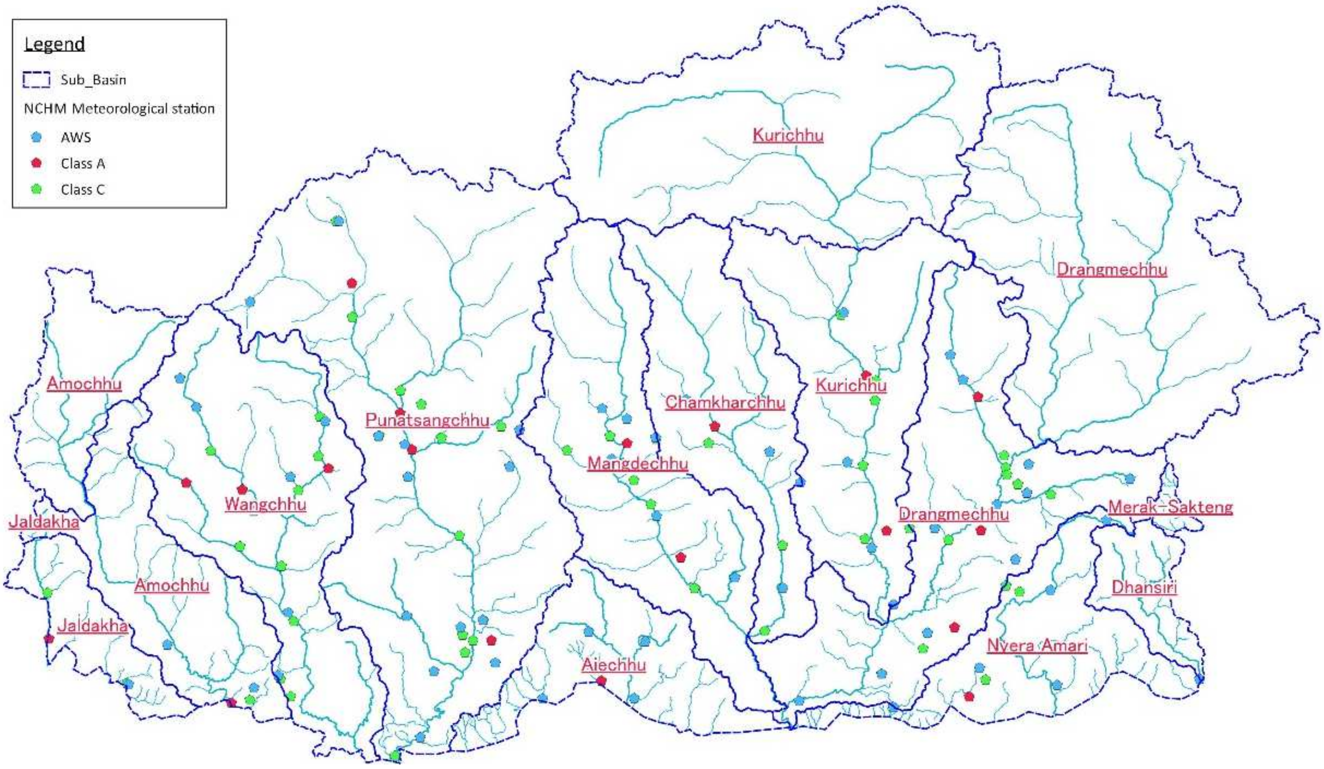
5.3 Hydrological Analysis

5.3.1 Availability of Meteorological and Hydrological Data

(1) Availability of Meteorological Data

The National Center for Hydrology and Meteorology (NCHM) monitors, collects and manages hydrological and meteorological data in Bhutan. NCHM operates 20 "Class A" stations, which are the principal meteorological observatories that collect meteorological data such as rainfall, temperature, or solar radiation. NCHM also operates 69 "Class C" stations, which are second-class meteorological observatories that collect rainfall, temperature and humidity data only. From 2010, NCHM started meteorological observations in 63 locations using Automatic Weather Stations (AWS). The locations of the rainfall stations operated by NCHM are shown in Figure 5-24.

The Class A and Class C rainfall data from NCHM were provided by DHPS. An inventory of this Class A and Class C meteorological station data is shown in Table 5-3 and Table 5-4.



(Source: NCHM)

Figure 5-24 Locations of Rainfall Observatories

Table 5-3 Inventory of Rainfall Data from Class A Stations

Class A Meteorological Station																												
Sl. No.	***Station Name***	***Latitude***	***Longitude***	***Altitude (m)***	***Status***	***1995***	***1996***	***1997***	***1998***	***1999***	***2000***	***2001***	***2002***	***2003***	***2004***	***2005***	***2006***	***2007***	***2008***	***2009***	***2010***	***2011***	***2012***	***2013***	***2014***	***2015***	***2016***	***2017***
1	Bhur	26.907 N	90.434 E	377	In function		■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	
2	Chamkhar	27.54 N	90.755 E	2470	In function		■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	
3	Dagana	27.071 N	89.884 E	1531	In function		■	■	■	■	■	■	■	■	■	■	■	▨	■	▨	■	■	■	■	■	■	■	
4	Damphu	27 N	90.122 E	1520	In function		■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	
5	Deothang	26.85 N	91.467 E	861	In function		■	■	■	■	■	■	■	■	■	■	▨	▨	■	■	■	■	■	■	■	■	▨	
6	Gasa	27.9 N	89.716 E	2760	In function									■	■	▨	▨	■	▨	▨	■	▨	■	■	▨	■	■	
7	Haa	27.403 N	89.262 E	2764	In function		■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	▨	■	■	
8	Kanglung	27.271 N	91.522 E	2005	In function		■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	
9	Mongar	27.279 N	91.238 E	1597	In function		■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	
10	Paro	27.383 N	89.42 E	2406	In function		■	■	■	■	■	■	■	■	■	■	■	■	■	■	▨	■	■	■	■	■	■	
11	Pemagatshel	27.02 N	91.424 E	1723	In function		■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	▨	■	■	
12	Phuntsholing	26.85 N	89.389 E	280	In function		■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	▨	■	▨	▨	▨	
13	Punakha	27.582 N	89.866 E	1236	In function		■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	
14	Sipsu	27.009 N	88.878 E	423	In function		■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	▨	■	■	
15	Simtokha	27.438 N	89.675 E	2310	In function		■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	
16	Tangmachu	27.595 N	91.197 E	1750	In function											■	■	■	■	■	■	▨	▨	■	▨	■	■	
17	Trashiyangtse	27.6 N	91.5 E	1855	In function		■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	
18	Trongsa	27.502 N	90.505 E	2120	In function		■	■	■	■	■	■		■	■	■	■	■	■	■	■	■	■	■	■	■	■	
19	Wangdue	27.487 N	89.901 E	1180	In function		■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	
20	Zhemgang	27.216 N	90.655 E	1862	In function		■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	

■ Data Complete (No missing data) ▨ Data Partially Complete (Including missing data) Blank No Data

(Source: NCHM)

Table 5-4 Inventory of Rainfall Data from Class C Stations

Class C Meteorological Station

Sl. No.	Station Name	Latitude	Longitude	Altitude (m)	Status	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
1	Airong	26.901 N	91.508 E	1305	Closed in 2014										■	■	■	■	■	■						■								
2	Autsho	27.442 N	91.176 E	800	Running																			■	■	■	■	■	■			■		
3	Begana	27.573 N	89.643 E	2520	Running																						■	■	■	■		■		
4	Betikha	27.25 N	89.416 E	2660	Running										■	■	■	■		■			■			■	■	■						
5	Bidung	27.368 N	91.661 E	1815	Running																												■	
6	Bjizam	27.52 N	90.456 E	1840	Running									■	■	■	■	■	■			■			■	■	■							
7	Buli	27.166 N	90.816 E	1780	Running																	■	■	■	■									
8	Bumdelling	27.664 N	91.592 E	1933	Running																							■						
9	Chapcha	27.2 N	89.55 E	2450	Running														■	■	■	■	■	■			■			■	■			
10	Chenary	27.321 N	91.534 E	830	Running				■	■	■	■	■	■			■			■	■	■			■			■					■	
11	Chendebji	27.508 N	90.276 E	2660	Running									■	■	■	■	■	■	■						■	■	■						
12	Chhukha	27.066 N	89.566 E	1380	Running								■	■			■			■	■	■			■			■			■	■		
13	Daifam	26.89 N	92.108 E	280	Running										■	■	■	■	■	■			■			■		■						
14	Damji	27.826 N	89.737 E	-	Running																						■		■					
15	Dechenling	26.916 N	91.233 E	1000	Running																			■	■	■	■	■	■					
16	Degala	27.028 N	90.851 E	975	Running																													
17	Doksum	27.435 N	91.577 E	950	Closed in 2013														■	■	■	■	■											
18	Drujeygang	26.975 N	90.042 E	1140	Running				■	■	■	■	■	■			■			■	■				■			■			■	■		
19	Drukgyel	27.5 N	89.333 E	2547	Running										■	■	■		■	■			■			■	■	■			■		■	
20	Dungkar	27.823 N	91.197 E	2010	Running																			■	■	■	■		■					
21	Dungmain	26.982 N	91.338 E	1265	Running										■	■	■	■	■	■			■			■	■	■			■			
22	Gaselo	27.418 N	89.888 E	1960	Running										■	■	■	■	■	■			■			■	■	■			■			
23	Gedu	26.906 N	89.526 E	1980	Running				■	■	■	■	■	■			■			■	■	■						■			■			
24	Gidakom	27.38 N	89.575 E	2210	Running										■	■	■	■	■	■			■			■	■	■						
25	Gunitsawa	27.611 N	89.287 E	2840	Running																						■							
26	Gyetsa	27.502 N	90.736 E	2630	Running										■	■	■	■	■	■			■			■	■	■			■			
27	Kamichu	27.271 N	90.026 E	710	Running										■	■	■		■	■						■	■							
28	Kerabari	26.764 N	89.92 E	170	Running																										■	■		
29	Khaling	27.206 N	91.592 E	2070	Running										■	■	■	■	■	■			■			■	■	■			■			
30	Kuengarabten	27.406 N	90.518 E	1780	Closed in 2010										■	■	■	■	■	■			■				■							
31	Langthel	27.366 N	90.907 E	1150	Running											■	■	■	■	■			■				■	■						
32	Laya	28.059 N	90.174 E	3800	Running																													
33	Lhamoizingkha	26.72 N	89.855 E	110	Running																										■	■		
34	Lingmethang	27.264 N	91.166 E	700	Running										■	■	■	■	■	■			■				■				■			
35	Lingshi	-	-	-	Closed																		■	■	■	■								
36	Malbase	26.864 N	89.452 E	403	Running																												■	
37	Mendrelgang	26.953 N	90.135 E	1460	Running																									■				
38	MoEA	27.471 N	89.637 E	2380	Functioning										■	■	■	■	■	■			■			■	■	■						
39	Nanglam	26.85 N	91.266 E	550	Running																			■	■			■	■					
40	Nobding	27.548 N	90.153 E	2600	Closed in 2012										■	■	■	■	■	■			■											
41	Panbang	26.85 N	90.966 E	220	Running				■	■				■			■														■			
42	Pelela	27.534 N	90.203 E	3480	Running																	■	■	■						■		■		
43	Phobjikha	27.455 N	90.174 E	2860	Running										■	■	■	■	■	■			■				■	■						
44	Radhi	27.361 N	91.694 E	1540	Running										■	■	■	■	■	■			■			■								
45	Sakteng	27.404 N	91.928 E	2953	Running																													
46	Samdingkha	27.705 N	90.114 E	1295	Running																													
47	Samtengang	27.55 N	90 E	1960	Running										■	■	■	■	■	■			■			■	■	■						
48	Samtse NIE	26.9 N	89.1 E	430	Running				■	■	■	■	■	■			■			■	■	■			■			■					■	
49	Sarpang	26.89 N	90.269 E	330	Running										■	■	■	■	■	■						■		■			■			
50	Shelgana	27.583 N	89.862 E	1680	Running										■	■	■	■	■	■			■				■						■	
51	Sherichu	27.355 N	91.413 E	705	Running																			■				■	■			■		
52	Shingkhar	27.166 N	90.946 E	1280	Running																													
53	Sumpa	27.133 N	90.95 E	1380	Running				■	■	■	■	■	■			■			■	■	■			■			■					■	
54	Sunkosh	27.017 N	90.071 E	410	Running				■	■	■	■	■	■			■			■	■	■			■			■					■	
55	Surey	27.017 N	90.537 E	1060	Running										■	■	■	■	■	■			■			■	■	■			■			
56	Tala	26.88 N	89.57 E	1745	Closed										■	■	■	■	■	■			■			■								
57	Tashithang	27.03 N	90.05 E	1270	Running										■			■	■	■			■											
58	Tendru	27.133 N	88.866 E	1000	Running										■	■	■	■	■	■			■			■	■	■						
59	Thinlaygang	27.522 N	89.805 E	1920	Running																				■	■	■	■			■			
60	Thragom	27.435 N	91.643 E	2100	Running										■	■	■	■	■	■			■			■	■	■						
61	Thrimshing	27.133 N	91.633 E	1350	Running																			■	■		■	■	■		■			
62	Thsenkharla	27.475 N	91.572 E	1940	Running										■	■	■	■	■	■			■					■						
63	Tsirangtoe	27.061 N	90.098 E	1480	Running																													
64	Ura	27.474 N	90.907 E	3090	Running										■								■			■	■	■						
65	Wamrong	27.136 N	91.588 E	2180	Running										■	■	■	■	■	■			■			■	■						■	
66	Yadi	27.266 N	91.374 E	1580	Running										■	■	■	■	■	■			■				■							
67	Yabilaptsa	27.125 N	90.703 E	850	Running										■	■	■	■	■	■			■			■		■						
68	Yotongla	27.575 N	90.588 E	3530	Running																	■	■	■	■	■		■						
69	Yurung	27.019 N	91.343 E	1435	Running										■	■							■				■	■			■			

■ Data Complete (No missing data) ▨ Data Partially Complete (Including missing data)

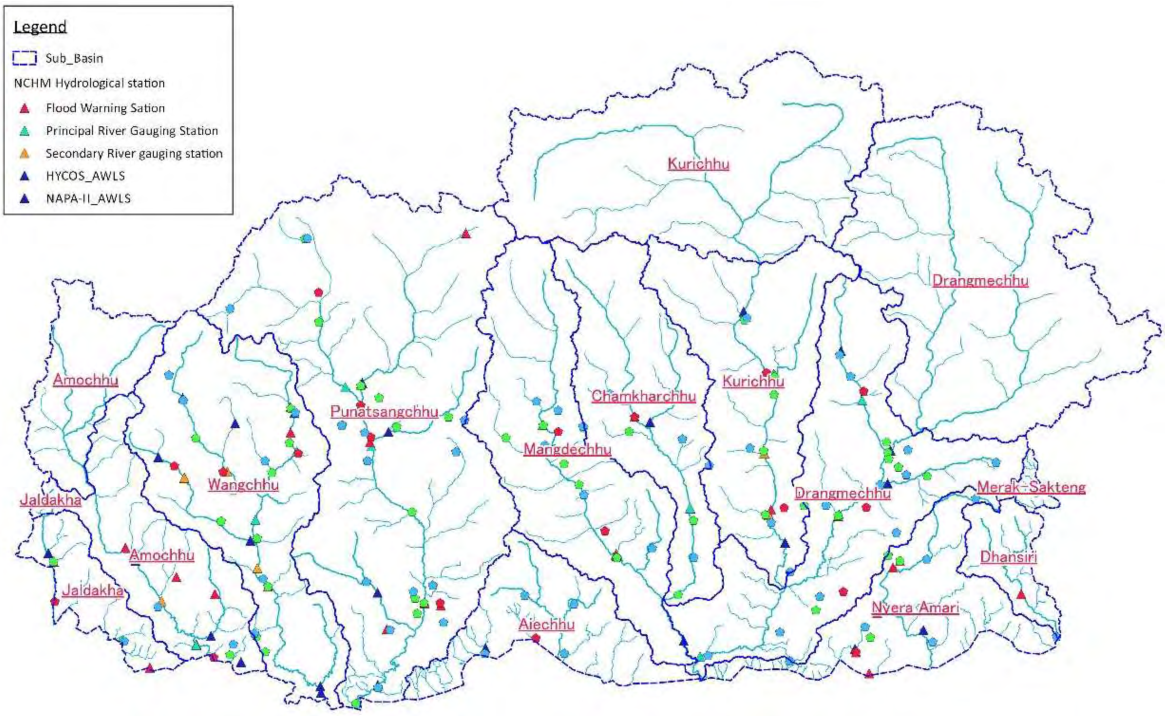
(Source: NCHM)

(2) Availability of Hydrological Data

NCHM operates 16 principal streamflow stations and 13 secondary streamflow stations, and carries out hydrological observations to monitor river water level, streamflow rate, and suspended load. In 2012, UNDP funded capacity building to strengthen the response to climate-induced hazards, namely the “National Adaptation Programme of Action II” (NAPA II), and installed 32 Automatic Water Level Stations (AWLS) in Bhutan.

Further, ICIMOD is implementing HKH-HYCOS (The Hindu Kush Himalayan Hydrological Cycle Observing System) with Finnish government funds and installed two AWLSs, with the aim of enhancing flood forecasting abilities and warning systems to reduce flood damage.

The locations of water level and streamflow stations operated by NCHM are shown in Figure 5-25.



(Source: NCHM)

Figure 5-25 Location Map of Water Level and Streamflow Stations

The streamflow records of principal and secondary streamflow stations operated by NCHM were provided by DHPS. An inventory of the streamflow records in the data from the principal and secondary streamflow stations is shown in Table 5-5 and Table 5-6.

Table 5-5 Inventory of Streamflow Data from Principal Streamflow Stations

Principal River Gauging Stations

Sl. No.	Basin No:	Station Name	Catchment Name	Latitude	Longitude	Altitude (m)	Catchment Area (km²)	Status	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
1	1121	Doyagang	Amochhu	26.887 N	89.335 E	253	3650	In function																	▨	■	■	▨	■	■	■	■	■	■	■	▨	
2	1280	Lungtenphu	Wangchhu	27.447 N	89.658 E	2,280	663	In function		▨	■	■	■	■	■	■	■	■	■	■	■		■	■	■	■	■	■	■	■	■	■	■	■	■	▨	
3	1249	Damchhu/Tamchu	Wangchhu	27.25 N	89.525 E	2,019	2,520	In function													▨	■	■	■	■	■	■	■	■	■	■	■	■	■	■	▨	
4	1332	Kerabari	Punatsangchhu	26.771 N	89.923 E	145	10,355	In function																		▨	▨	■	■	■	■	■	■	■	■	▨	
5	1330	Sunkosh/Turitar	Punatsangchhu	27.012 N	90.072 E	324	8,593	In function																	■	■	■	▨	■	▨	■	▨	■	■	■	▨	
6	1349	Wangdue/Wangdirapids	Punatsangchhu	27.463 N	89.9 E	1,204	6,271	In function		▨	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	▨	
7	1370	Yebesa	Mocchu/Punatsangchhu	27.634 N	89.815 E	1,255	2,320	In function		▨	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	▨	■	■	■	■	■	■	■	▨	
8	1458	Bjizam	Mangdechhu	27.524 N	90.455 E	1,921	1,390	In function					▨	■	■	■	■	■	■	■	■	■	■	■	■	■	■	▨	■	■	■	■	■	■	■	▨	
9	1418	Tingtibi	Mangdechhu	27.145 N	90.692 E	546	3,322	In function																▨	■	■	■	■	■	■	■	■	■	■	■	▨	
10	1549	Kurjey	Chamkharchhu	27.594 N	90.726 E	2,625	1,350	In function		▨	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	▨	
11	1560	Shingkhar/Bemethang	Chamkharchhu	27.282 N	90.931 E	1,465	2,728	In function																				▨	■	■	■	■	■	■	▨	▨	
12	1620	Kurizampa	Kurichhu	27.274 N	91.193 E	559	8,600	In function		▨	■	■	■	■	■	■	■	■	■	■	■	■	■		■	■	■	■	■	■	■	■	■	■	■		
13	1712	Panbang	Kurichhu	26.852 N	90.96 E	133	20,925	In function																						■	■	■	■	■	■	▨	
14	1652	Sumpa	Kurichhu	27.589 N	91.492 E	1,178	7,270	In function																		▨	■	▨	■	■	■	■	■	■	■	▨	
15	1767	Muktrap	Kholong Chhu	27.589 N	91.492 E	1,691	905	In function												▨	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	▨	
16	1740	Uzorong	Drangmechhu	27.259 N	91.413 E	573	8,560	In function			▨	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■		▨	■	■	■	■	▨	▨	

■ Data Complete (No missing data) ▨ Data Partially Complete (Including missing data) Blank No Data

(Source: NCHM)

Table 5-6 Inventory of Streamflow Data from Secondary Streamflow Stations

Secondary River Gauging Stations

Sl. No.	Station Name	Basin Name	Latitude	Longitude	Altitude (m)	Catchment Area (km²)	Status	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
1	Dorokha	Amochu	27.013 N	89.223E	479	3055	In function																					■	■	■	■	▨	■	■	▨	■	■	■	■	■	■	■	■	■	■	■	■	■		
2	Chukha	Wangchhu	27.056 N	89.566E	1376	3573	In function	■	■	■	■	■	■	■	■	■	■	▨	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	▨	■	■	▨	
3	Paro(closed)	Wangchhu	-	-	2220	1101	Closed												■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	▨	■	▨						
4	Paro Bondey	Wangchhu	27.389 N	89.433E	2225	1284	In function																																							■	■	■	▨	
5	Haa/Hachhu	Wangchhu	27.37 N	89.294E	2700	2320	In function												▨	■	■	■	■	■								■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	▨	
6	Dagachu(closed)	Punatsangchhu	27.04 N	89.92E	929	671	In function																														▨	▨	▨	▨	▨	▨	▨							
7	Samdingkha	Punatsangchhu	27.641 N	89.865E	1271	2310	In function																																						▨	■	■	■		
8	Dakpaichu	Mangdechhu	27.15 N	90.691E	562	580	In function														▨	▨	■	▨	▨		▨	■	▨	■	▨	▨	▨	▨	■	■	■	■	■	■	■	■	■	■	■	■	■	■	▨	
9	Dokarna(closed)	Punatsangchhu	-	-	1290	2296	Closed																																	▨	■	■	■	■						
10	Autsho	Kurichhu	27.438 N	91.173E	850	8547	In function												■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	▨		■	▨	■	■	■	■	■	■	▨				
11	Lhuentse(Sumpa)	Kurichhu	27.658 N	91.21E	1178	611	In function												■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	▨	▨	▨	■	■	▨	
12	Lingmethang	Shongarchhu	27.258 N	91.183E	562	320	In function																									▨	■	■	■	■	■	■	■	■	▨	▨	■	■	■	■	▨			
13	Sherichu	Drangmechhu	27.254 N	91.41E	573	437	In function																	▨	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	▨	▨	

■ Data Complete (No missing data) ▨ Data Partially Complete (Including missing data) Blank No Data

(Source: NCHM)

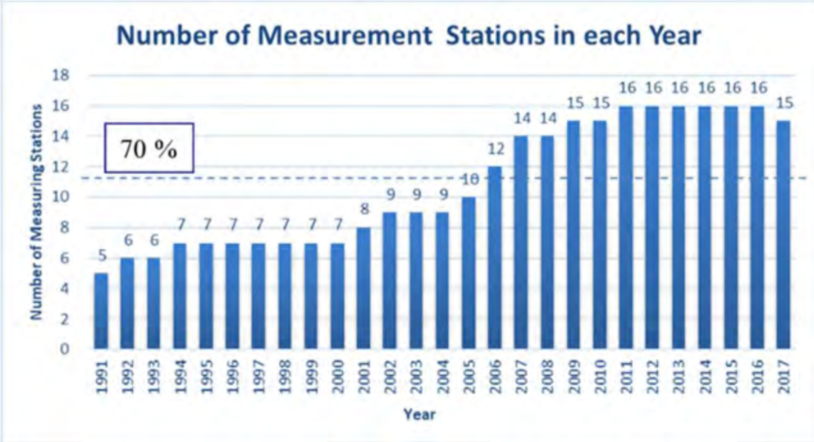
5.3.2 Data Period for Creation of Flow Duration Curves

In Bhutan, there are large elevation differences in the principal river basins from the Himalayas region in the north to near the Indian border, with a low altitude, in the south. Accordingly, it is assumed that the outflow will differ greatly depending on the altitude and topography of the river, even in the same basin. Therefore, for the primary screening of hydropower potential, the main river basins were devided into three - namely, upper, middle, and lower basins - and prepare flow duration curves for each river basin thus divided.

In order for the streamflow data to be statistically significant, it is desirable that the data period is longer than 30 years. However, in many cases, the availability of data is limited due to there being few observation stations or little reliable data. In preparing the flow duration curves for the primary screening, it was decided to set the period for the flow rate data considering the following.

- Prioritize principal stations considering high data quality,
- The missing period is short and the data interpolation is minimized,
- Number of gauging stations is sufficient to cover the nation, and
- The data period is longer than 10 years.

Figure 5-26 shows the transition in the number of principal streamflow stations from year 1991 to 2017.



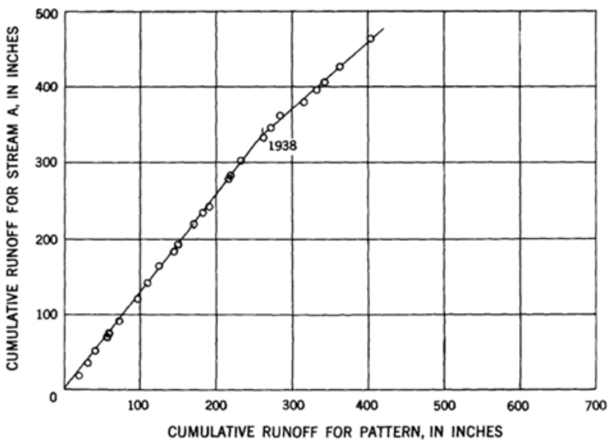
(Source: NCHM)

Figure 5-26 Transition in the Number of Principal Streamflow Stations

Based on the above figure and the inventory table, the number of principal streamflow stations after 2006 is over 70% of the total, and the gauging stations cover most of the principal river basins in Bhutan. Also, if 2006 is selected as the start year for the data period, a period of 10 years or more can be secured. Therefore, the streamflow data start year for creating the flow duration curves was set at 2006. For the end year, since most of the data for 2017 was incomplete, it was set to 2016. In summary, the streamflow data period for creating the flow duration curves was set at 11 years, from 2006 to 2016.

5.3.3 Verification of Meteorological and Hydrological Data

The consistency of rainfall data and streamflow data is verified via double mass curve analysis. The double mass curve is a graph plotting the annual accumulated data from the two observation stations. When any change occurs in one observation station, the gradient of the plotted graph is changed. In addition, when the gradient of the graph tends to gradually change, it infers that the surrounding conditions of either observation station are changing over the long term. An example of a mass curve is shown in the figure below.



(Source: J.K. Searcy and C.H. Hardison, "Manual of Hydrology; Part 1. General Surface-Water Techniques, Double-Mass Curves," U.S. Department of the Interior 1960.)

Figure 5-27 Example of Double Mass Curve

In this study, the consistency of the NCHM rainfall and streamflow data received from DHPS was verified via double mass curve analysis in the following manner.

- Class A stations are compared with all Class A stations.
- Class C stations are compared with all Class A stations data. (We do not compare Class C stations due to low data quality.)
- Principal streamflow stations are compared with all Principal streamflow stations' data.
- Secondary streamflow stations are compared with Principal streamflow stations where located in the same or neighboring river basins.

In addition, the rainfall data from Class A stations show that there are very few missing data, while those of Class C have too many missing data, hindering the calculation of yearly accumulated rainfall for the double mass curve analysis. Therefore, missing data in the Class A and C rainfall data are interpolated before verification.
The results of verification of the data via double mass curve analysis are shown in the following tables.

Table 5-7 Verification Results for Class A Rainfall Gauging Stations

Class A Meteorological Stations					
Sl. No.	*Station Name*	*Latitude*	*Longitude*	*Altitude (m)*	*Data Consistency (Assessed by Double Mass Curve)*
1	Bhur	26.907 N	90.434 E	377	Good
2	Chamkhar	27.54 N	90.755 E	2470	Good
3	Dagana	27.071 N	89.884 E	1531	Poor (Greatly deviating)
4	Damphu	27 N	90.122 E	1520	Good
5	Deothang	26.85 N	91.467 E	861	Good
6	Gasa	27.9 N	89.716 E	2760	Fair (Some shifts are observed)
7	Haa	27.403 N	89.262 E	2764	Good
8	Kanglung	27.271 N	91.522 E	2005	Good
9	Mongar	27.279 N	91.238 E	1597	Fair (Some shifts are observed)
10	Paro	27.383 N	89.42 E	2406	Fair (Some shifts are observed)
11	Pemagatshel	27.02 N	91.424 E	1723	Good
12	Phuntsholing	26.85 N	89.389 E	280	Poor (Greatly deviating)
13	Punakha	27.582 N	89.866 E	1236	Fair (Some shifts are observed)
14	Sipsu	27.009 N	88.878 E	423	Good
15	Simtokha	27.438 N	89.675 E	2310	Good
16	Tangmachu	27.595 N	91.197 E	1750	Good
17	Trashiyangtse	27.6 N	91.5 E	1855	Good
18	Trongsa	27.502 N	90.505 E	2120	Fair (Some shifts are observed)
19	Wangdue	27.487 N	89.901 E	1180	Good
20	Zhemgang	27.216 N	90.655 E	1862	Good

Note: "shifts" is parallel displacement from a trend of cumulative value, "deviation" is displacement of cumulative value but it is not parallell displacement.

(Source: JICA Survey Team)

Table 5-8 Verification Results for Class C Rainfall Gauging Stations (1/2)

Class C Meteorological Station					
Sl. No.	***Station Name***	***Latitude***	***Longitude***	***Altitude (m)***	***DMC Assessment***
1	Airong	26.901 N	91.508 E	1305	Fair (Some shifts are observed)
2	Autsho	27.442 N	91.176 E	800	Good
3	Begana	27.573 N	89.643 E	2520	Good
4	Betikha	27.25 N	89.416 E	2660	Good
5	Bidung	27.368 N	91.661 E	1815	Poor (Greatly deviating)
6	Bjizam	27.52 N	90.456 E	1840	Good
7	Buli	27.166 N	90.816 E	1780	Poor (Greatly deviating)
8	Bumdelling	27.664 N	91.592 E	1933	Good
9	Chapcha	27.2 N	89.55 E	2450	Good
10	Chenary	27.321 N	91.534 E	830	Good
11	Chendebji	27.508 N	90.276 E	2660	Poor (Greatly deviating)
12	Chhukha	27.066 N	89.566 E	1380	Fair (Some shifts are observed)
13	Daifam	26.89 N	92.108 E	280	Fair (Deviation of DMC is observed)
14	Damji	27.826 N	89.737 E	-	Poor (Greatly deviating)
15	Dechenling	26.916 N	91.233 E	1000	Good
16	Degala	27.028 N	90.851 E	975	Fair (Deviation of DMC is observed)
17	Doksum	27.435 N	91.577 E	950	Fair (Some shifts and deviation are observed)
18	Drujeygang	26.975 N	90.042 E	1140	Good
19	Drukgyel	27.5 N	89.333 E	2547	Fair (Some shifts and deviation are observed)
20	Dungkar	27.823 N	91.197 E	2010	Fair (Some shifts and deviation are observed)
21	Dungmain	26.982 N	91.338 E	1265	Fair (Some shifts and deviation are observed)
22	Gaselo	27.418 N	89.888 E	1960	Good
23	Gedu	26.906 N	89.526 E	1980	Good
24	Gidakom	27.38 N	89.575 E	2210	Good
25	Gunitsawa	27.611 N	89.287 E	2840	Good
26	Gyetsa	27.502 N	90.736 E	2630	Good
27	Kamichu	27.271 N	90.026 E	710	Poor (Greatly deviating)
28	Kerabari	26.764 N	89.92 E	170	Good
29	Khaling	27.206 N	91.592 E	2070	Poor (Greatly deviating)
30	Kuengarabten	27.406 N	90.518 E	1780	Good

(Source: JICA Survey Team)

Table 5-9 Verification Results for Class C Rainfall Gauging Stations (2/2)

Class C Meteorological Station					
Sl. No.	*Station Name*	*Latitude*	*Longitude*	*Altitude (m)*	*Data Consistency (Assessed by Double Mass Curve)*
31	Langthel	27.366 N	90.907 E	1150	Fair (Some shifts and deviation are observed)
32	Laya	28.059 N	90.174 E	3800	Fair (Deviation of DMC is observed)
33	Lhamoizingkha	26.72 N	89.855 E	110	Good
34	Lingmethang	27.264 N	91.166 E	700	Good
35	Lingshi	-	-	-	Poor (Greatly deviating)
36	Malbase	26.864 N	89.452 E	403	Fair (Deviation of DMC is observed)
37	Mendrelgang	26.953 N	90.135 E	1460	Poor (Greatly deviating)
38	MoEA	27.471 N	89.637 E	2380	Good
39	Nanglam	26.85 N	91.266 E	550	Fair (Some shifts are observed)
40	Nobding	27.548 N	90.153 E	2600	Good
41	Panbang	26.85 N	90.966 E	220	Good
42	Pelela	27.534 N	90.203 E	3480	Good
43	Phobjikha	27.455 N	90.174 E	2860	Good
44	Radhi	27.361 N	91.694 E	1540	Fair (Deviation of DMC is observed)
45	Sakteng	27.404 N	91.928 E	2953	Poor (Greatly deviating)
46	Samdingkha	27.705 N	90.114 E	1295	Fair (Some shifts are observed)
47	Samtengang	27.55 N	90 E	1960	Good
48	Samtse NIE	26.9 N	89.1 E	430	Good
49	Sarpang	26.89 N	90.269 E	330	Good
50	Shelgana	27.583 N	89.862 E	1680	Fair (Some shifts are observed)
51	Sherichu	27.355 N	91.413 E	705	Good
52	Shingkhar	27.166 N	90.946 E	1280	Fair (Deviation of DMC is observed)
53	Sumpa	27.133 N	90.95 E	1380	Good
54	Sunkosh	27.017 N	90.071 E	410	Good
55	Surey	27.017 N	90.537 E	1060	Fair (Deviation of DMC is observed)
56	Tala	26.88 N	89.57 E	1745	Fair (Some shifts are observed)
57	Tashithang	27.03 N	90.05 E	1270	Poor (Greatly deviating)
58	Tendru	27.133 N	88.866 E	1000	Good
59	Thinlaygang	27.522 N	89.805 E	1920	Good
60	Thragom	27.435 N	91.643 E	2100	Fair (Deviation of DMC is observed)
61	Thrimshing	27.133 N	91.633 E	1350	Fair (Deviation of DMC is observed)
62	Thsenkharla	27.475 N	91.572 E	1940	Fair (Deviation of DMC is observed)
63	Tsirangtoe	27.061 N	90.098 E	1480	Fair (Some shifts are observed)
64	Ura	27.474 N	90.907 E	3090	Good
65	Wamrong	27.136 N	91.588 E	2180	Fair (Some shifts are observed)
66	Yadi	27.266 N	91.374 E	1580	Good
67	Yabilaptsa	27.125 N	90.703 E	850	Fair (Deviation of DMC is observed)
68	Yotongla	27.575 N	90.588 E	3530	Fair (Deviation of DMC is observed)
69	Yurung	27.019 N	91.343 E	1435	Good

(Source: JICA Survey Team)

Table 5-10 Verification Results for Principal Streamflow Station data

Class A Meteorological Stations					
Sl. No.	*Station Name*	*Latitude*	*Longitude*	*Altitude (m)*	*Data Consistency (Assessed by Double Mass Curve)*
1	Bhur	26.907 N	90.434 E	377	Good
2	Chamkhar	27.54 N	90.755 E	2470	Good
3	Dagana	27.071 N	89.884 E	1531	Poor (Greatly deviating)
4	Damphu	27 N	90.122 E	1520	Good
5	Deothang	26.85 N	91.467 E	861	Good
6	Gasa	27.9 N	89.716 E	2760	Fair (Some shifts are observed)
7	Haa	27.403 N	89.262 E	2764	Good
8	Kanglung	27.271 N	91.522 E	2005	Good
9	Mongar	27.279 N	91.238 E	1597	Fair (Some shifts are observed)
10	Paro	27.383 N	89.42 E	2406	Fair (Some shifts are observed)
11	Pemagatshel	27.02 N	91.424 E	1723	Good
12	Phuntsholing	26.85 N	89.389 E	280	Poor (Greatly deviating)
13	Punakha	27.582 N	89.866 E	1236	Fair (Some shifts are observed)
14	Sipsu	27.009 N	88.878 E	423	Good
15	Simtokha	27.438 N	89.675 E	2310	Good
16	Tangmachu	27.595 N	91.197 E	1750	Good
17	Trashiyangtse	27.6 N	91.5 E	1855	Good
18	Trongsa	27.502 N	90.505 E	2120	Fair (Some shifts are observed)
19	Wangdue	27.487 N	89.901 E	1180	Good
20	Zhemgang	27.216 N	90.655 E	1862	Good

(Source: JICA Survey Team)

Table 5-11 Verification Results for Secondary Streamflow Station data

Secondary River Gauging Stations					
Sl. No.	*Station Name*	*Basin Name*	*Altitude (m)*	*Catchment Area (km^2)*	*Data Consistency (Assessed by Double Mass Curve)*
1	Dorokha	Amochu	479	3055	Good
2	Chukha	Wangchhu	1376	3573	Good
3	Paro(closed)	Wangchhu	2220	1101	Good
4	Paro Bondey	Wangchhu	2225	1284	(Data too short for DMC assessment)
5	Haa/Hachhu	Wangchhu	2700	2320	Fair to Poor
6	Dagachu(closed)	Punatsangchhu	929	671	(Data too short for DMC assessment)
7	Samdingkha	Punatsangchhu	1271	2310	(Data too short for DMC assessment)
8	Dakpaichu	Mangdechhu	562	580	Fair to Poor
9	Dokarna(closed)	Punatsangchhu	1290	2296	Fair
10	Autsho	Kurichhu	850	8547	Good
11	Lhuentse(Khoma)	Kurichhu	1178	611	Good
12	Lingmethang	Kurichhu	562	320	Good
13	Sherichu	Drangmechhu	573	437	Good

(Source: JICA Survey Team)

5.3.4 Generation of Missing Data

The period of missing data for the principal streamflow stations is approximately 20% of the total period from 2006 to 2016. The period of missing data at each principal streamflow station is indicated in blue in the table below.

Table 5-12 Missing Data Periods for Principal Streamflow Stations

Principal River Gauging Stations																			
Sl. No.	*Basin No:*	*Station Name*	*Catchment Name*	*Latitude*	*Longitude*	*Altitude (m)*	*Catchment Area (km^2)*	*2006*	*2007*	*2008*	*2009*	*2010*	*2011*	*2012*	*2013*	*2014*	*2015*	*2016*	*2017*
1	1121	Doyagang	Amochhu	26.88666667	89.335	253	3650												
2	1280	Lungtenphu	Wangchhu	27.44719001	89.65804205	2280	663												
3	1249	Damchhu/Tamchu	Wangchhu	27.25010785	89.52495641	2019	2520												
4	1332	Kerabari	Punatsangchhu	26.77083738	89.9229915	145	10355												
5	1330	Sunkosh/Turitar	Punatsangchhu	27.01205839	90.07235046	324	8593												
6	1349	Wangdue/Wangdirapids	Punatsangchhu	27.46315758	89.90003256	1204	6271												
7	1370	Yebesa	Mocchu/Punatsangchhu	27.63363296	89.81478272	1255	2320												
8	1458	Bjizam	Mangdechhu	27.52438789	90.4549457	1921	1390												
9	1418	Tingtibi	Mangdechhu	27.14460292	90.69230578	546	3322												
10	1549	Kurjey	Chamkharchhu	27.59422127	90.72603661	2625	1350												
11	1560	Shingkhar/Bemethang	Chamkharchhu	27.2821858	90.93133475	1465	2,728												
12	1620	Kurizampa	Kurichhu	27.27390754	91.19347442	559	8600												
13	1712	Panbang	Kurichhu	26.85182008	90.96033593	133	20925												
14	1652	Sumpa	Kurichhu	27.58887357	91.49217654	1178													
15	1767	Muktrap	Kholong Chhu	27.58887357	91.49217654	1691	905												
16	1740	Uzorong	Drangmechhu	27.2586643	91.41294357	573	8560												

Data Complete (No missing data) | Data Partially Complete (Including missing data) | No Data

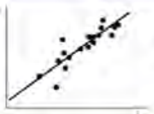
(Source: JICA Survey Team)

According to the "Guideline and Manual for Hydropower Development" (JICA, 2011), the following methods are listed for data estimation for missing periods.

- Conversion via catchment area ratio
- Conversion via catchment area ratio considering the weight of the rainfall
- Use of correlations between the gauging stations
- Simulation with a mathematical model such as the tank model
- Correlation between the flow and rainfall
- Other methods

Table 5-13 shows an outline and the application conditions for each method.

Table 5-13 Estimation Methods for Missing Data and Their Applicable Conditions

No.	Name of Method	Method	Application
1	Conversion by the catchment area ratio	$Qd=\left(\frac{Qg_1\times AB_1}{Ag_1}+\frac{Qg_2\times AB_2}{Ag_2}\right)\times\frac{Ad}{AB_1+AB_2}$	- When a gauging station is **located near the dam site,** - The **meteorological conditions** at the gauging station and watershed of the dam site **are the same.**
2	Conversion by the catchment area ratio considering the weight of the rainfall	$Qd=Qg\times\frac{Rd\times Ad}{Rg\times Ag}$	- When the dam site and stream gauging station are **located separately,** - The **meteorological conditions** (rainfall) at the two sites **are different**.
3	Use of the correlation between the gauging stations	 Y=a+bX Y : Discharge data at Sta. Y X: Discharge data at Sta. X	- When the runoff data at the dam site is **not long enough,** - But there are other gauging station nearby having data of long enough and **good correlation**.
4	Simulation with a mathematical model such as tank model, etc	Lumped Model (such as tank model) or Distributed Model	- When the method No.1, 2 and 3 are not applicable. - Rainfall data and concurrent discharge data is available for model identification.
5	Correlation between the flow and rainfall	 Y=a+bX Y : Discharge data at Sta. Y X: Rainfall Data at Sta. X	(This method is merely used)
6	Other method	Ex) Stochastic method: $X_t=A\times X_{t-1}+B\times\varepsilon_t$	(This method is merely used)

(Source: "Guideline and Manual for Hydropower Development" (JICA, 2011))

For the estimation of the missing streamflow data for the flow duration curve for the primary screening, correlation and regression analysis are adopted because the stream flow data for principal streamflow stations are highly correlated as shown in Table 5-14.

In estimating the streamflow via correlation analysis, the following points were considered.

- According to the "Guideline and Manual for Hydropower Development", the correlation coefficient should be greater than 0.7 for interpolation between principal streamflow stations.
- For estimation of missing data, reference should first be made to the station that has the highest correlation coefficient value with the target station. If observed data for the highest correlation coefficient station is also missing, data for the second highest correlation coefficient station should be referenced.
- The catchment area ratio of the reference station and the target station should be in the range of 0.333 to 3.0 according to the "Guideline and Manual for Hydropower Development".

The correlation coefficients for the principal streamflow stations are shown in Table 5-14. Table 5-15 shows the ratio of the catchment area of the principal streamflow stations. In Table 5-15, the cells that out of the range of 0.333 to 3.0 are indicated by colored cells.

Table 5-14 Correlation Coefficients for Principal Streamflow Stations

Correlation Coefficient

River Basin→	Amochhu	Wangchhu		Punatsangchhu				Mangdechhu		Chamkharchhu		Kurichhu			Drangmechhu	
Sta. Name	Amochu	Tamchu	Lungtenphu	Wangdue	Yebesa	Kerabari	Sunkosh	Bjizam	Tingtibi	Shingkhar	Kurjey	Sumpa	Panbang	Kurizam	Uzorong	Muktirap
Amochu		0.831		0.873	0.868	0.877	0.887	0.873	0.900	0.675	0.860	0.776		0.843	0.837	
Tamchu	0.831			0.886	0.872			0.874	0.896	0.803	0.905	0.800				0.740
Lungtenphu								0.868			0.885					0.754
Wangdue	0.873	0.886			0.982	0.943	0.964		0.922	0.837		0.916		0.956	0.937	
Yebesa	0.868	0.872		0.982				0.958	0.919	0.818	0.946					0.877
Kerabari	0.877			0.943			0.959					0.869	0.938	0.905	0.893	
Sunkosh	0.887			0.964		0.959			0.930			0.882	0.924	0.924	0.919	
Bjizam	0.873	0.874	0.868		0.958				0.928	0.818	0.970					0.902
Tingtibi	0.900	0.896		0.922	0.919		0.930	0.928		0.790	0.921	0.840		0.913	0.894	
Shingkhar	0.675	0.803		0.837	0.818			0.818	0.790		0.814	0.796				
Kurjey	0.860	0.905	0.885		0.946			0.970	0.921	0.814						0.861
Sumpa	0.776	0.800		0.916		0.869	0.882		0.840	0.796			0.905	0.946	0.907	
Panbang						0.938	0.924					0.905		0.944	0.950	
Kurizam	0.843			0.956		0.905	0.924		0.913			0.946	0.944		0.948	
Uzorong	0.837			0.937		0.893	0.919		0.894			0.907	0.950	0.948		
Muktirap		0.740	0.754		0.877			0.902			0.861					

Note: Blank cell indicates that the area ratio is over 3.0 or less than 0.33. The colored cells indicate the correlation value is less than 0.7 therefore it is eliminated from furher study.

(Source: JICA Survey Team)

Table 5-15 Ratio of Catchment Area among Principal Streamflow Stations

Ratio of Catchment Area

Sta. Name		Amochu	Tamchu	Lungtenph	Wangdue	Yebesa	Kerabari	Sunkosh	Bjizam	Tingtibi	Shingkhar	Kurjey	Sumpa	Panbang	Kurizam	Uzorong	Muktirap
	C.A. Area (km2)	3650	2520	663	6271	2320	10355	8593	1390	3322	2728	1350	7270	20925	8600	8560	905
Amochu	3650		0.690	0.182	1.718	0.636	2.837	2.354	0.381	0.910	0.747	0.370	1.992	5.733	2.356	2.345	0.248
Tamchu	2520	1.448		0.263	2.488	0.921	4.109	3.410	0.552	1.318	1.083	0.536	2.885	8.304	3.413	3.397	0.359
Lungtenphu	663	5.505	3.801		9.459	3.499	15.618	12.961	2.097	5.011	4.115	2.036	10.965	31.561	12.971	12.911	1.365
Wangdue	6271	0.582	0.402	0.106		0.370	1.651	1.370	0.222	0.530	0.435	0.215	1.159	3.337	1.371	1.365	0.144
Yebesa	2320	1.573	1.086	0.286	2.703		4.463	3.704	0.599	1.432	1.176	0.582	3.134	9.019	3.707	3.690	0.390
Kerabari	10355	0.352	0.243	0.064	0.606	0.224		0.830	0.134	0.321	0.263	0.130	0.702	2.021	0.831	0.827	0.087
Sunkosh	8593	0.425	0.293	0.077	0.730	0.270	1.205		0.162	0.387	0.317	0.157	0.846	2.435	1.001	0.996	0.105
Bjizam	1390	2.626	1.813	0.477	4.512	1.669	7.450	6.182		2.390	1.963	0.971	5.230	15.054	6.187	6.158	0.651
Tingtibi	3322	1.099	0.759	0.200	1.888	0.698	3.117	2.587	0.418		0.821	0.406	2.188	6.299	2.589	2.577	0.272
Shingkhar	2728	1.338	0.924	0.243	2.299	0.850	3.796	3.150	0.510	1.218		0.495	2.665	7.670	3.152	3.138	0.332
Kurjey	1350	2.704	1.867	0.491	4.645	1.719	7.670	6.365	1.030	2.461	2.021		5.385	15.500	6.370	6.341	0.670
Sumpa	7270	0.502	0.347	0.091	0.863	0.319	1.424	1.182	0.191	0.457	0.375	0.186		2.878	1.183	1.177	0.124
Panbang	20925	0.174	0.120	0.032	0.300	0.111	0.495	0.411	0.066	0.159	0.130	0.065	0.347		0.411	0.409	0.043
Kurizam	8600	0.424	0.293	0.077	0.729	0.270	1.204	0.999	0.162	0.386	0.317	0.157	0.845	2.433		0.995	0.105
Uzorong	8560	0.426	0.294	0.077	0.733	0.271	1.210	1.004	0.162	0.388	0.319	0.158	0.849	2.445	1.005		0.106
Muktirap	905	4.033	2.785	0.733	6.929	2.564	11.442	9.495	1.536	3.671	3.014	1.492	8.033	23.122	9.503	9.459	

(Source: JICA Survey Team)

Table 5-16 shows the ranking of the correlation coefficients for the principal streamflow stations. The station that has the highest correlation coefficient ranks as “1”. The regression equation coefficients for data interpolation are shown in Table 5-17 and Table 5-18.

Table 5-16 Ranking of Correlation Coefficients for Principal streamflow stations

Ranking of Correlation Coefficient

River Basin→	Amochhu	Wangchhu		Punatsangchhu				Mangdechhu		Chamkharchhu		Kurichhu			Drangmechhu	
Sta. Name	Amochu	Tamchu	Lungtenphu	Wangdue	Yebesa	Kerabari	Sunkosh	Bjizam	Tingtibi	Shingkhar	Kurjey	Sumpa	Panbang	Kurizam	Uzorong	Muktirap
Amochu	–	6	–	9	7	6	7	6	7	–	7	10	–	8	8	–
Tamchu	10	–	–	8	6	–	–	5	8	5	4	8	–	–	–	5
Lungtenphu	–	–	–	–	–	–	–	7	–	–	5	–	–	–	–	4
Wangdue	4	3	–	–	1	2	1	–	3	1	–	2	–	1	3	–
Yebesa	6	5	–	1	–	–	–	2	5	3	2	–	–	–	–	2
Kerabari	3	–	–	4	–	–	2	–	–	–	–	6	3	7	7	–
Sunkosh	2	–	–	2	–	1	–	–	1	–	–	5	4	5	4	–
Bjizam	5	4	2	–	2	–	–	–	2	2	1	–	–	–	–	1
Tingtibi	1	2	–	6	4	–	3	3	–	7	3	7	–	6	6	–
Shingkhar	–	7	–	10	8	–	–	8	11	–	8	9	–	–	–	–
Kurjey	7	1	1	–	3	–	–	1	4	4	–	–	–	–	–	3
Sumpa	11	8	–	7	–	7	8	–	10	6	–	–	5	3	5	–
Panbang	–	–	–	–	–	3	4	–	–	–	–	4	–	4	1	–
Kurizam	8	–	–	3	–	4	5	–	6	–	–	1	2	–	2	–
Uzorong	9	–	–	5	–	5	6	–	9	–	–	3	1	2	–	–
Muktirap	–	9	3	–	5	–	–	4	–	–	6	–	–	–	–	–

(Source: JICA Survey Team)

Table 5-17 Slope of Regression Line for Principal Streamflow Stations ("a" of y=ax+b)

a of Y = a X + b

River Basin→	Amochhu	Wangchhu		Punatsangchhu				Mangdechhu		Chamkharchhu		Kurichhu			Drangmechhu	
↓X, →Y	Amochu	Tamchu	Lungtenphu	Wangdue	Yebesa	Kerabari	Sunkosh	Bjizam	Tingtibi	Shingkhar	Kurjey	Sumpa	Panbang	Kurizam	Uzorong	Muktirap
Amochu	–	0.343	–	1.362	0.527	2.163	1.614	0.279	0.653	–	0.240	0.718	–	1.172	1.177	–
Tamchu	2.016	–	–	3.364	1.310	–	–	0.691	1.578	1.098	0.614	1.891	–	–	–	0.644
Lungtenphu	–	–	–	–	–	–	–	1.962	–	–	1.727	–	–	–	–	1.887
Wangdue	0.560	0.234	–	–	0.388	1.493	1.141	–	0.428	0.269	–	0.542	–	0.853	0.820	–
Yebesa	1.430	0.580	–	2.489	–	–	–	0.504	1.099	0.685	0.427	–	–	–	–	0.511
Kerabari	0.355	–	–	0.596	–	–	0.719	–	–	–	–	0.323	1.754	0.502	0.499	–
Sunkosh	0.488	–	–	0.814	–	1.279	–	–	0.371	–	–	0.427	2.523	0.691	0.710	–
Bjizam	2.732	1.104	0.384	–	1.819	–	–	–	2.106	1.246	0.831	–	–	–	–	0.999
Tingtibi	1.240	0.508	–	1.986	0.768	–	2.333	0.408	–	0.607	0.355	1.113	–	1.755	1.671	–
Shingkhar	–	0.588	–	2.599	0.977	–	–	0.537	1.028	–	0.445	1.525	–	–	–	–
Kurjey	3.082	1.333	0.453	–	2.097	–	–	1.132	2.390	1.488	–	–	–	–	–	1.103
Sumpa	0.838	0.338	–	1.549	–	2.343	1.822	–	0.634	0.415	–	–	4.186	1.377	1.315	–
Panbang	–	–	–	–	–	0.502	0.339	–	–	–	–	0.196	–	0.291	0.302	–
Kurizam	0.607	–	–	1.071	–	1.631	1.235	–	0.475	–	–	0.650	3.061	–	0.899	–
Uzorong	0.596	–	–	1.071	–	1.597	1.189	–	0.478	–	–	0.626	2.989	0.999	–	–
Muktirap	–	0.851	0.302	–	1.504	–	–	0.815	–	–	0.672	–	–	–	–	–

(Source: JICA Survey Team)

Table 5-18 Intercept of Regression Line for Principal Streamflow Stations ("b" of y=ax+b)

b of Y = a X + b

River Basin→	Amochhu	Wangchhu		Punatsangchhu				Mangdechhu		Chamkharchhu		Kurichhu			Drangmechhu	
↓X, →Y	Amochu	Tamchu	Lungtenphu	Wangdue	Yebesa	Kerabari	Sunkosh	Bjizam	Tingtibi	Shingkhar	Kurjey	Sumpa	Panbang	Kurizam	Uzorong	Muktirap
Amochu	–	6.534	–	61.722	18.112	83.461	83.498	13.363	22.645	–	11.535	49.658	–	71.181	97.312	–
Tamchu	38.905	–	–	73.957	23.625	–	–	16.242	30.932	19.738	12.379	48.868	–	–	–	20.887
Lungtenphu	–	–	–	–	–	–	–	18.562	–	–	14.821	–	–	–	–	21.811
Wangdue	5.395	−3.700	–	–	−4.937	13.728	24.432	–	7.932	9.798	–	13.302	–	18.866	51.584	–
Yebesa	15.083	1.001	–	22.216	–	–	–	6.129	15.504	16.297	5.677	–	–	–	–	7.633
Kerabari	8.676	–	–	23.530	–	–	35.817	–	–	–	–	25.913	−27.168	40.267	68.005	–
Sunkosh	−5.143	–	–	0.182	–	−10.988	–	–	1.562	–	–	15.171	−113.042	19.573	42.851	–
Bjizam	3.008	−3.385	−2.085	–	−2.569	–	–	–	6.121	11.401	1.359	–	–	–	–	2.218
Tingtibi	4.018	−3.210	–	27.056	4.299	–	43.077	5.692	–	12.874	4.849	26.082	–	34.381	68.317	–
Shingkhar	–	11.001	–	63.450	18.392	–	–	14.038	34.406	–	12.835	41.215	–	–	–	–
Kurjey	8.147	−5.030	−2.134	–	−1.055	–	–	1.948	8.319	11.244	–	–	–	–	–	5.096
Sumpa	24.975	6.579	–	25.772	–	48.297	49.596	–	21.497	15.806	–	–	18.213	27.497	66.751	–
Panbang	–	–	–	–	–	63.647	85.833	–	–	–	–	26.084	–	47.419	73.243	–
Kurizam	6.592	–	–	5.133	–	16.558	27.894	–	5.837	–	–	0.608	−65.190	–	47.048	–
Uzorong	−9.617	–	–	−20.967	–	−19.239	1.458	–	−6.788	–	–	−12.110	−150.031	−19.845	–	–
Muktirap	–	10.842	2.498	–	12.557	–	–	9.113	–	–	9.844	–	–	–	–	–

(Source: JICA Survey Team)

5.3.5 Monthly and Annual Average Flow

Table 5-19 shows monthly averages for the principal streamflow stations from 2006 to 2017. Missing data in the period from 2006 to 2017 were estimated as described in section 5.3.4.

Table 5-19 Monthly Average Flow of the Principal Streamflow Stations (from 2006 to 2017)

River Basin	Station Name	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Amochhu	Amochu	45.3	40.1	43.4	76.7	134.7	242.5	443.1	376.1	319.1	159.5	87.1	59.1
Wangchhu	Tamchu	19.3	16.3	15.9	19.5	38.6	73.4	161.2	171.0	126.4	69.5	38.1	25.7
	Lungtenphu	5.2	4.3	4.0	5.6	14.7	27.1	52.6	57.2	45.8	23.6	11.2	6.9
Punatsangchhu	Wangdue	75.4	65.7	72.2	113.8	212.8	421.8	743.1	715.1	565.2	269.5	146.0	99.6
	Yebesa	24.5	22.5	26.4	39.7	75.8	160.2	278.6	274.1	216.2	99.1	49.5	32.6
	Kerabari	128.3	110.1	110.5	152.8	275.1	592.4	1,128.1	1,096.0	911.2	481.6	253.4	169.2
	Sunkosh	109.2	93.3	95.8	139.2	254.2	488.1	851.0	843.6	699.4	362.2	208.7	146.8
Mangdechhu	Bjizam	15.1	13.4	16.0	27.6	50.1	91.0	154.5	145.3	113.1	56.1	29.1	19.5
	Tingtibi	41.6	36.9	38.7	57.8	100.0	175.7	323.7	302.9	258.3	138.9	73.5	49.1
Chamkharchhu	Shingkhar	29.5	25.8	28.7	42.6	73.3	106.8	223.1	213.9	157.7	78.9	45.6	34.6
	Kurjey	13.0	11.7	13.1	22.5	41.4	72.6	128.8	128.6	98.0	52.1	26.4	16.9
Kurichhu	Sumpa	43.2	41.6	58.2	82.2	141.9	281.0	463.7	405.5	302.9	142.0	77.1	54.3
	Panbang	134.1	118.0	163.8	370.5	652.8	1,120.4	1,889.9	1,614.5	1,357.1	626.2	310.0	191.8
	Kurizam	67.6	64.3	83.0	129.8	225.8	431.3	669.7	609.7	483.2	237.5	125.1	86.1
Drangmechhu	Uzorong	86.0	79.6	98.7	185.3	302.9	432.0	653.6	587.7	498.9	263.4	153.7	110.4
	Muktirap	12.7	12.1	19.1	39.7	67.4	109.2	156.4	131.1	109.1	51.7	25.6	17.3

(Source: JICA Survey Team)

Table 5-20 shows annual averages and standard deviation in the annual flow for the principal streamflow stations. The annual averages and standard deviation are obtained from the average from 2006 to 2017.

Table 5-20 Annual Averages and Standard Deviation of the Principal Streamflow Stations

River Basin	Station Name	Average (m^3/s)	Standard Deviation (m^3/s)
Amochhu	Amochu	169.8	34.5
Wangchhu	Tamchu	65.0	10.1
	Lungtenphu	21.6	2.1
Punatsangchhu	Wangdue	293.3	19.7
	Yebesa	108.9	11.3
	Kerabari	453.2	38.7
	Sunkosh	359.5	45.7
Mangdechhu	Bjizam	61.2	4.8
	Tingtibi	133.8	18.7
Chamkharchhu	Shingkhar	88.9	14.4
	Kurjey	52.4	4.0
Kurichhu	Sumpa	175.4	17.8
	Panbang	716.5	65.1
	Kurizam	269.2	13.7
Drangmechhu	Uzorong	289.1	22.8
	Muktirap	62.9	6.5

(Source: JICA Survey Team)

5.3.6 Preparation of Flow Duration Curves

(1) Reference Stations for making Flow Duration Curves

The principal river basins are divided into upper, middle and lower basins, and the flow duration curves are prepared for the basins thus divided. The streamflow stations that are referred to for making the flow duration curves are shown in Table 5-21.

Table 5-21 Streamflow Stations Referred to Flow Duration Curves

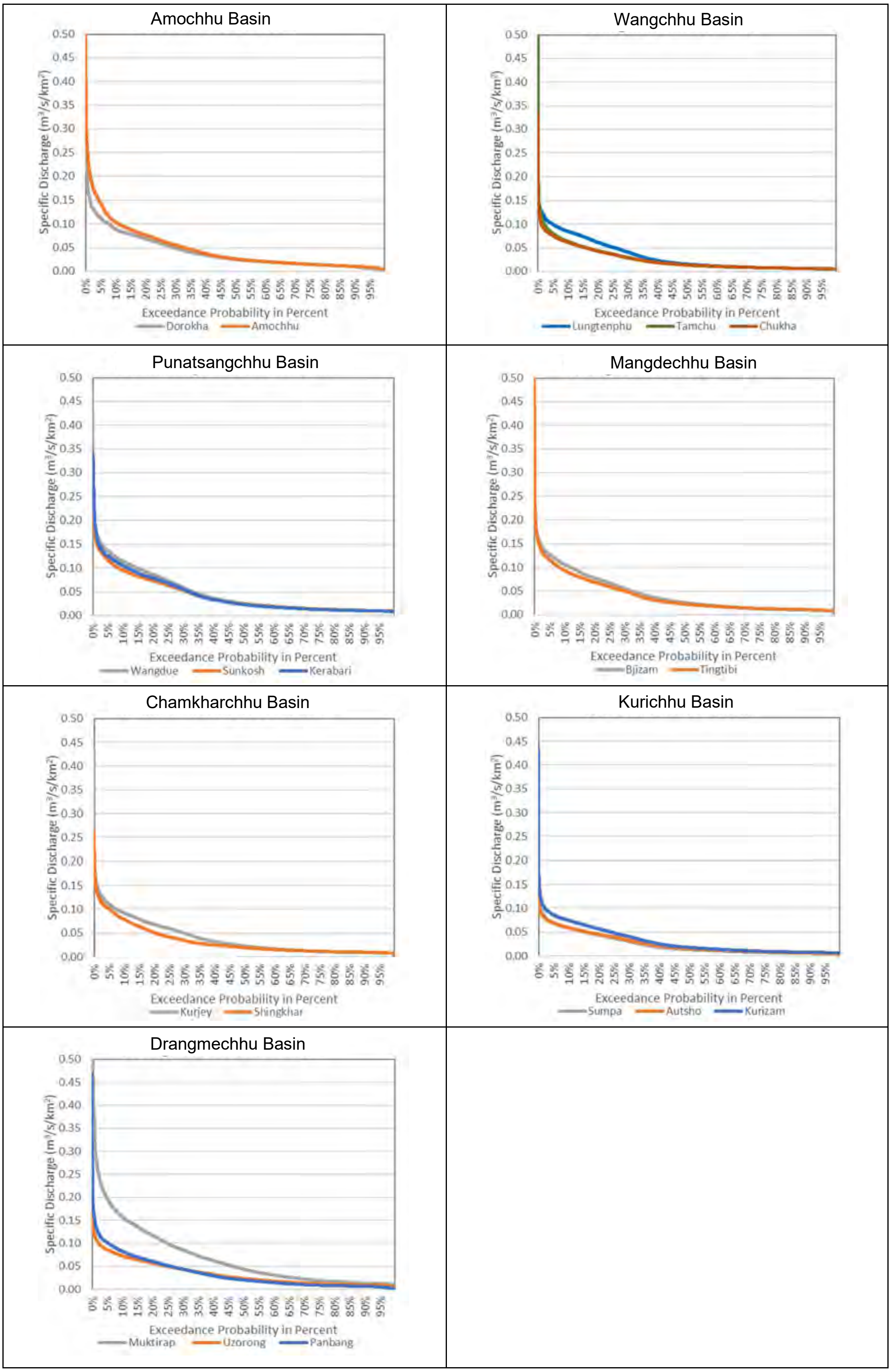
Basin Name	Upper	Middle	Lower
Amochhu	Dorokha		Amochhu
Wangchhu	Lungtenphu	Tamchu	Chukha
Punatsangchhu	Wangdue	Sunkosh	Kerabari
Mangdechhu	Bjizam	Tingtibi	
Chamkharchhu	Kurjey	Shingkhar	
Kurichhu	Sumpa	Autsho	Kurizampa
Drangmechhu	Muktirap	Uzorong	Panbang

(Source: the JICA Survey Team)

The flow duration curve is made based on the data for the principal streamflow stations. If there are no principal streamflow stations in the basin as divided, the data for the secondary stations are used. However, prior to applying a secondary station’s data, consistency of this data is confirmed.

(2) Flow Duration Curves for each Basin

The flow duration curves are prepared for the divided basins as shown in Figure 5-28.



(Source: the JICA Survey Team)

Figure 5-28 Flow Duration Curves for Principal Basins (For Primary Screening)

According to the flow duration curves prepared, the following is observed.

- The flow duration curves of the upper, middle and lower basins are almost identical in the same basin.

There are no big differences in the shape of the flow duration curves in the upper, middle, and lower basins of each river. In other words, although there is a difference in elevation between the upstream and the downstream reach, it is considered that there are no big differences in the runoff process throughout the year, except for Muktirap station in the Drangmechhu river basin as described below.

- The flow duration curve of Muktirap station in the Drangmechhu river basin differs from the others in the same basin

As shown in Figure 5-28, the flow duration curve of the Muktirap station in the Drangmechhu river basin is different to the others in the middle and lower stream of the same basin. The flow duration curve of Muktirap station shifts upward and this implies that its runoff is larger than that of others in the same basin.

There are no problems in the consistency of the hydrological data for the Muktirap station with respect to the double mass curve analysis, so it is unlikely that this can be attributed to an observation error.

Such results were also observed in the Power System Master Plan implemented via NORAD/UNDP funding in the 1990s, and the specific flow of the rivers near the Muktirap station shows higher results than that of other rivers.

Although it is necessary to confirm the observation accuracy for the station with respect to observation method, observation equipment, etc., the streamflow observed at Muktirap station is likely larger than others. This fact is also recognized by DHPS, but the reason for it is unknown.

Possible reasons are that topography/geology or rainfall conditions are unique and different to the others. The upstream area of the Kholongchhu River, where the Muktirap station is located, is close to the Himalayas, but the height difference from the river bed to the top of the surrounding mountain is around 3000 meters, and this height difference is considerably larger than that of other areas in Bhutan. There is a possibility that groundwater tends to flow out due to the large height difference. Also, due to such topographical conditions, clouds are likely to gather locally, bringing large rainfall. However, since the available information for the survey is limited, the reason is unknown at this time.

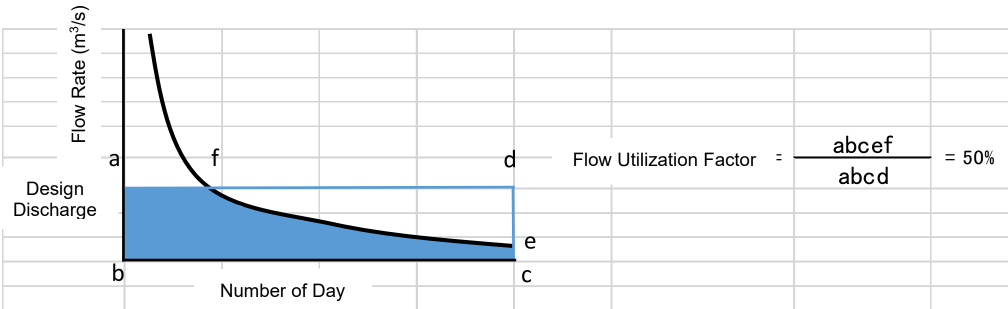
- Specific Flow in Amochhu and Kurichhu Basins

In general, the specific flow tends to decrease as it goes from upstream to downstream in the same basin. However, for the Amochhu and Kurichhu basins, the specific flow in the downstream reach is larger than that of the upstream reach. This is likely due to the distribution of rainfall in the country. The downstream of the Amochhu river basin receives heavy rainfall, and this has resulted in the downstream area having a higher specific flow. In addition, the upstream reach of the Kurichhu basin is an area with very little rainfall, so the specific flow increases as it goes downstream.

5.3.7 Setting of designed Unit Discharge

As for the Plant Load Factor (PLF) of hydropower projects in Bhutan, while PLFs of the existing hydropower plants are 63% for Chhukha HPP and 54% for Tala HPP, most of the hydropower projects at the planning stage in Bhutan are set with a PLF of 45% to 50%. For the moment at this stage, PLF for site identification of potential hydropower sites was uniformly set as 50% in order to equally compare the project sites identified.

In order to easily calculate designed discharge once the catchment area is determined, the designed unit discharge was set for each river basin as shown in Table 5-22. At this potential site identification stage, PLF was set equal to the Flow Utilization Factor without consideration of plant stoppages. The designed unit discharge was calculated as the design discharge per km^2 of catchment area when its PLF is 50%, as shown the figure below. The designed unit discharges of Aiechhu, Nyera Amari and Jomori river basins were calculated by adjusting from other main river basins, since their hydrological data was insufficient and/or inaccurate.



(Source: JICA Survey Team)

Figure 5-29 Flow Utilization Factor

Table 5-22 Designed Unit Discharge for Each River Basin

River Basin	Location	Designed Unit Discharge ($m^3/s/km^2$)	Reference Stations (Catchment Area)
Amochhu	Upstream	0.06717	Dorokha (3055 km^2)
	Downstream	0.07479	Amochhu (3650 km^2)
Wangchhu	Upstream	0.04593	Lungtenphu (663 km^2)
	Middle stream	0.03807	Tamchu (2520 km^2)
	Downstream	0.03870	Chukha (3573 km^2)
Punatsangchhu	Upstream	0.07380	Wangdue (6271 km^2)
	Middle stream	0.06950	Sunkosh (8593 km^2)
	Downstream	0.06892	Kerabari (10355 km^2)
Mangdechhu	Upstream	0.07085	Bjizam (1390 km^2)
	Downstream	0.06530	Tingtibi (3322km^2)
Chamkharchhu	Upstream	0.06282	Kurjey (1350 km^2)
	Downstream	0.05164	Shingkhar (2728 km^2)
Kurichhu	Upstream	0.03824	Sumpa (7270km^2)
	Middle stream	0.04274	Autsho (8547km^2)
	Downstream	0.05138	Kurizampa (8600 km^2)
Drangmechhu	Upstream	0.11157	Muktirap (905km^2)
	Middle stream	0.06041	Uzorong (8560 km^2)
	Downstream	0.05320	Panbang (20925 km^2)
Aiechhu, Nyera Amari		0.07487	Panbang-Uzorong-Kurizampa (1821 km^2)
Jomori		0.06170	Tingtibi-Bizam (2090 km^2)

(Source: JICA Survey Team)

5.3.8 Design Flood Peak Discharge

In the MP level study, the dimensions of the flood control facilities are empirically determined referring to data from similar projects. In order to estimate the cost of the spill way gate, design flood peak discharge for each semi-long listed site was calculated via Creager's formula, which is incorporated in the Cost Estimation Kit.

$$Q = 46 \cdot C \cdot A^{\left(0.894A^{-0.048}\right)}$$

Q= Flood peak discharge (ft^3s^{-1})
C= Creager coefficient (100 was applied in this MP)
A= Drainage area ($mile^2$)

$$Q = C \cdot A^{\left(A^{-0.05}\right)}$$

Q= Flood peak discharge (m^3s^{-1})
C= Creager coefficient
A= Drainage area (km^2)

C value of 100 is adopted as the maximum enveloped curve for flood discharges according to the "Creager and flood wave diffusion Victor M. Ponce August 2013[6]".

Further detailed flood analysis for each project shall be carried out at the Pre-FS or FS stage.

Table 5-23 Estimated Flood Discharges for all 18 Promising Sites

Project Code	Project Name	Catchment Area at Intake Site (km^2)	Creager Coefficient of the Basin	Estimated Flood Discharge at Intake (m^3s^{-1})
A-8	Dorokha	2,602	100	10,985
C-10	Chamkharchhu-II	2,525	100	10,844
P-30	Pinsa	427	100	4,636
A-5	Tingma	2,252	100	10,319
M-6	Jongthang	1,298	100	8,050
G-14	Uzorong	10,164	100	18,813
P-17	Tseykha	2,205	100	10,225
P-26	Thasa	6,892	100	16,286
P-29	Kago	250	100	3,464
P-34	Darachhu	220	100	3,223
P-35	Dagachhu-II	593	100	5,497
M-11	Wangdigang	2,490	100	10,779
M-17	Buli	216	100	3,190
C-7	Chamkharchhu-IV	2,080	100	9,966
K-13	Minjey	8,926	100	17,942
G-10	Gamrichhu-2	416	100	4,572
G-11	Gamrichhu-1	573	100	5,401
N-1	N.A. Kangpara (G)	146	100	2,540

(Source: JICA Survey Team)

5.3.9 Estimation of Sediment Specific Yield

The National Center for Hydrology and Meteorology (NCHM) carries out monitoring of suspended loads in the principal rivers of Bhutan. The wash load is estimated at 30% of the observed suspended load according to the measurement data in Bhutan. However, monitoring data for suspended loads are severely lacking and only data from the years 2011 to 2014 are available for most of the observatories. In this evaluation, the suspended load results are taken from the years 2011 to 2014, and specific

[6] http://ponce.sdsu.edu/creager_and_flood_wave_diffusion.html

sediment yield[7], which is the total of suspended load and wash load per river basin area (km^2), is calculated. The specific sediment yields are calculated as shown in the table below.

Table 5-24 Average Specific Yields from 2011 to 2014

Name of Station	River Basin Name	Catchment Area	Specific Sediment Yield* (ton/km^2/year)
Kurjey	Chamkarchhu	1350	56
Kurizampa	Kurichhu	8600	552
Mangdechhu	Mangdechhu	1390	153
Sankosh	Punatsangchhu	8050	965
Yebesa	Punatsangchhu	2320	437
Wandirapids	Punatsangchhu	6271	516

*Average of the data from the years 2011 to 2014

(Source: NCHM, JICA Survey Team)

The specific yield of the river gauging stations is assigned from the nearest sediment monitoring station shown in the above table. The assigned sediment specific yield for each of the gauging stations is shown in the table below.

Table 5-25 Assignment of Sediment Specific Yield to River Gauging Station

Pr. Code	*Station Name*	*Catchment Name*	*Altitude (m)*	*Catchment Area (km^2)*	*Sediment Specific Yield (ton/km^2)*	*Reference Station*
Principal River Gauging Stations						
1	Doyagang	Amochhu	253	3,650	516	Wandirapids
2	Lungtenphu	Wangchhu	2280	663	516	Wandirapids
3	Damchhu/Tamchu	Wangchhu	2019	2,520	516	Wandurapids
4	Kerabari	Punatsangchhu	145	10,355	964.75	Sankosh
5	Sunkosh/Turitar	Punatsangchhu	324	8,593	964.75	Sankosh
6	Wangdue/Wangdirapids	Punatsangchhu	1204	6,271	516	Wandurapids
7	Yebesa	Punatsangchhu	1255	2,320	437.25	Yebesa
8	Bjizam	Mangdechhu	1921	1,390	152.5	Mangdechhu
9	Tingtibi	Mangdechhu	546	3,322	152.5	Mangdechhu
10	Kurjey	Chamkharchhu	2625	1,350	56	Kurjey
11	Shingkhar/Bemethang	Chamkharchhu	1465	2,728	56	Kurjey
12	Kurizampa	Kurichhu	559	8,600	551.75	Kurizampa
13	Panbang	Drangmechhu	133	20,925	551.75	Kurizampa
14	Sumpa	Kurichhu	1178	7,270	551.75	Kurizampa
15	Muktrap	Drangmechhu	1691	905	551.75	Kurizampa
16	Uzorong	Drangmechhu	573	8,560	551.75	Kurizampa
Secondary River Gauging Stations						
1	Dorokha	Amochhu	479	3055	516	Wandurapids
2	Chukha/Chimakoti	Wangchhu	1376	3573	516	Wandurapids
3	Paro (closed)	Wangchhu	2220	1101	516	Wandurapids
10	Autsho	Kurichhu	850	8547	551.75	Kurizampa
11	Lhuentse (Khoma)	Kurichhu	1178	611	551.75	Kurizampa
12	Lingmethang	Kurichhu	562	320	551.75	Kurizampa
13	Sherichu	Drangmechhu	573	437	551.75	Kurizampa

(Source: JICA Survey Team)

The sediment risk of the potential projects is evaluated via the specific yield of the reference gauging station assigned by the above table.

7 The unit of specific yield is "m^3/km^2", however, the unit of "ton/km^2" is used for monitoring sediment yield in Bhutan, therefore the unit of "ton/km^2" is used in the evaluation.

5.4 Collection of Cost Data for Hydropower Projects and Creation of Cost Estimation Kit

5.4.1 Collection of Cost Data for Hydropower Projects

The construction costs for the potential hydropower plants mainly consist of the onshore costs for civil work and the offshore costs for hydro-electrical equipment.
The sub-chapters below provide brief, general descriptions of the data collected, which is utilized for developing the cost estimation kit.

(1) Civil Works

(a) Data Collection

The costs of civil and hydro-mechanical work are calculated by multiplying the quantity of main work items by unit cost. The unit cost should be an appropriate value based on reliable cost data from existing hydropower projects, including information on both the quantity and unit cost for main work items such as excavation work, concrete work and reinforcing-bar work.
The survey team has collected the following data via DHPS and the KUNFEN consultant, which include the actual cost data and contract documents.

Table 5-26 Cost Data List

Project	Document	Year
Kurichhu	Contract Document	1997
Basochhu	Contract Document	1996
Tala	Contract Document	1998
Mangdechhu	Contract Price	1998
	2nd revised cost estimation by DHPS	2016
Punatsangchhu I	Contract Price	2008
	2nd revised cost estimation by DHPS	2012
Punatsangchhu II	Contract Price	2009
	2nd revised cost estimation by DHPS	2015
Nikachhu	Contract Document	2016
Dagachhu	Contract Document	2009

(Source: JICA Survey Team)

(b) Composite Unit Price

The cost data collected is regarded as inappropriate because the content is too detailed to use for cost estimation at the master plan level. The survey team generated composite unit prices by combining detailed cost items for each major construction item, such as excavation work, concrete work and reinforcing-bar work. These composite unit prices consist of direct costs and non-direct costs. The non-direct costs include the costs for temporary work, safety control, overhead, etc.
The costs other than the major construction items are not included in the composite unit price and categorized as “Others”, which are calculated by the ratio to the summation cost of major work items. Table 5-27 shows the composite unit prices for civil work, Table 5-28 shows the composite unit prices for hydro-mechanical work, and Table 5-29 shows a list of unit prices generated for several projects in Bhutan.

Table 5-27 Composite Unit Price (Civil Work)

III. Civil Work		
III.1 Open Excavation	Included in unit cost	Included in "Other"
(1) Common	Excavation of loose material, hauling of excavated material	Quantities for diversion/coffering work
(2) Rock	Excavation of rock material, hauling of excavated material	
III.2 Underground Excavation	Included in unit cost	Included in "Other"
(1) Tunnel	Excavation in tunneling in all classes of materials via all methods, hauling of excavated materials, structural steel support, rock bolts and wire mesh, shotcrete	Grout work, adit tunnel work
(2) Shaft	Excavation in underground shaft in all classes of materials via all methods, hauling of excavated materials, structural steel support, rock bolts and wire mesh, shotcrete	Grout work, steel lining support
(3) PH cavern	Excavation in powerhouse/transformer cavern in all classes of materials via all methods, hauling of excavated materials, structural steel support, rock bolts and wire mesh, shotcrete	Grout work, access tunnel work
III.3 Concrete	Included in unit cost	Included in "Other"
(1) Dam Concrete	Concrete work of all grades in dam, and all associated items such as admixture formwork, waterstops, joint materials, etc.	Quantities for diversion/coffering work, grouting work
(2) Structural Concrete	Structural concrete work of all grades, and all associated items such as admixture formwork, waterstops, joint materials, etc.	
(3) Tunnel Concrete	Concrete work of all grades for tunneling, and all associated items such as admixture formwork, waterstops, joint materials, etc.	Grout work, adit tunnel work
(4) Shaft Concrete	Concrete work of all grades for underground shaft, and all associated items such as admixture formwork, waterstops, joint materials, etc.	Grout work, steel lining support
(5) PH Concrete	Concrete work of all grades for powerhouse/transformer cavern, and all associated items such as admixture formwork, waterstops, joint materials, etc.	Grout work, access tunnel work
(6) Penstock Concrete (embedded)	Concrete work of all grades for penstock, and all associated items such as admixture formwork, waterstops, joint materials, etc.	
III.4 Reinforcing Bar	Included in unit cost	Included in "Other"
Reinforcing Bar	Material, fabrication and installation	

(Source: JICA Survey Team)

Table 5-28 Composite Unit Price (Hydro-mechanical Work)

IV. Hydro-mechanical	Included in unit cost	Included in "Other"
IV.1 Penstock	All materials for penstock and associated assemblies such as ring girders, stiffeners, bifurcations etc. Fabrication, installation and testing are also included	
IV.2 Gate	All materials for gate and associated assemblies such as hoisting equipment, guide frame etc. Fabrication, installation and testing are also included	
IV.3 Screen	All materials for screen and associated assemblies such as guide frame. Fabrication and installation are also included	Raking equipment

(Source: JICA Survey Team)

Table 5-29 Summary of Composite Prices

Items	Unit	Tala Contract Document 1998	Basochhu Tender Document of Open Penstock works 1996	Mangdechhu As per Contract 2008	Punatsangchhu I As per Contract 2009	Punatsangchhu II As per Contract 2009	Mangdechhu 2nd Revised Cost March 2016	Punatsangchhu I 2nd Revised Cost 2012 (Dec. 2008 price level)	Punatsangchhu II 2nd Revised Cost March 2015	Nikachhu Contract Document 2016	Kurichhu	Dagachhu Contract Document 2009	Adopted
III. Civil Work													
III.1 Surface Excavation													
(1) Common	BTN / m3	177	178	332	339	209	446	602	880	167			470
(2) Rock	BTN / m3	430	284	617	352	388	809	1,277	1,581	412			873
III.2 Underground Excavation													
(1) Tunnel	BTN / m3	2,213	-	2,618	2,237	2,372	2,842	2,052	3,000	1,528			3,706
(2) Shaft	BTN / m3	1,930	-	2,984	2,403	2,602	3,562	3,285	2,397	2,030			4,224
(3) PH cavern	BTN / m3	1,187		2,054	2,226	2,319	2,017	3,098	2,367	931		2,322	2,907
III.3 Concrete													
(1) Dam Concrete	BTN / m3	3,100	-	3,707	4,424	4,740	4,524	4,241	4,740	-			5,247
(2) Structural Concrete	BTN / m3	3,100	5,055	3,770	4,927	3,347	5,100	5,026	3,412	-			5,336
(3) Tunnel Concrete	BTN / m3	3,738	-	4,687	5,670	5,056	7,643	5,653	6,070	6,528			6,634
(4) Shaft Concrete	BTN / m3	3,469	-	4,336	6,271	3,918	5,700	6,100	4,020	-			6,138
(5) PH Concrete	BTN / m3	3,638	-	4,798	4,939	3,821	7,902	5,000	3,846	-		Lump Sum	6,792
(6) Penstock Concrete	BTN / m3	3,313	-	2,646	5,508	4,495	4,175	5,370	4,314	4,969			3,745
III.4 Reinforcing Bar	BTN / ton	33,000	36,000	56,875	55,000	51,000	56,875	55,000	51,000	86,392			80,507
III.5 Road & Bridge													
(1) New Construction	BTN / km			15,114,184									21,394,151
(2) Project Road	BTN / km			15,114,184									21,394,151
IV. Hydromechanical													
IV.1 Penstock	BTN / ton	135,000	118,972	-	174,538	147,074	-	165,957	147,074	158,865			203,401
IV.2 Sand Flush Gate	BTN / ton	142,018	-	292,958	486,837	427,552	292,958	486,837	427,552	-			341,403
IV.3 Intake/Tailrace Gate	BTN / ton	256,189	-	576,961	716,948	518,496	576,961	716,948	518,496	-			672,371
IV.3 Screen	BTN / ton	-	-		84,385	115,840	-	84,385	115,840	-			98,339

(Source: JICA Survey Team)

(c) Unit Prices for Cost Estimation

The unit prices in the contract document for the Mangdechhu project in 2012 were collected, since these are relatively new and the actual construction progress has been steady without much deviation. The unit prices are adjusted in consideration of price escalation. Average inflation rates from 2013 to 2018 officially published by the IMF were applied as follows:
Average inflation rates are BTN: 6.978% and USD: 1.322%.
The following ratios of LC : FC for each component were assumed.

	Local currency	Foreign currency
Civil	80%	20%
Hydro-Mechanical	20%	80%
Electro-Mechanical	10%	90%

The on-going data for Mangdechhu or Punatsangchhu I & II is the latest information among all the data collected. These costs, however, are not typical data and have been eliminated since they contain many unclear cost increases due to geological issues and design modifications. Table 5-29 shows the unit prices applied for the cost estimation kit.
We applied 10 years' average of infration rate officially published by IMF.

(2) Electro-Mechanical Works

The costs for electro-mechanical work have changed due to the type of hydraulic turbine, number of units, head and output of the hydroelectric power plants changing. Furthermore, the costs have changed due to the location of the projects and the manufacturer chosen may affect the cost of manufacturing, transportation, installation etc., but the cost impact is not particularly large. The cost estimation kit used for the economic analysis was developed in an Excel sheet which includes the type of hydraulic turbine, number of units, head and output of the hydroelectric power plants. The following cost estimation methods for hydroelectric plants were reviewed:

(a) Guideline for Cost Estimation in Hydroelectric Power Plant Planning

(Published in March 2013 by the "Agency of Natural Resources and Energy" and "New Energy Foundation" in Japan)
In this Guideline, the costs are calculated at two (2) different development stages, as follows.

Planning Stage I: Based on map scaled at 1/5,000
The costs are calculated with, and divided into, every turbine type, every generator and other equipment.
The calculation formulas are as follows.

Where, P: Output of Hydroelectric Power Plant (kW), H: Head of project (m)
Turbine: $7.03 \times (P/\sqrt{H})^{0.555}$ (million Yen) for Francis type,
$3.78 \times (P/\sqrt{H})^{0.677}$ (million Yen) for Kaplan type,
$2.64 \times (P/\sqrt{H})^{0.847}$ (million Yen) for Pelton Type,
Generator: $1.49 \times (P/H^{0.5})^{0.768}$ (million Yen)

Other equipment (main transformer, Control equipment, Switchgear equipment etc.): 55% of costs for turbine and generator.

Planning Stage II: Based on map scaled at 1/25,000
The cost is applied at the stage of optimizing the route and output of the hydroelectric power plant.
Total cost of Electro-Mechanical Equipment: $23.0 \times (P/\sqrt{H})^{0.539}$ (Million Japanese Yen)

Though the above calculations are applied to hydroelectric power plants which have 50MW of output in the Guideline, the calculation for Planning Stage II was reviewed as one of the candidates for the

Cost Estimation Kit, since potential sites were identified using 1/50,000 precision GIS topographical data.

(b) Benchmark Costs for Small and Large Hydropower Projects
(Published in August 2015 by the "Alternate Hydro Energy Center, Indian Institute of Technology Roorkee" in India)
The cost data for 167 small hydroelectric power plants (smaller than 25MW) and 69 large hydroelectric power plants (larger than 25MW) installed during the previous 10 years (2005-2015) in 18 Indian states were collected from project developers and financial institutions. For appraisal of projects the costs were divided into major areas, like civil work, electro-mechanical work and transmission & distribution work. But the type of hydraulic turbine and number of units are unknown. The following calculation is presented:

Cost Calculation: $a \times I^b \times H^c$
Where, I: Installed capacity of project (kW)
H: Head of project (m)
a, b, c: Cost coefficients

The cost coefficients are given in Table 5-30 and Table 5-31.

Table 5-30 Values for a, b, c for Cost Coefficients (2005-2015)

	a	b	c	R-square
Total Cost Vs Capacity	102.1	0.9528	0	0.9016
Total Cost Vs Head Vs Capacity	190.5	0.8602	0.02622	0.8972
Civil Works Costs Vs Head Vs Capacity	100.6	0.8668	0.3646	0.8395
E&M Works Costs Vs Head Vs Capacity	31.68	0.96	-0.1027	0.8627
T&D Works Costs Vs Head Vs Capacity	8.732	0.7983	0.1078	0.5876
Other Works Costs Vs Head Vs Capacity	36.7	0.7999	0.1083	0.5917

(Source: JICA Survey Team)

Table 5-31 Values for a, b, c for Cost Coefficients (2010-2015)

	a	b	c	R-square
Total Cost Vs Capacity	146	0.9069	0	0.9088
Total Cost Vs Head Vs Capacity	158.2	0.8881	0.01666	0.9194
Civil Works Costs Vs Head Vs Capacity	143.4	0.8727	-0.04245	0.9407
E&M Works Costs Vs Head Vs Capacity	29.41	0.9797	-0.1187	0.8707
T&D Works Costs Vs Head Vs Capacity	0.9278	0.882	0.3895	0.7112
Other Works Costs Vs Head Vs Capacity	3.972	0.882	0.3881	0.7149

(Source: JICA Survey Team)

(c) Estimating E&M Powerhouse Cost
(Published in February 2009 by the magazine "International Water Power")
The cost data for 81 large hydroelectric power plants were collected from existing publications, journals, calls for tenders, websites and suppliers of Electro-Mechanical Equipment, project developers, financial institutions and so on. The data covered country, Power plant output, number of units type of hydraulic turbine and contract amount each of 81 projects from 32 countries, with 28 projects in the Americas (90% Latin America), 9 projects in Europe, 35 projects in Asia and 9 projects in Africa. The hydroelectric power plants have net heads ranging from 9 m to 800 m and plant capacities from 0.5MW up to 800MW per unit.

5.4.2 Cost Estimation Method

(1) Cost Estimation for Civil Works

The applied empirical formulas and procedures for cost accumulation are given in “Guideline and Manual for Hydropower Development Vol. 1 Conventional Hydropower and Pumped Storage Hydropower, JICA 2011” (hereinafter referred to as the “Cost Estimation Guideline”).

In the Cost Estimation Guideline, there are some estimation formulas for which the conditions and assumptions are different from those of hydropower plants in Bhutan. The survey team has collected actual examples of hydropower plants and analyzed the data to create new estimation formulas that fit the actual hydropower plant situation in Bhutan.

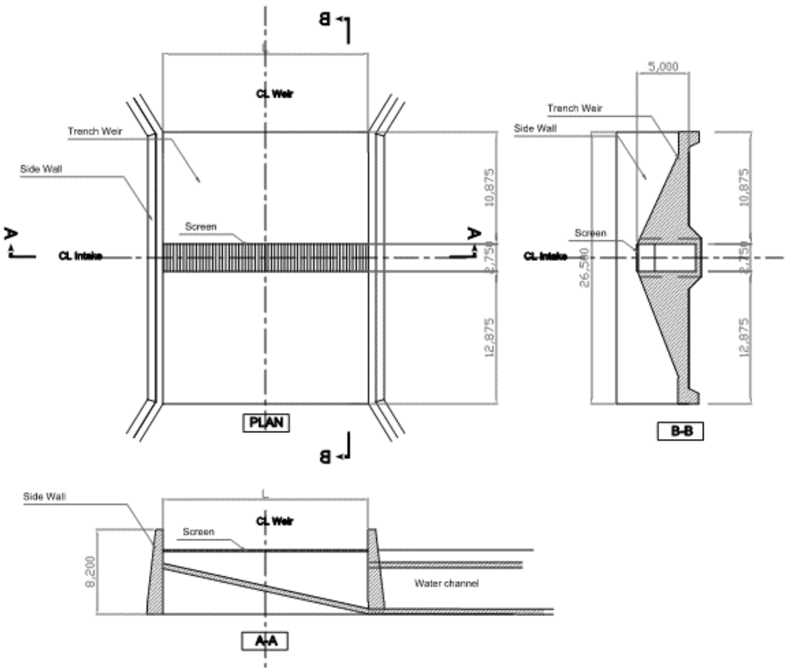
(a) Calculation of Quantities for Dam

In Bhutan, because of the geographical and hydrological features it is commonly considered that the sedimentary layer is very thick at the dam site and the excavation volume needed to remove the weak sedimentary layer will be considerable. In the Cost Estimation Guideline, however, such a condition is not incorporated in the quantity calculations. Taking into account this condition, the following formula is provided in the quantity calculation to estimate the extra riverbed excavation volume.

V = (Br + (Br + 2 x 0.3 x Drb)) x Drb/2 x Lrb (m^3)
Lrb = 2 x Hd
Where, Br: width of riverbed (m)
Drb: assumed depth of riverbed (m)
Lrb: length of riverbed excavation (m)
Hd: height of dam (from foundation elevation) (m)

(b) Calculation of Quantities for Trench Type Intake Weir

A trench type intake weir is adopted for small scale intake facilities such as mountain stream intakes for which the design discharge is less than 20 m3/s. The concrete volume is calculated based on the following conceptual design, the design discharge parameters and the width of the river.



(Source: JICA Survey Team)

Figure 5-30 Conceptual Design for Trench Type Intake

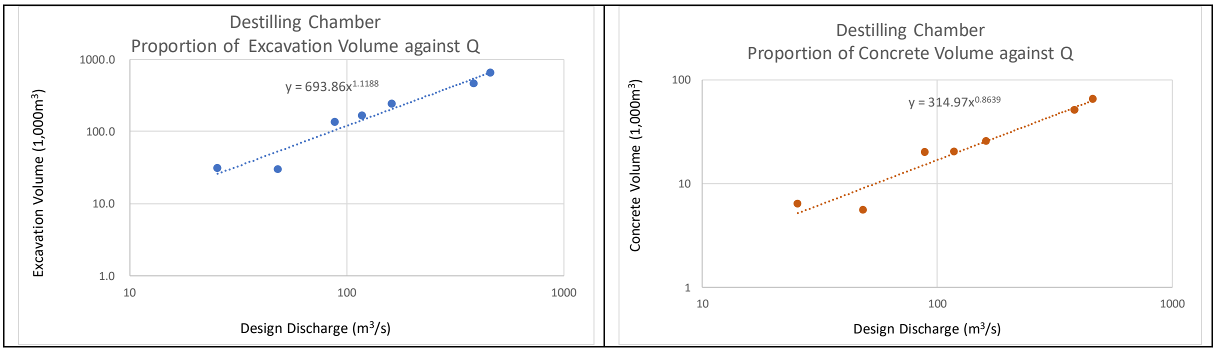
(c) Calculation of Quantities for Underground Desilting Basin

Due to the steep terrain of mountainous project sites in Bhutan, there are many cases in which an underground desilting chamber is employed instead of this being placed on the ground. In the Cost Estimation Guideline, however, only an estimation formula for the open-air type desilting pond is provided.

Taking into account such conditions, the following formula is provided to estimate the underground desilting chamber.

Ve = 693.86 x Qd_ssb1.1188
Vc = 314.97 x Qd_ssb0.8639

Where, Ve: total excavation volume of underground desilting basin (m^3)
Vc: total concrete volume of underground desilting basin (m^3)
Qssb: design discharge of underground desilting basin (m^3/s)



(Source: JICA Survey Team)

Figure 5-31 Proportion of Quantities against Design Discharge of the Desilting Basin

(d) Calculation of Quantities for Penstock

In most of the projects in Bhutan, the design of the penstock is made complying with the Indian Standard (IS). One of the conditions in which assumptions are remarkably different from the Japanese guidelines is described below.

- In the Japanese Standard, the safety factor for the penstock strength against internal pressure is 1.8. This safety factor is applied in both the normal operation case and load rejection case, causing a pressure rise in the penstock.
- In the Indian Standard, a safety factor of 2.0 is applied for the normal operation case, and 1.33 for the load rejection case. The safety factor is decreased in the load rejection case.

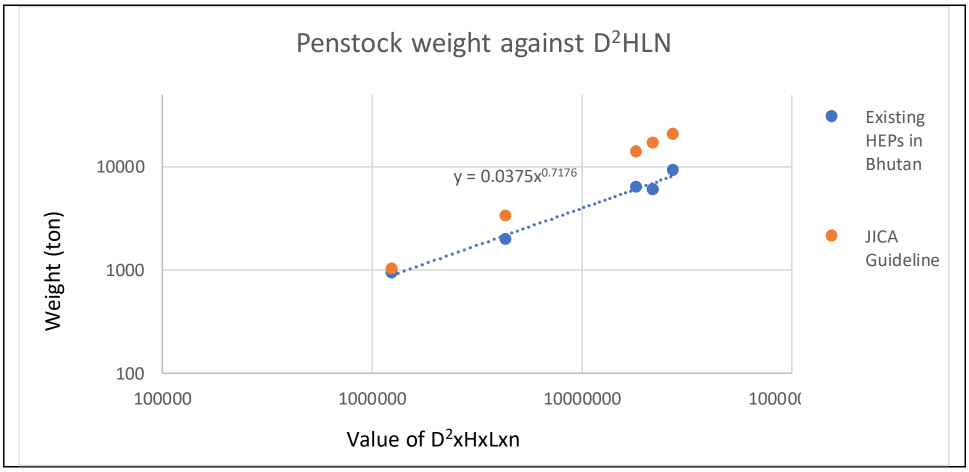
Because a higher safety factor is employed in the Japanese standard, designed pipe thickness is thicker than in actual hydropower projects in Bhutan. There could be deviations in estimation of the quantities and costs due to this.

The figure below shows plots of the existing cases and a proportion formula for the penstock weight compared with plots via the calculation in the original Cost Estimation Guideline. Based on this proportion, the following formula is applied for the estimation of penstock quantity.

$Wp = 0.0375 \times (Dp2 \times He \times Lp \times np)^{0.7176} \times a$

Where, Wp: weight of penstock (ton)
Dp: diameter of penstock (m)
He: design effective head (m)
Lp: length of penstock (m)
np: numbers of penstock lane (nos)

a: increase factor for associated materials
embedded type: 1.0
exposed type: 1.18 (=1.3/1.1)



(Source: JICA Survey Team)

Figure 5-32 Proportion of Quantities against Design Values of the Penstock

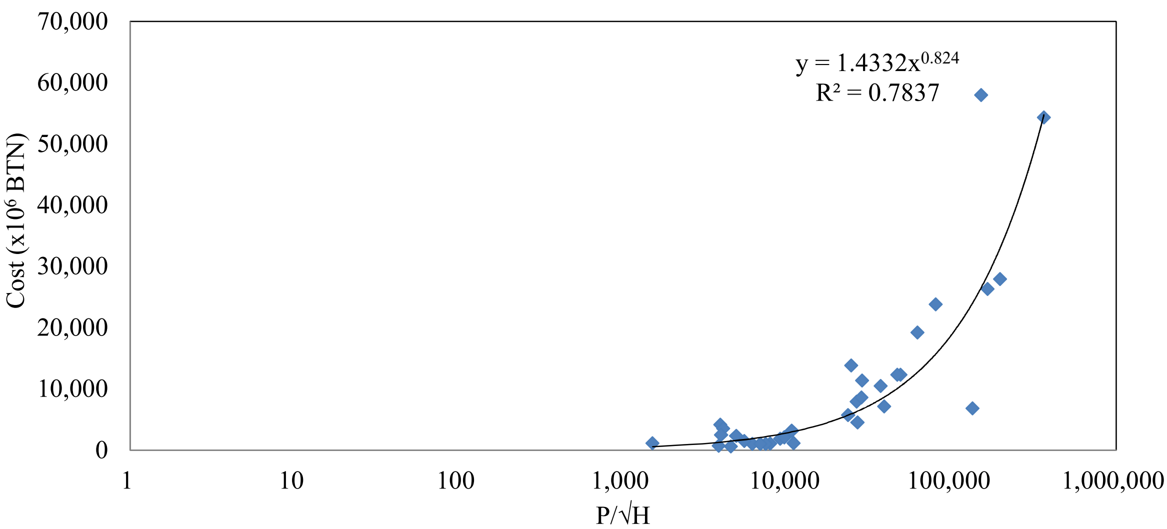
(2) Cost Estimation for E&M

The data collected from websites was analyzed via the following steps and a final approximate formula was determined from among five.

(a) Benchmark Costs for Small and Large Hydropower Projects

The cost data for 69 large projects listed in "Benchmark Costs for Small and Large Hydropower Projects" were entered into an Excel sheet and made into an approximate formula by using an application prepared in the Excel sheet. As a result, the following cost estimation formula was determined.

Cost estimation: $1.4332x(P/\sqrt{H})^{0.824}$ (Million BTN)



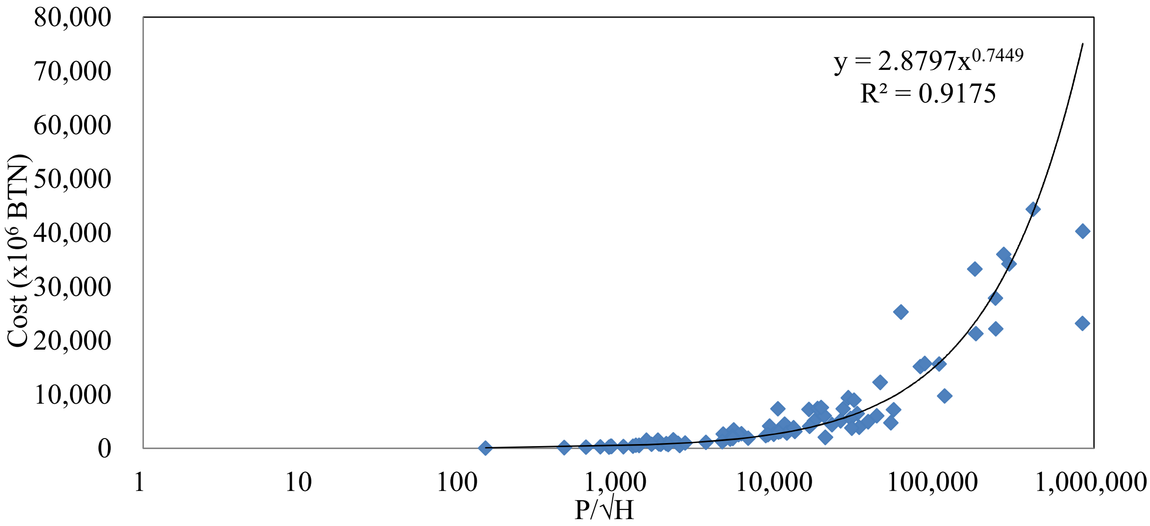
(Source: JICA Survey Team)

Figure 5-33 Cost Estimation Formula from "Benchmark Costs for Small and Large Hydropower Projects"

(b) Estimating E&M Powerhouse Cost

The cost data for 81 projects listed in "Estimating E&M Powerhouse Cost" were entered into an Excel sheet and made into an approximate formula by using an application prepared in the Excel sheet. As a result, the following cost estimation formula was determined.

Cost estimation: $2.8797x(P/\sqrt{H})^{0.7449}$ (Million BTN)



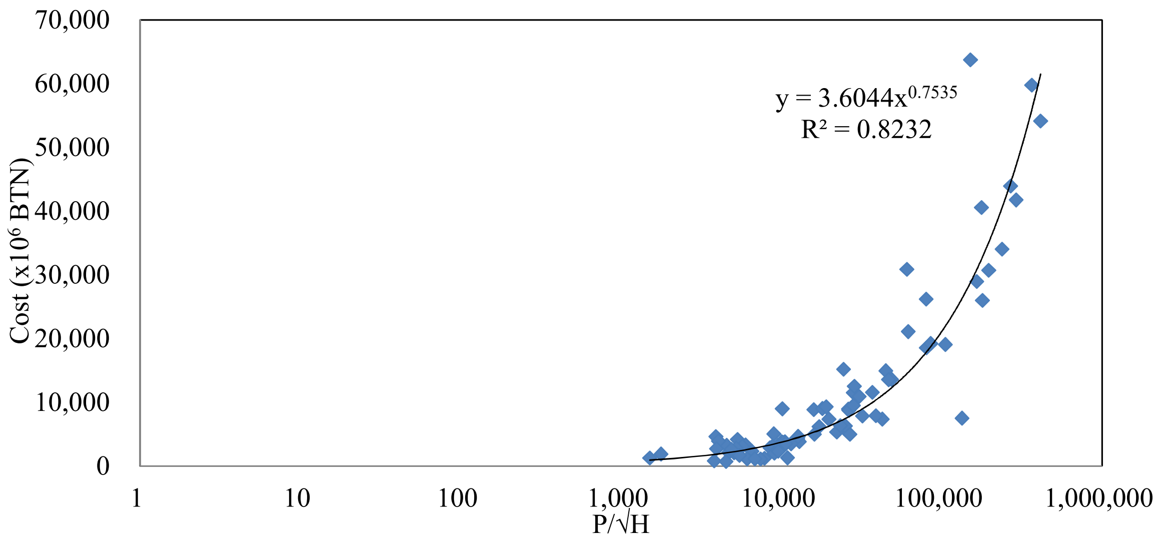
(Source: JICA Survey Team)

Figure 5-34 Cost Estimation Formula from "Estimating E&M Powerhouse Cost"

(c) Both of (a) and (b)

The data listed in both "Benchmark Costs for Small and Large Hydropower Projects" and "Estimating E&M Powerhouse Cost" were entered into one Excel sheet and made into an approximate formula by using an application prepared in the Excel sheet.

Cost estimation: $3.6044 \times (P/\sqrt{H})^{0.7535}$ (Million BTN)



(Source: JICA Survey Team)

Figure 5-35 Cost Estimation Formula from "Benchmark Costs for Small and Large Hydropower Projects" and "Estimating E&M Powerhouse Cost"

The following cost estimation formulas, mentioned above in (a), (b) and (c) and presented in "Guideline for Cost Estimation in Hydroelectric Power Plant Planning" and in "Benchmark Costs for Small and Large Hydropower Projects", were reviewed.

(a) $1.4332x(P/\sqrt{H})^{0.824}$ (Million BTN) from "Benchmark Costs for Small and Large Hydropower Projects"
(b) $2.8797x(P/\sqrt{H})^{0.7449}$ (Million BTN) from "Estimating E&M Powerhouse Cost"
(c) $3.6044x(P/\sqrt{H})^{0.7535}$ (Million BTN) from "Benchmark Costs for Small and Large Hydropower Projects" and "Estimating E&M Powerhouse Cost"

As a result of the review, cost estimation formula (c) was adopted.

5.4.3 Cost Estimation Kit

The cost estimation kit aims to provide automatic and efficient accumulation of project costs by inputting only several, specific pieces of information into empirical formulas that could calculate the costs of the major items for a hydropower plant. Based on the Cost Estimation Guidelines, the components of the project costs are determined simply in the cost estimation kit, as listed in Table 5-32.

Table 5-32 Components of Project Costs

I.	Preparatory Work
I.1	Access Road
I.2	Camp and Facilities
I.3	Compensation and Resettlement
II	Environmental Mitigation Cost
III	Civil Work
III.1	Intake Dam
III.2	Intake
III.3	Desilting Basin
III.4	Headrace Tunnel
III.5	Head Tank/Surge Tank
III.6	Penstock & Side Spillway
III.7	Powerhouse
III.8	Tailrace
III.9	Miscellaneous Work
IV	Hydro-Mechanical Work
IV.1	Gates and Screens
IV.2	Penstock
IV.3	Miscellaneous Work
V	Electro-Mechanical Work
V.1	Electro-Mechanical Equipment
V.2	Miscellaneous Work
VI	Transmission Line
VII	Administration Cost and Engineering Cost
VIII	Physical Contingency
IX	Interest During Construction

(Source: JICA Survey Team)

(1) Conditions of Cost Estimation

The conditions of the cost estimation are set out below.

(a) General

Construction costs are calculated for each component as shown in Table 5-32 without distinguishing between local and foreign currencies. In the cost estimation kit, Bhutan Ngultrum (BTN) is applied for the currency of all the costs.

(b) Type of Hydropower Plan

The conditions above explained are applied for each type of hydropower plant. The assumptions and empirical formulas for cost estimation differ by type of hydropower plant. Thus, the cost estimation using the Cost Estimation Kit starts from the selection of the type of hydropower plant.

In this study, the three major categories, Run-of-River Type (no regulating capability), Run-of-River Type with Pond (daily regulating capability) and Reservoir/Pondage Type (Regulating capability: Reservoir type > 5% >= Pondage type), are assumed.

Run-of-River Type and Reservoir/Pondage Type are conventional types of hydropower plant. Run-of-River type with Pond, which has the function of daily discharge regulation, is not regarded as a conventional type of hydropower plant in the JICA guidelines, but it is included in the major categories because this type is commonly used in existing hydropower plants in Bhutan.

Each major category has the following sub-categories in terms of waterway type, which would affect the quantity and cost estimation.

- Type I: Run-of-River Type
  - I-1: Run-of-River Type with headrace open channel and exposed penstock
  - I-2: Run-of-River Type with headrace free flow tunnel and exposed penstock
  - I-3: Run-of-River Type with headrace free flow tunnel and underground penstock
- Type II: Run-of-River Type with Pond
  - II-1: Run-of-River Type with pond and headrace pressure tunnel and exposed penstock
  - II-2: Run-of-River Type with pond and headrace pressure tunnel and embedded penstock
- Type III: Reservoir/Pondage Type
  - III-1: Reservoir/Pondage Type with headrace pressure tunnel and exposed penstock
  - III-2: Reservoir/Pondage Type with headrace pressure tunnel and embedded penstock

(c) Preparatory Work

The costs for Preparatory Work are calculated as follows.

- Cost of Access Roads for the preparatory work is calculated based on the quantity of work and unit costs.
- Cost of the office and camp facilities is calculated as 5% of the total cost of the Civil Work for Run-of-River type and 2% for reservoir and pondage type.
- Compensation and Resettlement costs are calculated as 5% of the total cost of the Civil Work for reservoir and pondage type. Since the run-of-river type is a relatively small-scale hydropower project, compensation and resettlement costs are ignored.
- Environmental mitigation cost is estimated as l% of the total cost of the Civil Work for run-of-river type, and 3% for reservoir and pondage type.

(d) Civil Work and Hydro-mechanical Work

The costs for Civil Work and Hydro-mechanical Work are calculated as follows.

- Costs for Civil Work and Hydro-Mechanical Work are calculated by multiplying the quantity of main work items by unit cost. The work quantity is obtained from empirical formulas provided for each item. The directions and estimation formulas for the quantities of each major item, except for the items (transmission and substation facilities) mentioned in Chapter 5.5.2 are explained in the JICA guideline.
- In this Kit, the main work items for Civil Work are excavation, concrete, dam embankment, and reinforcing bars. The main work items for Hydro-Mechanical Work are gate, screen, and steel pipe. The unit prices of each main work item consist of direct costs and non-direct costs. The

non-direct costs include the costs for temporary work, safety control and overhead, etc. The costs other than the major construction items are not included in the composite unit price and categorized as "Others", which are calculated by the ratio to the summation cost of major work items. Take a dam construction case for example, "Others" include works such as, foundation grout, diversion/coffering and slope protection.

Civil Work (excavation, dam embankment and concrete)

Cost (BTN) = Volume of Each Work (cums.) x Unit Price (BTN/cum.)

Civil Work (reinforcing bar)

Cost (BTN) = Weight of Reinforcing bars (tons) x Unit Price (BTN/ton)

Hydro-Mechanical Work

Cost (BTN) = Weight of Each Piece of Equipment (tons) x Unit Price (BTN/ton)

- The costs for work items other than the main items are calculated as "Other" in a lump-sum at a certain ratio against the total cost of the main work items.
- Unit costs are used by referring to the latest data for similar work in the relevant country. If it is difficult to collect such data in the relevant country, prices on the international market for hydraulic equipment are applied.

(e) Hydro-electrical Work

The costs of electro-mechanical equipment such as turbines, generators, control devices, main transformers, etc., as well as installation work for them, are estimated as a lump-sum cost.

The cost is estimated by assuming the relationship between a cost and a characteristic value - P: maximum output in kW, He: effective head in meters. The actual cost data from existing projects is collected and plotted so as to generate an approximated empirical formula.

(f) Administration Costs and Engineering Costs, Contingency

The following costs are included in the costs for "administration", "engineering services", and "contingencies", which are calculated by multiplying the direct construction cost by an appropriate ratio.

- The administration costs include personnel expense and expenses to maintain the construction office. The engineering service costs include expenses related to technical services such as design work and construction supervision by consultants. In this study, 15% of the direct construction cost is assumed as the cost for administration and engineering services.
- The contingency includes physical contingency, which is an increase in the quantity of work, and 30% of the direct construction cost is assumed for contingencies.

(g) Interest rate during construction

Interest rate (i) is calculated taking into account the ratio of local currency and foreign currency. For example, if the local and foreign currency portions are 40% and 60% respectively, the calculation is as follows.

$i = i_1 \times 0.4 + i_2 \times 0.6$

Where i_1: Interest rate for local currency

i_2: Interest rate for foreign currency

Interest during construction = (cost of preparatory work + cost of environmental mitigation work + cost of civil work + cost of hydraulic equipment + cost of electro mechanical equipment + cost of administration and engineering services + contingency) ×0.4×i×T

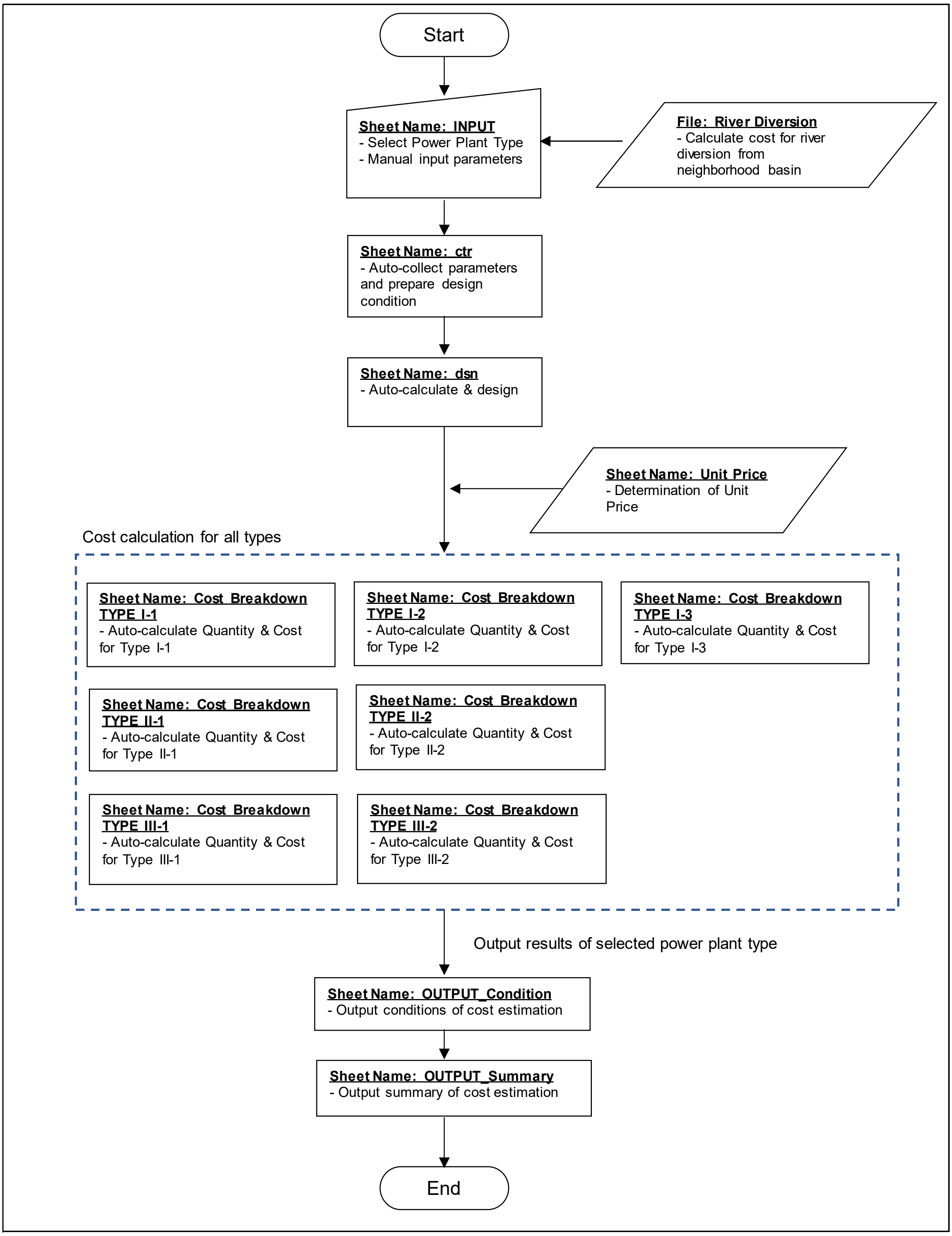
where,

T: Construction period (years)

The value of 0.4 is a cash flow coefficient, which is an empirical value from existing projects.

(2) Cost Estimation Kit

An outline of the cost estimation kit, input form and sample of output are shown in Figure 5-36, Table 5-33 and Table 5-34 respectively. The cost estimation kit is developed using MS Excel 2016.



(Source: JICA Survey Team)

Figure 5-36 Outline Flowchart for Cost Estimation Kit

Table 5-33 Sample of Cost Estimation Kit Input Form

Category No.		I-1		Input category number
Type		Run of River Type		Selected type is autofilled
Dam / Weir		Weir		
Intake		Non-pressure		
Desilting Basin		Open Type		
Headrace		Non-pressure Channel		
Head Tank / Surge Tank		Head Tank		
Penstock		Open Air		
Side Spillway		Yes		
Powerhouse		Open Air		
Tailrace		Non-pressure Channel		
Design Flood	Catchment Area of Intake Site	**277**	km^2	Input catchment area of planned intake location
	Creager's C value	**100**		In case of using Creager's C value
	Design Flood Discharge	3668	m^3/s	Directly Input design flood discharge or calculated by Creager's C value
General	Category No.	I-1		Selected category number is autofilled
	Full Supply Level	**1480**	EL-m	Input design full supply level
	Minimum Operating Level	**1480**	EL-m	Input design minimum operating level
	Tailwater EL./Turbine Center EL.	**1200**	EL-m	Input design tailwater level (Francis) or Turbine center level (Pelton)
	Effective Head	**252**	m	Input effective head (= gross head - assumed head loss in rated operation)
	Plant Discharge	**26**	m^3/s	Input design plant discharge
	Combined Efficiency	**0.88**		Input assumed efficiency of combination of turbine-generator
	Maximum Generating Output	56500	kW	Calculated as P=9.8*Q*He* ηc
Intake Weir/Dam		Weir		Selected type is autofilled
	Type	**Trench Weir**		Select Concrete Gravity Type or Rock Fill Type or Trench Weir Type (Trench Weir Type only for TYPE I-1,I-2, I-3)
	River width	**40**	m	Read from contour map
	Crest length of weir	**70**	m	Read from contour line of crest elevation
	Weir/Dam height	**15**	m	Input design weir / dam height. For Trench Weir Type, Input "5" m +Overburden depth.
	Overburden Sediment Thickness on River	**10**	m	Input assumed thickness of sedimentation on riverbed
Headrace Waterway	Type	Non-pressure Channel		Selected type is autofilled
	Number of Waterway	**1**	nos	Input number of headrace waterway
	Discharge per lane	26	m^3/s	Design discharge / number of headrace waterway
	Open Channel Section			
	Height of Channel Wall	3.4	m	Direct input or H=((1.09*Q^0.379)^2)/0.8)^0.5*0.8
	Width of Channel	4.25	m	Direct input or B:H = 1:0.8
	Length (Open Channel)	**3000**	m	Input length if there is open channel section, otherwise input 0.
	Tunnel Section			
	Diameter	4.2	m	Direct input, or D=1.24*Q^0.375 ≧2.1 (Non-pressure type), D=1.04*Q^0.375≧1.9(Pressure type)
	Length	**500**	m	Input length if there is tunnel section, otherwise input 0.
Head Tank /Surge Tank	Type	Head Tank		Selected type is autofilled
Penstock	Type	Open Air		Selected type is autofilled
	Number of Penstock	**1**	nos	Input number of penstock
	Discharge per lane	26	m^3/s	Design discharge / number of penstock
	Average Diameter	2.7	m	Direct Input or calculate using empirical formula
	Length (Underground)	**2545**	m	Input length if there are underground / embedded sections, otherwise input 0.
	Length (Open-air)	**0**	m	Input length if there are open-air sections, otherwise input 0.
Powerhouse	Type	Open Air		Selected type is autofilled
	Type of Turbine	**Pelton**		Select Francis type or Pelton type (horizontal or vertical is not discussed here)
	Number of Unit	**2**	nos	Input number of Turbine-generator unit
Tailrace	Type	Non-pressure Channel		Selected type is autofilled
	Number of Tailrace	**1**	nos	Input number of tailrace waterway
	Discharge per lane	26	m^3/s	Design discharge / number of tailrace waterway
	Open Channel Section			
	Height of Channel Wall	3.4	m	Direct input or H=((1.09*Q^0.379)^2)/0.8)^0.5*0.8
	Width of Channel	4.25	m	W:H = 1:0.8
	Length (Open Channel)	**500**	m	Input length if there is open channel section, otherwise input 0.
	Tunnel Section			
	Diameter	4.2	m	Direct input, or D=1.24*Q^0.375 ≧2.1 (Non-pressure type), D=1.04*Q^0.375≧1.9(Pressure type)
	Length (Tunnel)	**0**	m	Input length if there is tunnel section, otherwise input 0.
Access Road	Main Access Road			
	Distance (Improvement)	**0**	km	Input total distance in km if there are improvement sections, otherwise input 0.
	Distance (New Construction)	**10**	km	Input total distance in km if there are new construction sections, otherwise input 0.
	Bridge	**0**	m	Input total length in m if there are bridges, otherwise input 0.
	Project Road			
	Distance (New Construction)	**10**	km	Input total distance in km if there are new construction sections, otherwise input 0.
	Bridge	**0**	m	Input total length in m if there are bridges, otherwise input 0.
	Access Tunnel to PH			
	Distance	**3**	km	Input total distance of access tunnel in km, if the powerhouse is open-air type, input 0
River Diversions from Neighborhood Basins	Total Construction Cost	**1,712**	mil.Nu	Input total construction cost for river diversion from neighborhood basin
Transmission Line	Total Construction Cost	**6,317**	mil.Nu	Input total construction cost of transmission line
Indirect Cost	Administration & Engineering Cost	**10%**		Input proportion of administration & engineering cost to direct cost
	Physical Contingency	**30%**		Input proportion of physical contingency to direct cost
Interest During Construction	Construction period	**6**	years	Input total construction period
	LC / FC	**1.50**		Input ratio of local currency / foreign currency
	Interest rate for LC	**5%**		Input interest rate for Local loan
	Interest rate for FC	**5%**		Input interest rate for Foreign loan
	Interest rate weighted average	**5.00%**		Input interest rate average

(Source: JICA Survey Team)

Table 5-34 Sample of Cost Estimation Kit Output Form

C. Summary of Project Cost		(Unit: Mil.BTN)
Items	**Cost**	**Note**
I. Preparation Work	**848**	
(1) Access Road	514	
(2) Camp & Facilities	167	**RoR**: (III. Civil Works) x 5% **RES**:(III. Civil Works) x 2%
(3) Compensation & Resettlement	167	**RoR:** Omitted **RES**:(III. Civil Works) x 5%
II. Environmental Mitigation Cost	**33**	**RoR**: (III. Civil Works) x 1% **RES**:(III. Civil Works) x 3%
III. Civil Works	**3,343**	
III.1 Intake Dam	74	
III.2 Intake Facilities		
(1) Intake	12	
(2) Desilting Basin	-	
III.3 Headrace Tunnel	1,016	
III.4 Head Tank/Surge Tank	32	
III.5 Penstock & Side Spillway		
(1) Penstock	-	
(2) Side Spillway	-	
III.7 Powerhouse	171	
III.8 Tailrace		
(1) Tailrace Waterway	159	
(2) Tailrace Outlet	7	
III.9 River Diversions from Neighborhood Basin	1,712	
III.10 Miscellaneous Works	159	(Item III.1 to III.9) x 5%
IV. Hydromechanical Works	**607**	
(1) Gate and Screen	49	Spillway Gate, Intake Gate, Silt Flush Gate, Tailrace Gate
(2) Penstock	503	
(3) Miscellaneous Works (10% of above total)	55	
V. Electrical Works	**1,903**	
(1) Electro-Mechanical Equipment	1,812	Turbine, Generator, Transformer, Switchyard Equipment, etc.
(2) Miscellaneous works (5% of above total)	91	
VI. Transmission Line	**6,317**	
(1) Transmission Line	6,317	Transmission Line, Substation Equipment etc.
Direct Cost	**13,051**	
VII. Administration Cost and Engineering Cost	**1,958**	(Direct Cost) x 0.1
VIII. Contingency	**3,915**	(Direct Cost) x 0.3
IX. Interest During Construction	**2,271**	(Item I - VIII) x 0.4 x I x T (Assumed I = 0.05, T= 6years)
Subtotal of Non-Construction Cost	**8,144**	
Grand Total	**21,195**	

(Source: JICA Survey Team)

5.5 Construction Costs for Power Transmission Facilities

5.5.1 General Design Conditions for Transmission Facilities

The general design conditions for transmission facilities were obtained through a discussion with DHPS and BPC.

(1) Design Conditions

Maximum temperature:	50	deg C
Minimum temperature:	1	deg C
Maximum humidity:	95	%
Average temperature:	32	deg C
IKL:	50	days
Average annual rainfall:	1,250	mm
Wind velocity (peak gust velocity):	47	m/s
Seismic level:	0.3	G

(Source: Indian standard)

(2) Towers

Standardized towers - straight, light angle, heavy angle, river crossing and gantry towers - are applied for 400, 220 and 132kV.

(3) Conductors and ground wire

The following standardized conductors are applied for each voltage.
GSW type is used for ground wire and OPGW type has also been used recently.

Table 5-35 Standardized Conductors for each Voltage

Voltage	Standardized conductor
400 kV	ACSR Moose Double
220 kV	ACSR Zebra Single
132 kV	ACSR Panther Single

(4) Insulators

Standard disc type porcelain insulators with a ball and socket (70, 90, 120 and 160 kN) are used for most of the existing transmission lines.

5.5.2 Construction Unit Prices for Transmission and Substation Facilities

(1) Construction Unit Prices for Transmission and Substation Facilities

The unit construction costs for the latest transmission and substation facilities were obtained through a discussion with DHPS and BPC and these are shown in Table 5-36 and Table 5-37. These unit prices are quoted from data in the "National Transmission Grid Master Plan (NTGMP) of Bhutan - 2018", prepared in June 2018. However, NTGMP2018 only lists unit prices for some facilities. Therefore, for facilities whose unit price is not listed in NTGMP2018, it was estimated using the rate of price increase from the unit price listed in NTGMP2012.

For reference, the unit costs in Bhutan and India in 2012 are also described. It was found that construction costs in Bhutan are roughly 1.5 times higher than those in India because of the increased construction and transportation costs needed for steep, mountainous areas. Further, construction costs in Bhutan rose about 1.2 to 1.5 times from 2012 to 2018 because of an increase in prices.

Other information on transmission and substation costs found through discussion with BPC is as follows.

- Although the general ratio of material costs and construction costs for transmission facilities in Bhutan is usually 60% : 40%, the ratio may be 50% : 50% for large constructions passing through long-distance mountainous areas.
- Generally, in mountainous area construction, the construction process is often greatly delayed, so BPC considers large contingency costs in its budgets.
- Construction costs are not part of BPC's budget but that of the generation companies who construct power stations. Therefore, when construction costs increase, these business operators will bear the extra amount.
- Order placements for construction of transmission lines and construction of substations are separated.

Table 5-36 Unit Construction Costs for Transmission Lines

(Unit: million Nu./km)

Voltage	Conductor[8]	Area Passing	**Proposed Unit Price**	Reference 1 (NTGMP 2012)	Reference 2 (India in 2012)
400 kV	ACSR Moose Double	Mountain	**49**	33	22
		Plain	**(29)**	-	12
220 kV	ACSR Zebra Single	Mountain	**22**	15	9
		Plain	**(13)**	-	5
132 kV	ACSR Panther Single	Mountain	**17**	11.5	7
		Plain	**(10)**	-	4

Table 5-37 Unit Costs for Substation Equipment including Installation Costs

(Unit: million Nu.)

Voltage	Equipment	**Proposed Unit Price**	Reference 1 (NTGMP 2012)	Reference 2 (India in 2012)
400 kV	500 MVA 400/220 kV Transformer per unit	**152**	127	-
	200 MVA 400/220 kV Transformer per unit	**73**	61	-
	200 MVA 400/132/33 kV Transformer per unit	**78**	65	-
	GIS per bay	**134**	111	90
	AIS per bay	**66**	55	50
220 kV	GIS per bay	**78**	65	50
	AIS per bay	**42**	35	
132 kV	GIS per bay	**36**	30	-
	AIS per bay	**24**	20	-

(2) Conversion formula for transformer price

For transformer price estimation when the voltage and capacity are changed, as a result of consultation with a Japanese transformer manufacturer the following experimental conversion formula, in which voltage and capacity are proportional to 2/3 power for the transformer cost, is applied.
However, it is assumed that when the voltage on the high-voltage side does not change, the price will not change.

[8] According to BS standards (British Standards Institution). Moose: ACSR530mm^2, Zebra: ACSR430mm^2, Panther: ACSR210mm^2

<Conversion formula for transformer price>

Unit prices (including installation costs) of transformers by voltage and capacity are as follows. In addition, the converted cost of a 100 MVA machine using the 2/3 power law has been added in the right column.

Voltage	Capacity	Cost	Converted cost of 100 MVA machine
400/220 kV	500 MVA	152 million Nu.	152 x (100/500)^(2/3) = 52 million Nu.
400/220 kV	200 MVA	73 million Nu.	73 x (100/200)^(2/3) = 46 million Nu.
400/132/33 kV	200 MVA	78 million Nu.	78 x (100/200)^(2/3) = 49 million Nu.

By averaging the above three cases, the cost of a standard transformer with a high voltage side of 400kV and a capacity of 100MVA is 49 million Nu. The transformer price when the voltage and capacity vary was calculated based on the price of this standard transformer.

Specific examples are shown below.

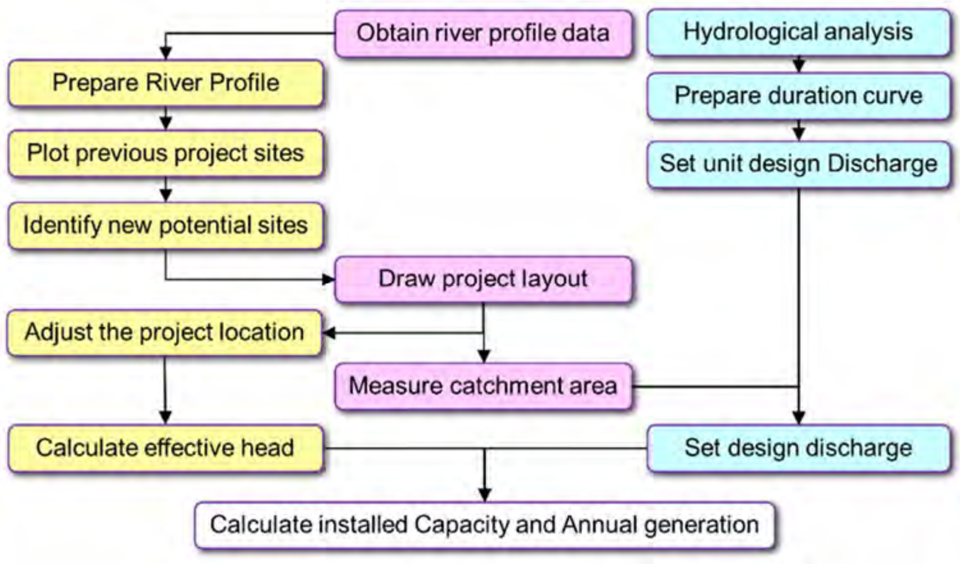
1. Step-up transformer with high voltage side of 400kV, and capacity of 250MVA
   49 x (400/400)^2/3 x (250/100)^(2/3) = 90 million Nu.
2. Step-up transformer with high voltage side of 220kV, and capacity of 120MVA
   49 x (220/400)^2/3 x (120/100)^(2/3) = 37 million Nu.
3. Step-up transformer with high voltage side of 132kV, and capacity of 50MVA
   49 x (132/400)^2/3 x (50/100)^(2/3) = 15 million Nu.

Chapter 6. Identification of Potential Hydropower Sites

6.1 Methodology

6.1.1 Flow chart Potential Site Identification

Potential site identification is carried out in accordance with the flowchart shown in Figure 6-1.



(Source: JICA Survey Team)

Figure 6-1 Flowchart for Potential Hydropower Site Identification

At the potential site identification stage, environmental/social impacts such as resettlement of local residents and the existence of national parks/protected areas are not taken into consideration. The social conditions are evaluated in the Multi Criteria Analysis (MCA) for the project site screening.

6.1.2 Required Conditions for Potential Site Identification

(1) River basins targeted for potential site identification

As described in Section 5.1, the five main river basins (Amochhu, Wangchhu, Punatsangchhu, Mangdechhu and Drangmechhu) and three small river basins (Aiechhu, Nyera Amari and Jomori) have been selected as target river basins for potential site identification.

(2) Basic criteria for potential site identification

For potential hydropower site identification, cascade development is taken into consideration in order to optimize a series of development from upstream to downstream in a river. PLF for site identification of potential hydropower sites was uniformly set as 50% in order to equally compare the project sites identified as mentioned in Chapter 5. In consideration of practically possible development from technical and economic aspects based on previous hydropower projects, other criteria were set whereby maximum gross head is approximately 800m; maximum horizontal length/distance of waterway is approximately 15km; and maximum dam height is approximately 200m.

A summary of the criteria is shown below:

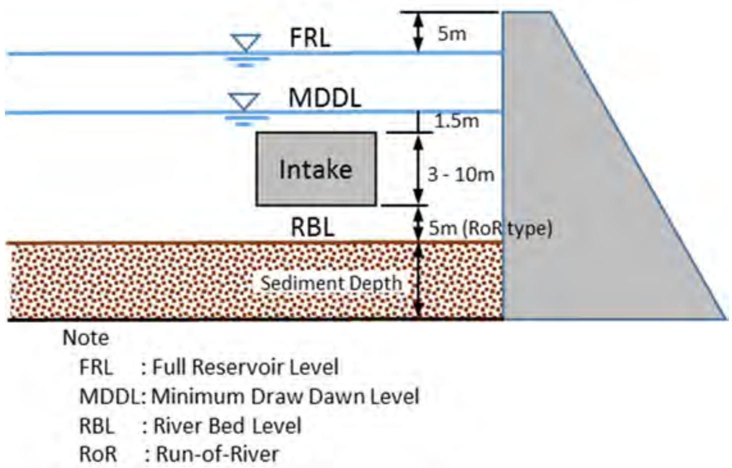
- Cascade Development

- Generation Type : Run-of-River (RoR)
- Plant Load Factor (PLF) : 50%
- Gross Head : Maximum approx. 800m
- Length of Waterway : Maximum approx. 15km (horizontal distance)
- Dam Height : Maximum approx. 200m (150m from riverbed)

(3) Other factors to be considered for project identification and layout review

During procedures for this PSMP2040, technically developable hydropower potential is first assessed without consideration of environmental/social impacts. This is then followed by site selection/screening based on the MCA. Despite the basic policy, it appears necessary to take into account the practical layout of each project even at the site identification stage. In this regard, the following points are added as parts of the site identification criteria:

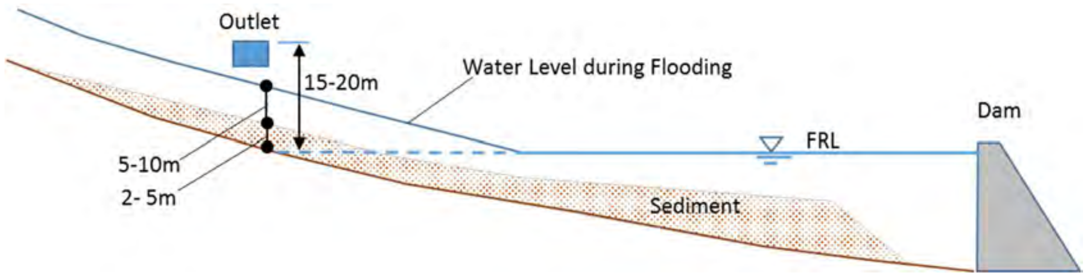
- In consideration of the effectiveness of head acquisition and river flow utilization, intake location is selected upstream of the river slope change points and downstream of the confluence of tributaries;
- Dam type projects are also considered as an option in the case of gentle river slopes of less than 1/100. For dam site selection, relatively narrow parts of the river are taken into account;
- For dam height and intake water level setting, the following are taken into account:
  - For assumption of the depth of riverbed sediment materials, the formula below is prepared via multiple linear regression analysis with parameters for river slope and elevation of dam location based on records of riverbed sediment depth from projects under development. Despite the formula, minimum and maximum depth are set as 10m and 40m respectively.
    $$(\text{Sediment Depth}) = 0.015 \times (\text{Dam riverbed EL}) - 1{,}195 \times (\text{Riverbed gradient}) + 25.9$$
  - Intake height is set from 3m to 10m according to designed discharge.
  - Dam height is calculated via the following formula:
    $$(\text{Dam Height}) = \text{FRL} + 5\text{m} - RBL + (\text{Sediment Depth})$$
    The 5m freeboard includes surging height due to floods, and waves due to wind and earthquakes at this potential identification stage.



(Source: JICA Survey Team)

Figure 6-2 Determination of Dam Height

- Tail water level is set at least 15m to 20m higher than FRL of a downstream project in consideration of the water level rising due to flooding and sedimentation.



(Source: JICA Survey Team)

Figure 6-3 Determination of Tail Water Level

- In consideration of effective utilization of water from tributaries, water intake not only from main rivers but also from several streams, if available, is taken into account.
- In order to minimize the construction costs of the waterway, the waterway route is set as straight as possible to shorten it. When selecting the waterway route, minimum overburden is set to at least 100m in consideration of geological soundness and water-tightness, since the waterway is pressurized. In the JICA Survey Team's experience, 100m overburden is normally chosen for waterway route selection at this stage.
- In consideration of the shortest waterway route, shorter headrace and longer tailrace, a so-called "head type" is adopted for some potential sites depending on topographic conditions.
- Powerhouse is basically set as underground type, but open air type is also considered if there is enough suitable flat space.
- Floating type dam with trench intake, which does not require excavation of riverbed sediment materials, is also adopted if designed discharge is less than $20m^3/s$.

6.1.3 Potential Site Identification Approach

(1) Preparation work

(a) Preparation work for designed discharge setting

Prior to the potential site identification work, analysis of the latest hydrological data and preparation of flow duration curves for each river basin are conducted. Further, design unit discharge for each river basin is determined on the assumption that PLF is 50%. Details of the preparation work related to hydrology are shown in Section 5.3.

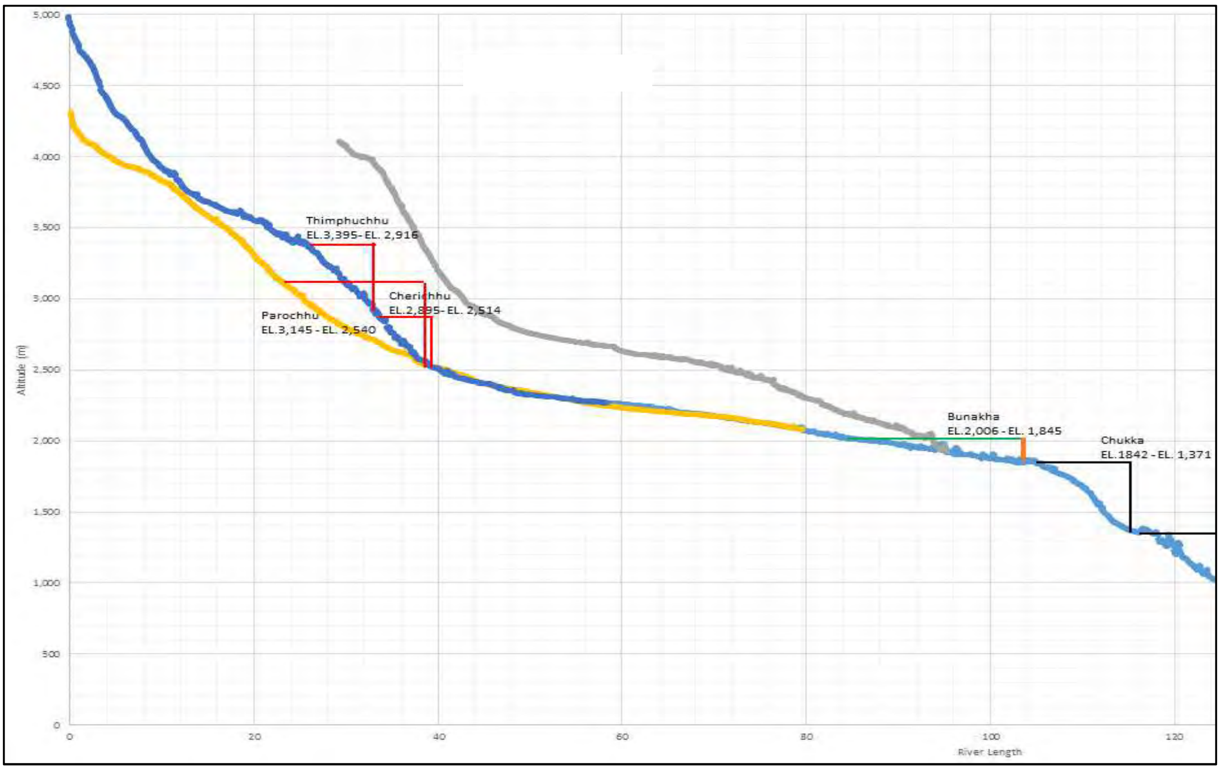
(b) Preparation of topographical data and river profile data

The potential site identification is conducted with QGIS, in which topographic map data is newly developed from 10m mesh elevation data of Bhutan as shown in Chapter 11. Riverbed elevation data is extracted from QGIS.

(c) Preparation of river profiles and plotting of existing hydropower projects

As the next piece of preparation work, river profiles are prepared based on the riverbed elevation. Details of the work are shown in Section 5.1.

The next step is to plot the existing and previously planned hydropower plants on the river profiles, which are prepared as described above. As a sample, the river profile of Wangchhu is shown in Figure 6-4.



(Source: JICA Survey Team)

Figure 6-4 Sample of River Profile (Wangchhu)

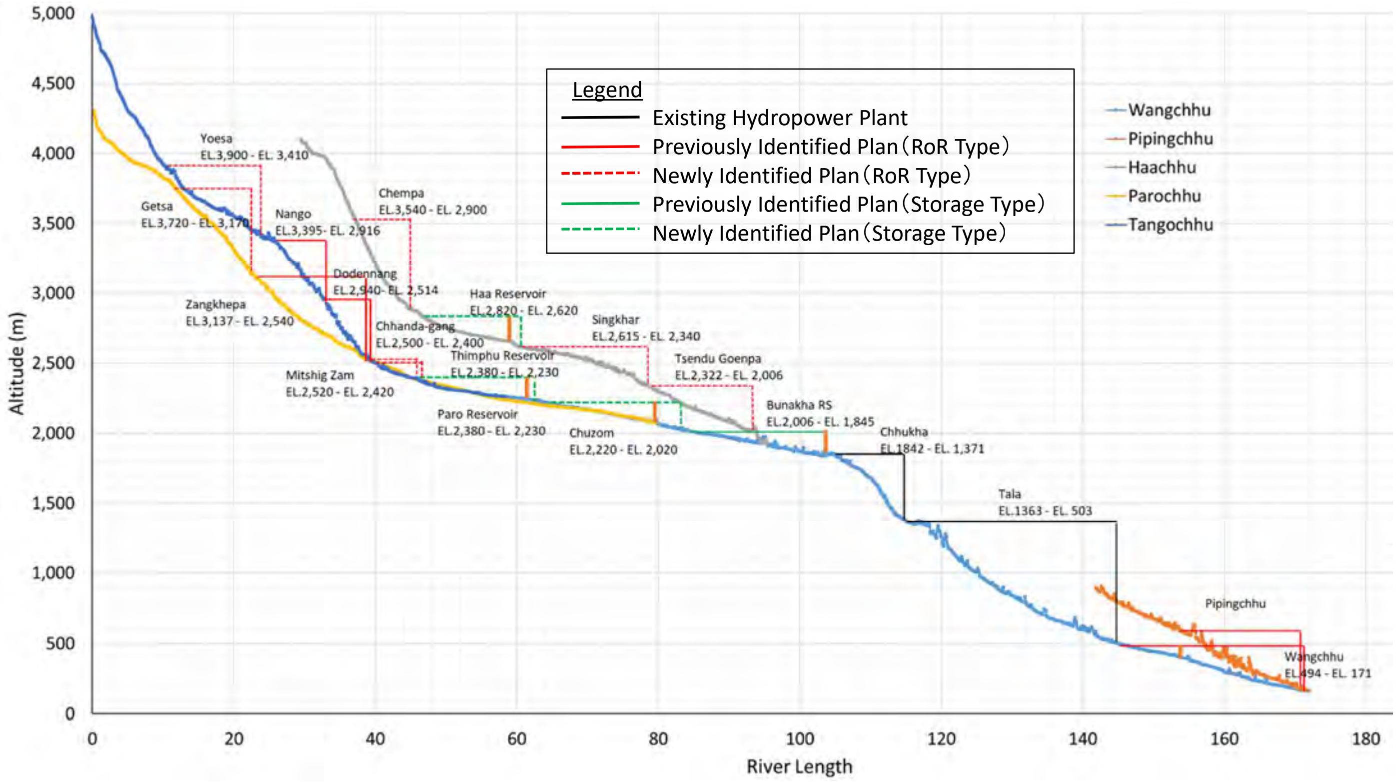
(2) Identification of new potential hydropower sites

(a) Potential site identification on river profile

New potential sites are identified and plotted on the river profile prepared in advance, taking into account avoidance of unutilized head as much as possible. In this step, limitations on waterway length and head are set for practical planning as shown in Section 6.1.2.

Since projects which have small L/H (L: waterway length, H: head) normally show higher economic efficiency, just upstream of river slope change points is generally regarded as a good location for the intake site. For effective river flow utilization, downstream of a confluence of tributaries is also regarded as a good location for the intake site. These considerations are taken into account during the potential site identification.

As a sample, the results of the new potential site identification process using the Wangchhu river profile are shown in Figure 6-5.



(Source: JICA Survey Team)

Figure 6-5 Sample of Identification Results for Potential Sites on River Profile (Wangchhu)

(b) Principles adopted for the naming of the projects

The project code is assigned for each project using the initial letter of each river basin, as shown below, and a project code is given from the upstream of the main river and tributaries. The name of the project is assigned based on the name of nearest villages located to the dam or powerhouse site. If there are more number of projects in the same river/tributies the stages are assigned from downstream to upstream.

Table 6-1 Head of Project Code

River Basin	Head of project code
Amochhu	A-
Wangchhu	W-
Punatsangchhu	P-
Mangdechhu	M-
Chamkharchhu	C-
Kurichhu	K-
Drangmechhu	G-
Aiechhu	Ai-
Jomori	J-
Nyera Amari	N-

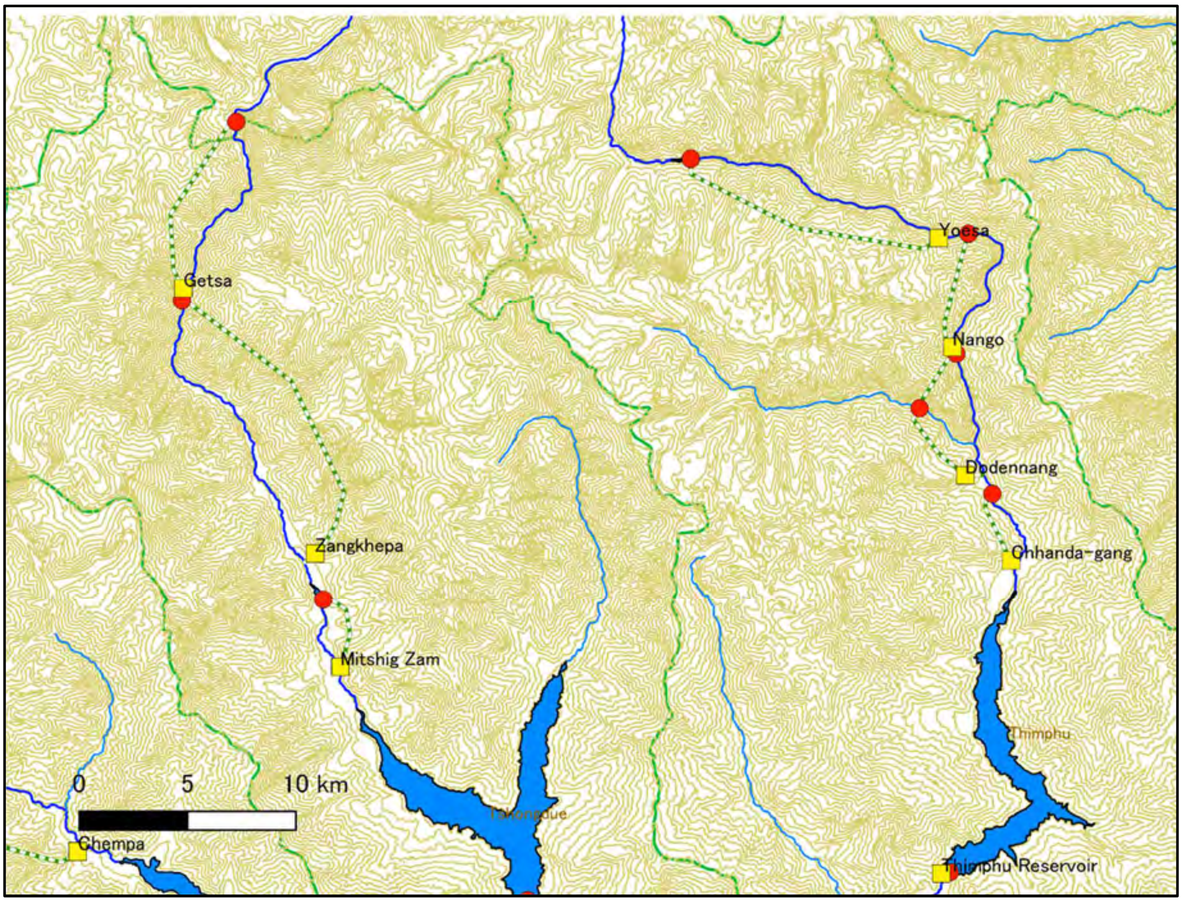
(Source: JICA Survey Team)

(c) Plotting project layout on topographical maps

The intakes and outlets of potential sites identified on the river profile are plotted on topographical maps in QGIS, and a waterway route for each potential site is drawn connecting the intake and outlet.

Waterway route is set making it as straight and short as possible, securing at least 100m of overburden. The powerhouse is basically set as underground type, but ground surface type is also considered if there is enough suitable flat space.

As a sample, layouts of newly identified potential sites upstream of Wangchhu, drawn on topographic maps, are shown in Figure 6-6.



(Source: JICA Survey Team)

Figure 6-6 Sample of Project Layout (Upstream of Wangchhu)

(3) Examination of key project profile

(a) Delination of catchment areas

After adjustment of the project layout, the catchment area of each potential site at the intake point is determined.

(b) Setting of designed discharge

Designed discharge for each potential site is calculated multiplying the designed unit discharge by the intake catchment area.

(c) Setting of effective head

Gross head is calculated subtracting tail water level from intake water level. In general, head losses depend on the layout and dimensions of facilities, such as the length and diameter of waterways. For simplification of the calculation, however, head loss is assumed as 7% for all type ignoring influence of designed discharge and waterway length. Effective head is calculated subtracting the head loss from the gross head.

(d) Preparation of Potential Hydropower Site List

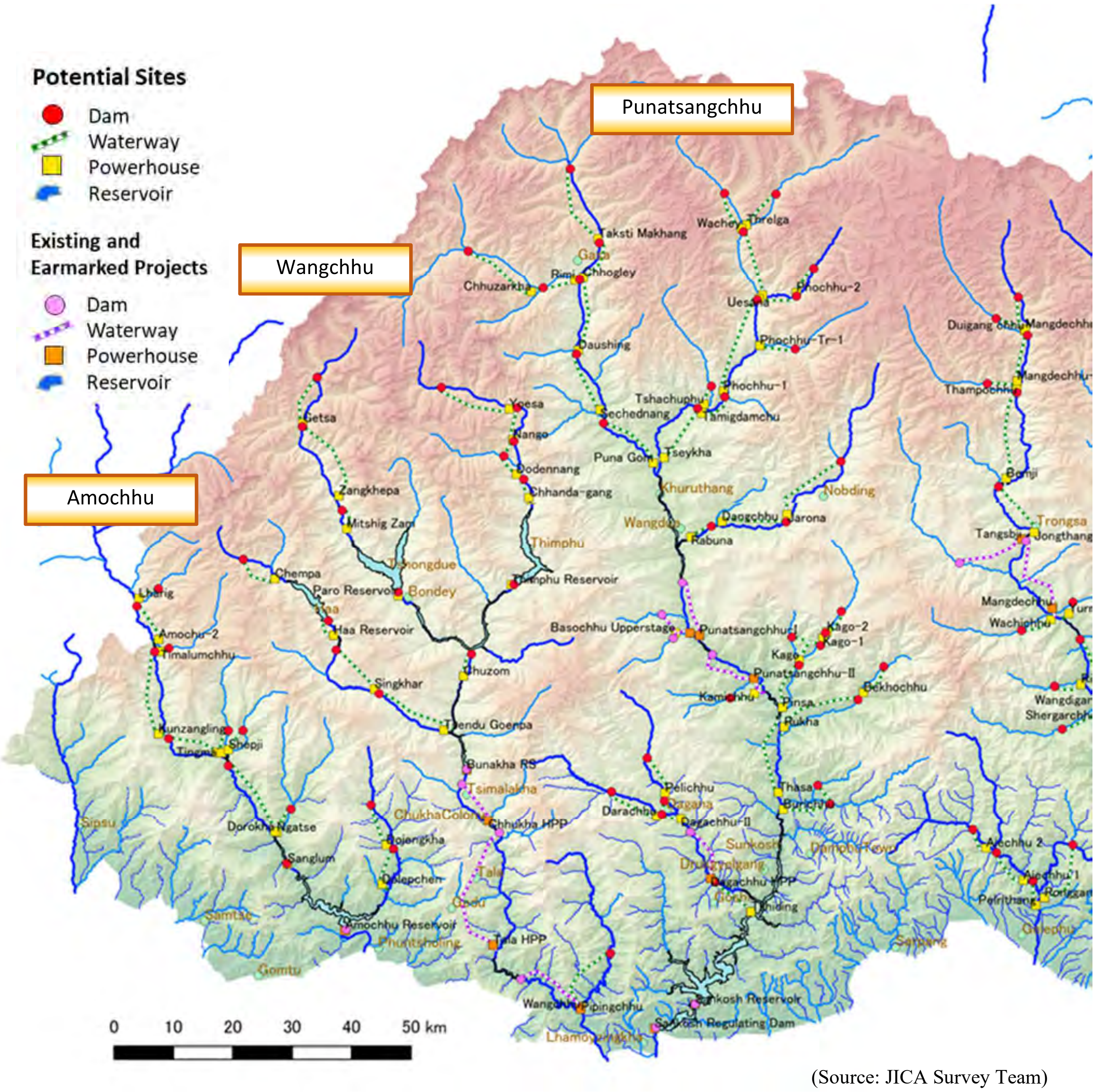
Finally, the installed capacity of each potential site is calculated with 88% of the combined efficiency of turbine and generator. Further, annual generation is calculated with assumption of PLF as 50%. For hydropower projects under Indian initiatives and projects which are excluded from this study, the project profile are kept as it is.

6.2 Results of Identification of Potential Hydropower Sites

In order to obtain conventional hydropower potential in Bhutan, potential sites were identified using 1/50,000 precision GIS topographical data, river longitudinal profile and river flow duration curves. The potential sites include 6 existing power plants and 13 earmarked project sites.

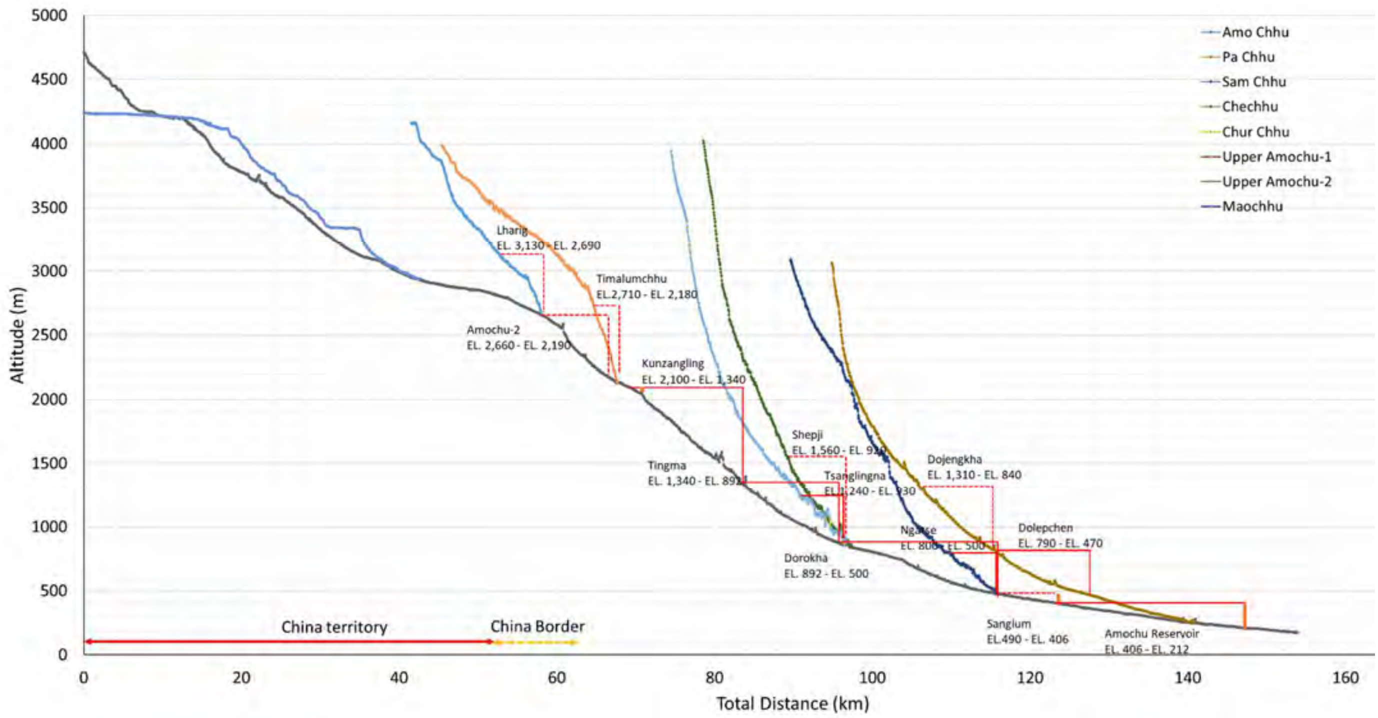
6.2.1 Potential Sites Identified in Western Region

Potential hydropower sites were identified in the Amochhu, Wangchhu, and Punatsangchhu basins, which are located in the Western Region. The location of every potential site is shown in Figure 6-7, the elevations of potential sites on the river longitudinal profile by basin are shown in Figure 6-8 to Figure 6-10, and the list of potential sites by basin is shown in Table 6-2 to Table 6-5.



(Source: JICA Survey Team)

Figure 6-7 Location Map of Potential Hydropower Sites Identified (Western Region)



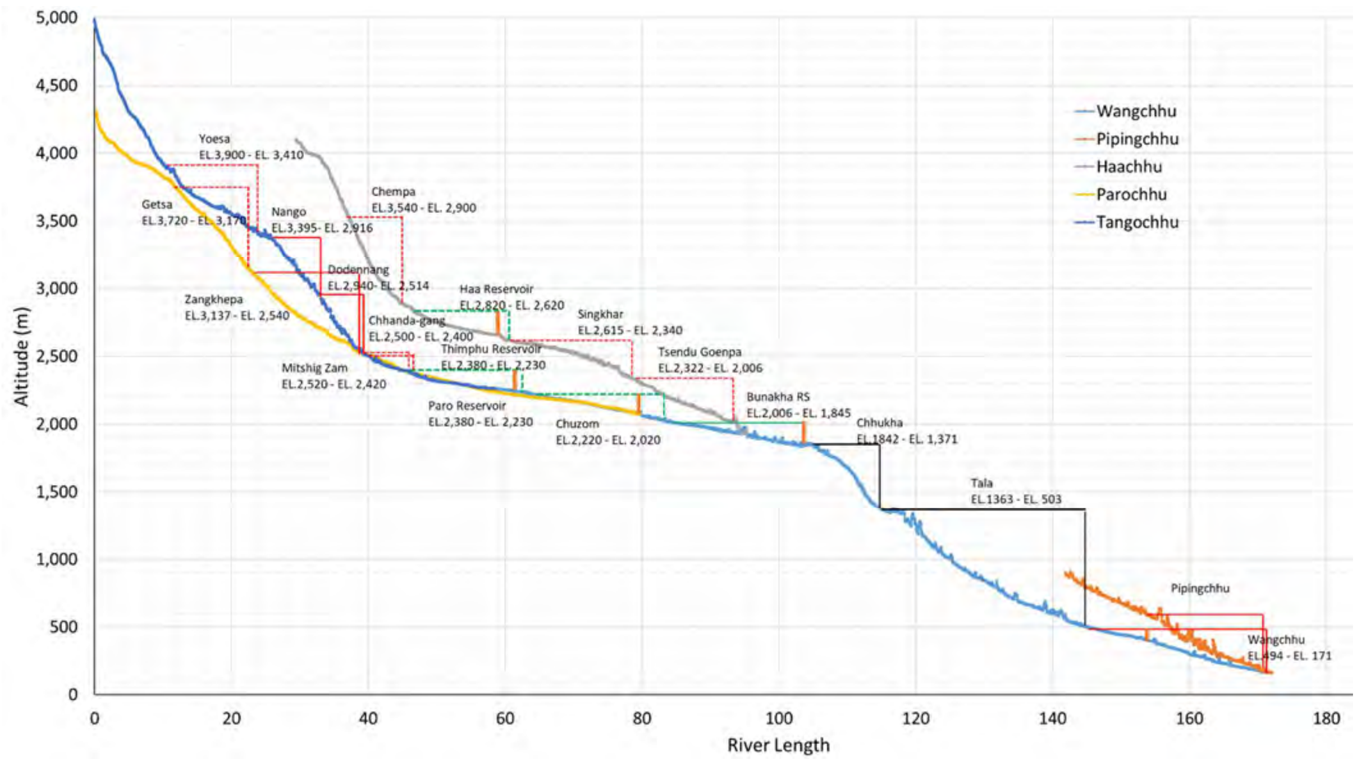
(Source: JICA Survey Team)

Figure 6-8 Elevations of Potential Sites on River Longitudinal Profile (Amochhu Basin)

Table 6-2 Primary Features of Potential Sites (Amochhu Basin)

Project code	Tributary	Status	Name of Project/Tributary	Project Type	Features										
					Catchment Area (km2)	Max. Discharge (50% Plant Factor)	RBL at Dam Site	Dam Height from RBL (m)	FRL or IWL	TWL	Gross Head (m)	Effective Head (m)	IC (MW)	Mean Annual/ Design Energy	PLF
Amochu Basin															
A-1	Tr-Amochu-2	<25MW	Lharig	ROR	62	4.2	3,120	15	3,130	2,690	440	409.2	15	65	50%
A-2	Amochu	Protected area	Amochhu-2	ROR+Pond	1,790	120.2	2,630	35	2,660	2,190	470	437.1	453	1,985	50%
A-3	Tr-Amochu-1	Protected area	Timalumchhu	ROR	132	8.8	2,700	15	2,710	2,180	530	492.9	38	165	50%
A-4	Amochu		Kunzangling	ROR+Pond	2,100	141.1	2,060	45	2,100	1,340	760	737.2	897	3,928	50%
A-5	Amochu		Tingma	ROR+Pond	2,252	151.3	1,280	65	1,340	892	448	434.6	567	2,483	50%
A-6	Cherchu	<25MW	Tsanglingna	ROR	80	5.4	1,240	25	1,260	930	330	306.9	14	62	50%
A-7	Chechu	<25MW	Shepji	ROR	65	4.4	1,540	25	1,560	920	640	595.2	22	98	50%
A-8	Amochu		Dorokha	ROR+Pond	2,602	174.8	840	57	892	500	392	364.6	550	2,407	50%
A-9	Samchu		Ngatse	ROR	237	15.9	800	5	800	500	300	279.1	38	193	50%
A-10	Amochu		Sanglum	Pondage	3,112	226.3	400	95	490	406	94	91.2	178	779	50%
A-11	Pachhu		Dojengkha	ROR	95	6.4	1,310	5	1,310	840	480	446.4	25	108	50%
A-12	Pachhu		Dolepchen	ROR	235	15.8	790	5	790	470	320	297.6	41	177	50%
A-13	Amochu	GOI	Amochhu Reservoir	Reservoir	3,744	272.3	235	176	406	212	194		540	1,835	39%
Total Amochhu Basin :			13	13									3,377	14,285	

(Source: JICA Survey Team)



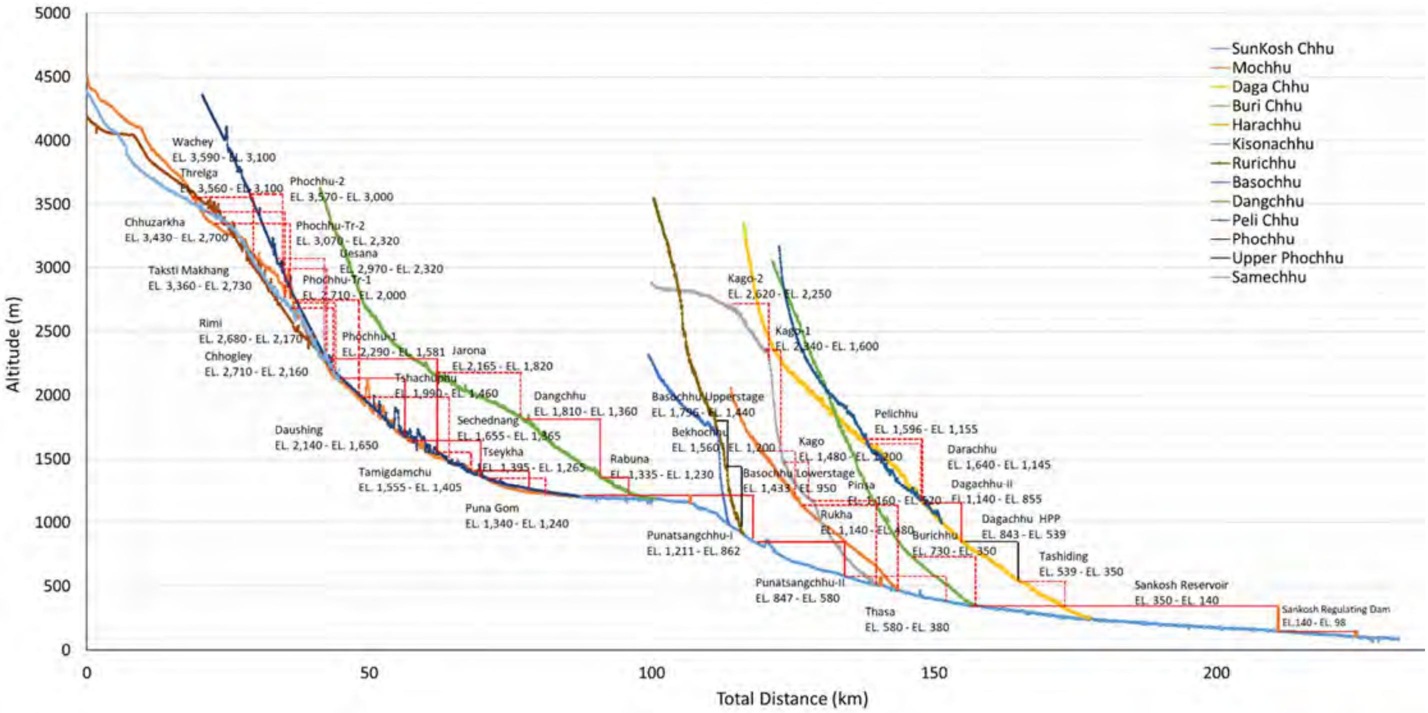
(Source: JICA Survey Team)

Figure 6-9 Elevations of Potential Sites on River Longitudinal Profile (Wangchhu Basin)

Table 6-3 Primary Features of Potential Sites (Wangchhu Basin)

Project code	Tributary	Status	Name of Project/Tributary	Project Type	Features										
					Catchment Area (km2)	Max. Discharge (50% Plant Factor)	RBL at Dam Site	Dam Height from RBL (m)	FRL or IWL	TWL	Gross Head (m)	Effective Head (m)	IC (MW)	Mean Annual/ Design Energy	PLF
Wangchhu Basin															
W-1	Tangochhu	<25MW	Yoesa	ROR	96	4.4	3,873	32	3,900	3,410	490	455.7	17	76	50%
W-2	Tangochhu	Protected area	Nango	ROR	212	9.7	3,376	24	3,395	2,916	479	445.5	37	164	50%
W-3	Tangochhu Cherichhu		Dodennang	ROR	410	18.8	2,907	38	2,940	2,514	426	396.2	64	269	48%
W-4	Tangochhu	<25MW	Chhanda-gang	ROR	490	22.5	2,473	32	2,500	2,400	100	93.0	18	79	50%
W-5	Wangchhu	Many relocation	Thimphu Reservoir	Reservoir	922	42.4	2,219	166	2,380	2,230	135	125.6	46	201	50%
W-6	Wangchhu		Chuzom	Reservoir	2,483	94.5	2,059	166	2,220	2,020	200	186.0	152	664	50%
W-7	Parochhu		Getsa	ROR	175	8.1	3,720	5	3,720	3,170	550	511.5	36	156	50%
W-8	Parochhu		Zangkhepa	ROR	325	14.9	3,137	5	3,137	2,540	597	555.2	71	313	50%
W-9	Parochhu	<25MW	Mitshig Zam	ROR	577	26.5	2,501	24	2,520	2,420	100	93.0	21	93	50%
W-10	Parochhu	Many relocation	Paro Reservoir	Reservoir	1,086	49.9	2,223	162	2,380	2,230	135	125.6	54	237	50%
W-11	Haachhu	<25MW	Chempa	ROR	43	2.0	3,488	57	3,540	2,900	640	595.2	10	45	50%
W-12	Haachhu	<25MW	Haa Reservoir	ROR	331	15.2	2,661	164	2,820	2,620	185	172.1	23	99	50%
W-13	Haachhu		Singkhar	ROR	380	17.4	2,581	39	2,615	2,340	275	255.8	38	169	50%
W-14	Haachhu		Tsendu Goenpa	ROR	646	29.7	2,312	15	2,322	2,006	316	293.9	75	329	50%
W-15	Wangchhu	GOI	Bunakha RS	Pondage	3,540		1,843	168	2,006	1,845	155		180	719	45%
W-16	Wangchhu	Existing	Chhukha HPP	ROR+Pond	3,746		1,813	34	1,842	1,371	468		336	1,840	63%
W-17	Wangchhu	Existing	Tala HPP	ROR+Pond	4,028		1,291	77	1,363	503	860		1,020	4,865	54%
W-18	Wangchhu	GOI	Wangchhu	Pondage	4,147		403	96	494		323		570	2,280	46%
W-19	Pipingchhu		Pipingchhu	ROR	217	29.9	585	15	595	180	415	386.0	100	436	50%
Total Wangchhu Basin :			19	19									2,869	13,031	

(Source: JICA Survey Team)



(Source: JICA Survey Team)

Figure 6-10 Elevations of Potential Sites on River Longitudinal Profile (Punatsangchhu Basin)

Table 6-4 Primary Features of Potential Sites (Punatsangchhu Basin-1)

Project code	Tributary	Status	Name of Project/Tributary	Project Type	Features										
					Catchment Area (km2)	Max. Discharge (50% Plant Factor)	RBL at Dam Site	Dam Height from RBL (m)	FRL or IWL	TWL	Gross Head (m)	Effective Head (m)	IC (MW)	Mean Annual/ Design Energy	PLF
Punatsangchhu Basin															
P-1	Mochhu	Protected area	Taksti Makhang	ROR	474	35.0	3,350	15	3,360	2,730	630	585.9	177	775	50%
P-2	Mochhu	Protected area	Chhogley	ROR	789	58.2	2,700	15	2,710	2,160	550	511.5	257	1,125	50%
P-3	Samechhu	Protected area	Chhuzarkha	ROR	381	28.1	3,420	15	3,430	2,700	730	678.9	165	721	50%
P-4	Samechhu	Protected area	Rimi	ROR	628	46.3	2,670	15	2,680	2,170	510	474.3	189	830	50%
P-5	Mochhu	Protected area	Daushing	ROR	1,706	125.9	2,125	20	2,140	1,650	490	455.7	495	2,167	50%
P-6	Mochhu	Protected area	Sechednang	ROR	1,922	141.9	1,640	20	1,655	1,365	290	269.7	330	1,445	50%
P-7	Mochhu		Puna Gom	ROR	2,145	158.3	1,310	35	1,340	1,240	100	93.0	127	556	50%
P-8	Phochhu	Protected area	Phochhu-2	ROR	176	13.0	3,560	15	3,570	3,000	570	530.1	59	260	50%
P-9	Phochhu	Protected area	Uesana	ROR	252	18.6	2,950	25	2,970	2,320	650	604.5	97	425	50%
P-10	Tr-Phochhu-3	Protected area	Wachey	ROR	279	20.6	3,580	15	3,590	3,100	490	455.7	81	354	50%
P-11	Tr-Phochhu-3	Protected area	Threlga	ROR	455	33.6	3,550	15	3,560	3,100	460	427.8	124	543	50%
P-12	Tr-Phochhu-3	Protected area	Phochhu-Tr-2	ROR	970	71.6	3,050	25	3,070	2,320	750	697.5	431	1,886	50%
P-13	Phochhu	Protected area	Phochhu-1	ROR	1,423	105.0	2,280	15	2,290	1,581	709	659.4	597	2,615	50%
P-14	Tr-Phochhu-2	Protected area	Phochhu-Tr-1	ROR	147	10.9	2,700	15	2,710	2,000	710	660.3	62	271	50%
P-15	Phochhu		Tamigdamchu	ROR	2,120	156.5	1,540	20	1,555	1,405	150	139.5	188	824	50%
P-16	Tr-Phochhu-1	Protected area	Tshachuphu	ROR	186	13.7	1,980	15	1,990	1,460	530	492.9	58	255	50%
P-17	Phochhu		Tseykha	ROR	2,205	162.8	1,380	20	1,395	1,265	130	120.9	170	743	50%
P-18	Dangchhu		Jarona	ROR	219	15.2	2,165	5	2,165	1,820	345	320.9	42	184	50%
P-19	Dangchhu		Dangchhu	ROR	404	28.1	1,800	15	1,810	1,360	450	418.5	101	444	50%
P-20	Dangchhu		Rabuna	ROR	561	39.0	1,325	15	1,335	1,230	105	97.7	33	144	50%

(Source: JICA Survey Team)

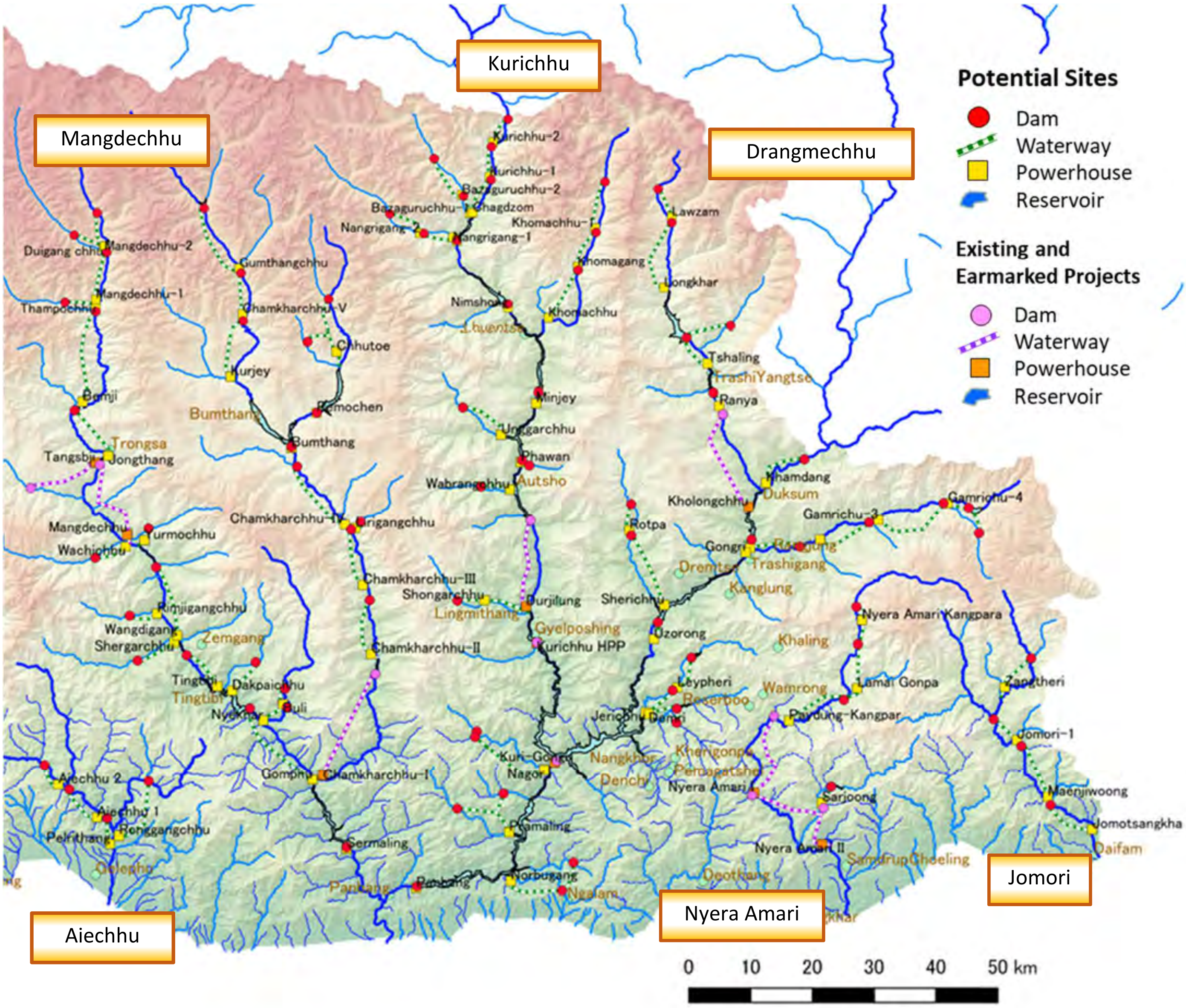
Table 6-5 Primary Features of Potential Sites (Punatsangchhu Basin-2)

Project code	Tributary	Status	Name of Project/Tributary	Project Type	Features										
					Catchment Area (km2)	Max. Discharge (50% Plant Factor)	RBL at Dam Site	Dam Height from RBL (m)	FRL or IWL	TWL	Gross Head (m)	Effective Head (m)	IC (MW)	Mean Annual/ Design Energy	PLF
P-21	Sankoshchhu	GOI	Punatsangchhu-I	ROR+Pond	5,839	405.8	1,145	71	1,211	862	349		1,200	5,585	54%
P-22	Basochhu	Existing	Basochhu Upperstage	ROR+Pond	162	8.0	1,796	5	1,796	1,440	356		24	110	52%
P-23	Basochhu/ Rurichhu	Existing	Basochhu Lowerstage	ROR+Pond	226	10.0	1,433	5	1,433	950	483		40	190	54%
P-24	Sankoshchhu	GOI	Punatshangchhu-II	ROR+Pond	6,102	424.1	784	68	847	580	267		1,020	4,667	53%
P-25	Kamichhu	<25MW	Kamichhu	ROR	57	3.9	1,070	25	1,090	620	470	437.1	15	65	50%
P-26	Sankoshchhu		Thasa	Pondage	6,892	479.0	505	80	580	380	200	186.0	768	3,365	50%
P-27	Kisonachhu	Protected area	Kago-2	ROR	197	13.7	2,600	15	2,610	2,250	360	334.8	40	174	50%
P-28	Kisonachhu		Kago-1	ROR	250	17.2	2,340	5	2,340	1,600	740	688.2	102	448	50%
P-29	Kisonachhu		Kago	ROR	377	26.0	1,470	15	1,480	1,200	280	260.4	58	256	50%
P-30	Kisonachhu		Pinsa	ROR	427	29.4	1,140	25	1,160	520	640	595.2	151	662	50%
P-31	Harachhu	<25MW	Bekhochhu	ROR	121	8.4	1,550	15	1,560	1,200	360	334.8	24	106	50%
P-32	Harachhu	Protected area	Rukha	ROR	221	15.4	1,120	25	1,140	480	660	613.8	81	356	50%
P-33	Burichhu		Burichhu	ROR+Pond	190	13.1	695	40	730	350	380	353.4	40	175	50%
P-34	Dagachhu		Darachhu	ROR	220	15.3	1,640	5	1,640	1,145	495	460.4	61	266	50%
P-35	Dagachhu		Dagachhu-II	ROR	593	41.2	1,130	15	1,140	855	285	265.1	94	413	50%
P-36	Dagachhu		Pelichhu	ROR	211	14.7	1,598	5	1,598	1,155	443	412.0	52	228	50%
P-37	Dagachhu	Existing	Dagachhu HPP	ROR+Pond	647	45.0	822	26	843	539	304		126	552	47%
P-38	Dagachhu		Tashiding	ROR+Pond	778	53.6	500	44	539	350	189	175.8	81	356	50%
P-39	Sankoshchhu	GOI	Sankosh Reservoir	Reservoir	9,606	662.1	135	220	350	140	210		2,500	5,848	27%
		GOI	Sankosh Regulating Dam	ROR	9,778	673.9	101	44	140	98	42		85	367	70%
Total Punatsangchhu Basin:			39	39									10,346	40,756	

(Source: JICA Survey Team)

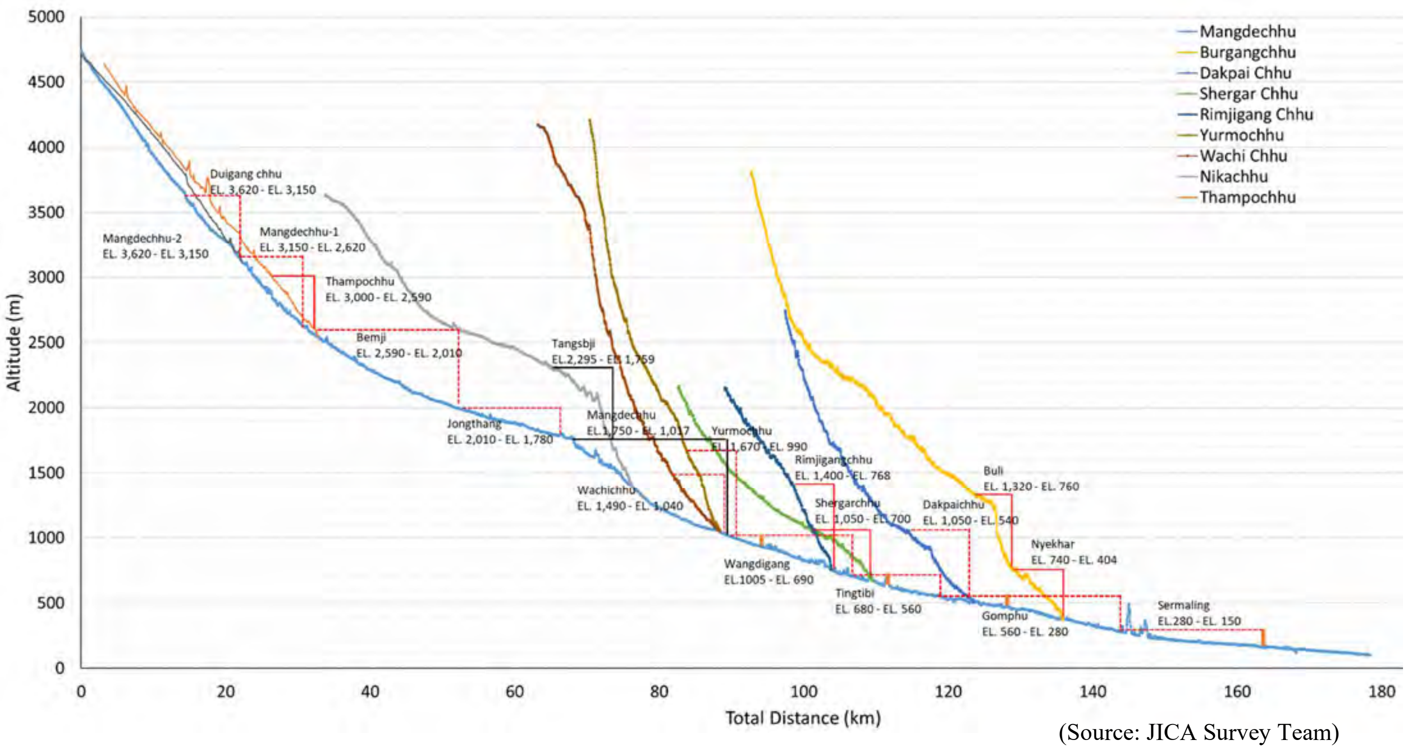
6.2.2 Potential Sites Identified in Eastern Region

Potential hydropower sites were identified in the Mangdechhu, Chamkharchhu, Kurichhu, and Drangmechhu basins, which are located in the Eastern Area, and in the Maochhu, Jomori, Nyera Amari basins, which are located in the South Area. The location of every potential site is shown in Figure 6-11, the elevations of potential sites on the river longitudinal profile by basin are shown in Figure 6-12 to Figure 6-16, and the list of potential sites by basin is shown in Table 6-6 to Table 6-10.



(Source: JICA Survey Team)

Figure 6-11 Location Map of Potential Hydropower Sites Identified (Eastern Region)



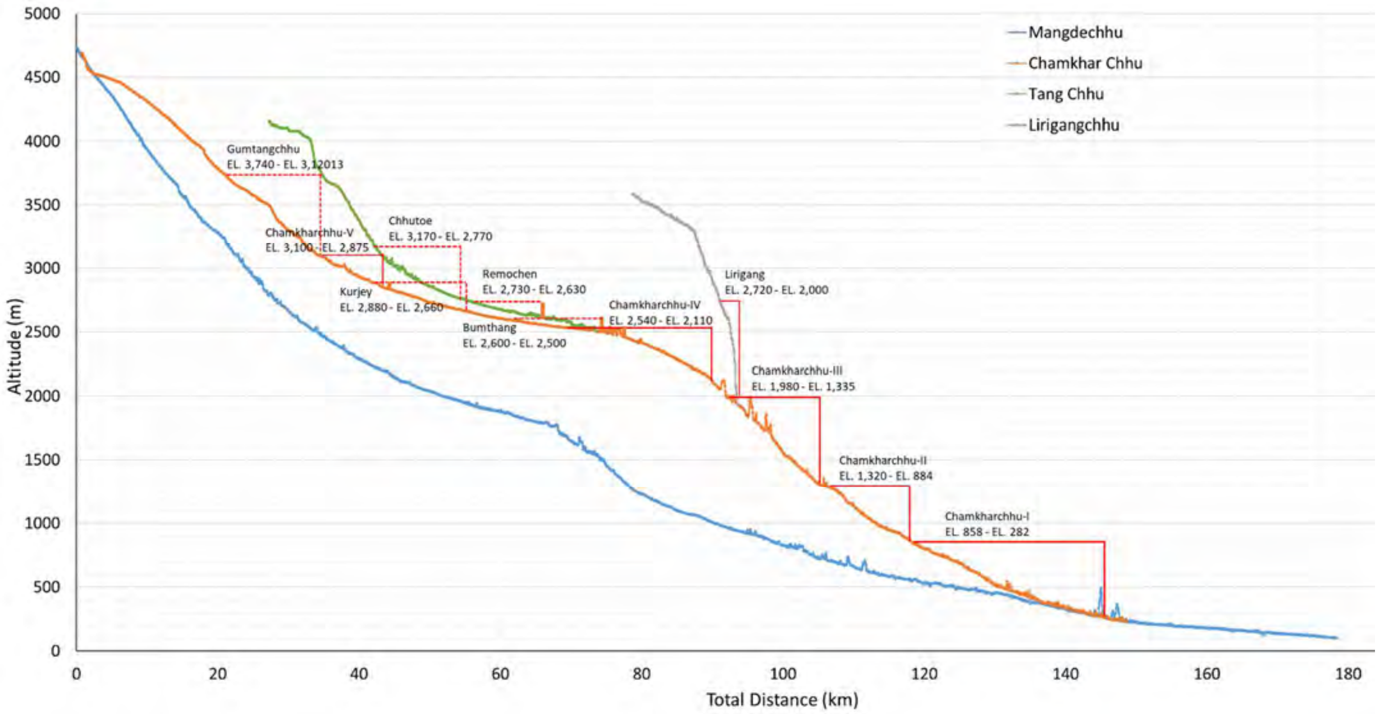
(Source: JICA Survey Team)

Figure 6-12 Elevations of Potential Sites on River Longitudinal Profile (Mangdechhu Basin)

Table 6-6 Primary Features of Potential Sites (Mangdechhu Basin)

Project code	Tributary	Status	Name of Project/Tributary	Project Type	Features										
					Catchment Area (km2)	Max. Discharge (50% Plant Factor)	RBL at Dam Site	Dam Height from RBL (m)	FRL or IWL	TWL	Gross Head (m)	Effective Head (m)	IC (MW)	Mean Annual/ Design Energy	PLF
Mangdechhu Basin															
M-1	Mangdechhu	Protected area	Mangdechhu-2	ROR	257	18.2	3,620	5	3,620	3,150	470	437.1	69	301	50%
M-2	Tr-Mangdechhu	Protected area	Duigang chhu	ROR	233	16.5	3,620	5	3,620	3,150	470	437.1	62	273	50%
M-3	Mangdechhu	Protected area	Mangdechhu-1	ROR	617	43.7	3,100	55	3,150	2,620	530	492.9	186	813	50%
M-4	Thampochhu	Protected area	Thampochhu	ROR	254	18.0	3,000	5	3,000	2,590	410	381.3	59	259	50%
M-5	Mangdechhu		Bemji	ROR+Pond	1,010	71.6	2,530	65	2,590	2,010	580	539.4	333	1,458	50%
M-6	Mangdechhu		Jongthang	ROR+Pond	1,298	92.0	1,935	80	2,010	1,780	230	213.9	170	743	50%
M-7	Mangdechhu	GOI	Mangdechhu	ROR+Pond	1,823	129.2	1,694	61	1,750	1,017	733		720	2,924	46%
M-8	Nikachhu	ADB	Tangsbji	ROR+Pond	353	25.0	2,262	38	2,295	1,759	536		118	492	48%
M-9	Wachichhu	Protected area	Wachichhu	ROR	113	8.0	1,490	5	1,490	1,040	450	418.5	29	127	50%
M-10	Yurmochhu	<25MW	Yurmochhu	ROR	61	4.3	1,670	5	1,670	990	680	632.4	24	103	50%
M-11	Mangdechhu		Wangdigang	ROR+Pond	2,490	176.4	910	100	1,005	690	315	293.0	446	1,952	50%
M-12	Rimjigangchhu	Protected area	Rimjigangchhu	ROR	87	5.7	1,400	5	1,400	768	632	587.8	29	126	50%
M-13	Shergarchhu	Protected area	Shergarchhu	ROR	151	9.9	1,050	5	1,050	700	350	325.5	28	121	50%
M-14	Mangdechhu		Tingtibi	ROR+Pond	2,878	187.9	610	75	680	560	120	111.6	181	792	50%
M-15	Mangdechhu		Gomphu	Pondage	3,328	217.3	432	133	560	280	280	260.4	488	2,138	50%
M-16	Dakpaichhu	<25MW	Dakpaichhu	ROR	80	5.2	1,050	5	1,050	510	540	502.2	23	99	50%
M-17	Burgangchu		Buli	ROR	216	14.1	1,305	5	1,305	760	545	506.9	62	270	50%
M-18	Burgangchu		Nyekhar	ROR	244	15.9	740	5	740	404	336	312.5	43	188	50%
M-19	Mangdechhu		Sermaling	Pondage	7,281	475.4	150	135	280	150	130	120.9	496	2,171	50%
Total Mangdechhu Basin:			19	19									3,563	15,351	

(Source: JICA Survey Team)



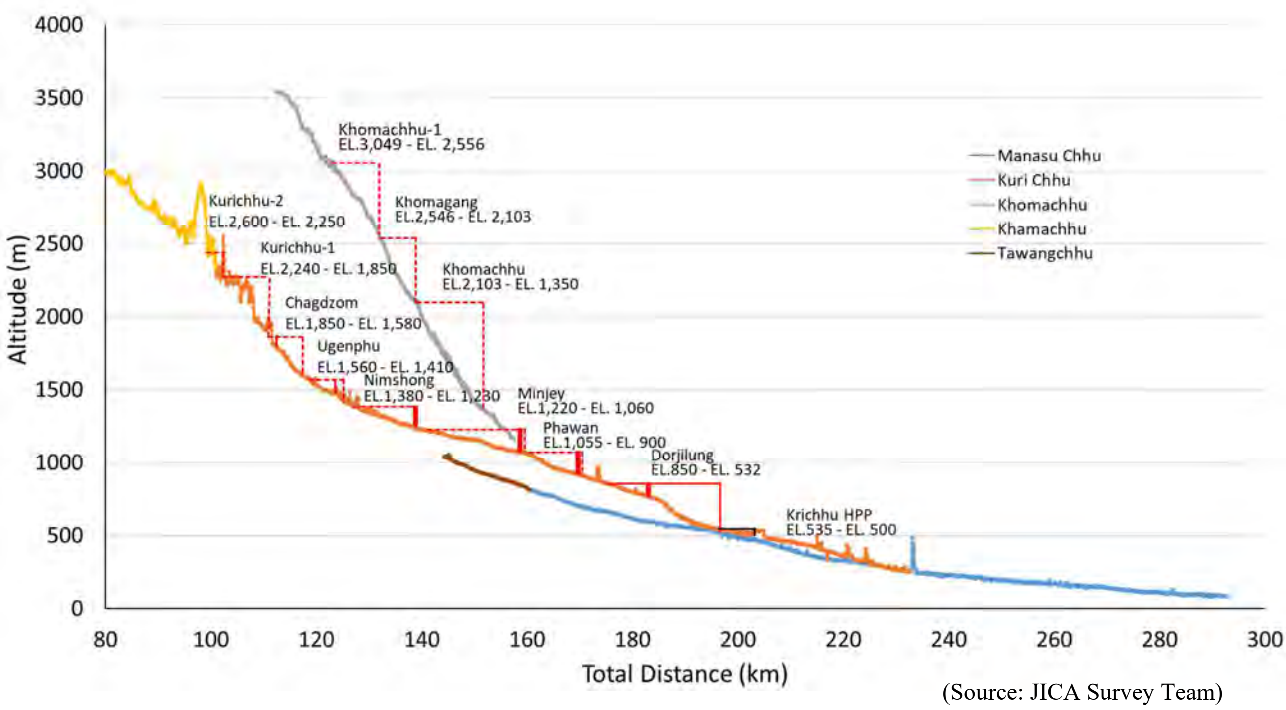
(Source: JICA Survey Team)

Figure 6-13 Elevations of Potential Sites on River Longitudinal Profile (Chamkharchhu Basin)

Table 6-7 Primary Features of Potential Sites (Chamkharchhu Basin)

Project code	Tributary	Status	Name of Project/Tributary	Project Type	Features										
					Catchment Area (km2)	Max. Discharge (50% Plant Factor)	RBL at Dam Site	Dam Height from RBL (m)	FRL or IWL	TWL	Gross Head (m)	Effective Head (m)	IC (MW)	Mean Annual/ Design Energy	PLF
Chamkharchhu Basin															
C-1	Chamkharchhu	Protected area	Gumthangchhu	ROR	400	25.1	3,660	85	3,740	3,120	620	576.6	125	548	50%
C-2	Chamkharchhu	Protected area	Chamkharchhu-V	ROR+Pond	639	40.2	3,080	25	3,100	2,875	225	209.3	72	317	50%
C-3	Chamkharchhu		Kurjey	ROR+Pond	804	50.5	2,830	55	2,880	2,660	220	204.6	89	390	50%
C-4	Tangchhu		Chhutoe	ROR	146	9.2	3,170	5	3,170	2,770	400	372.0	29	129	50%
C-5	Tangchhu	<25MW	Remochen	ROR	457	28.7	2,630	105	2,730	2,630	100	93.0	23	101	50%
C-6	Chamkharchhu	Many relocation	Bumthang	Pondage	2,023	127.1	2,500	105	2,600	2,500	100	93.0	102	447	50%
C-7	Chamkharchhu		Chamkharchhu-IV	Pondage	2,080	130.7	2,467	78	2,540	2,110	430	399.9	451	1,974	50%
C-8	Lirigangchhu	<25MW	Lirigangchhu	ROR	44	2.7	2,720	5	2,720	2,000	720	669.6	16	70	50%
C-9	Chamkharchhu	Protected area	Chamkharchhu-III	Pondage	2,323	145.9	1,920	65	1,980	1,335	645	599.9	755	3,307	50%
C-10	Chamkharchhu		Chamkharchhu-II	ROR+Pond	2,525	130.4	1,270	55	1,320	884	436	405.5	456	1,997	50%
C-11	Chamkharchhu	GOI	Chamkharchhu-I	Pondage	2,731	141.0	777	86	858	282	576		770	3,373	50%
Total Chamkharchhu Basin:			11	11									2,888	12,652	

(Source: JICA Survey Team)



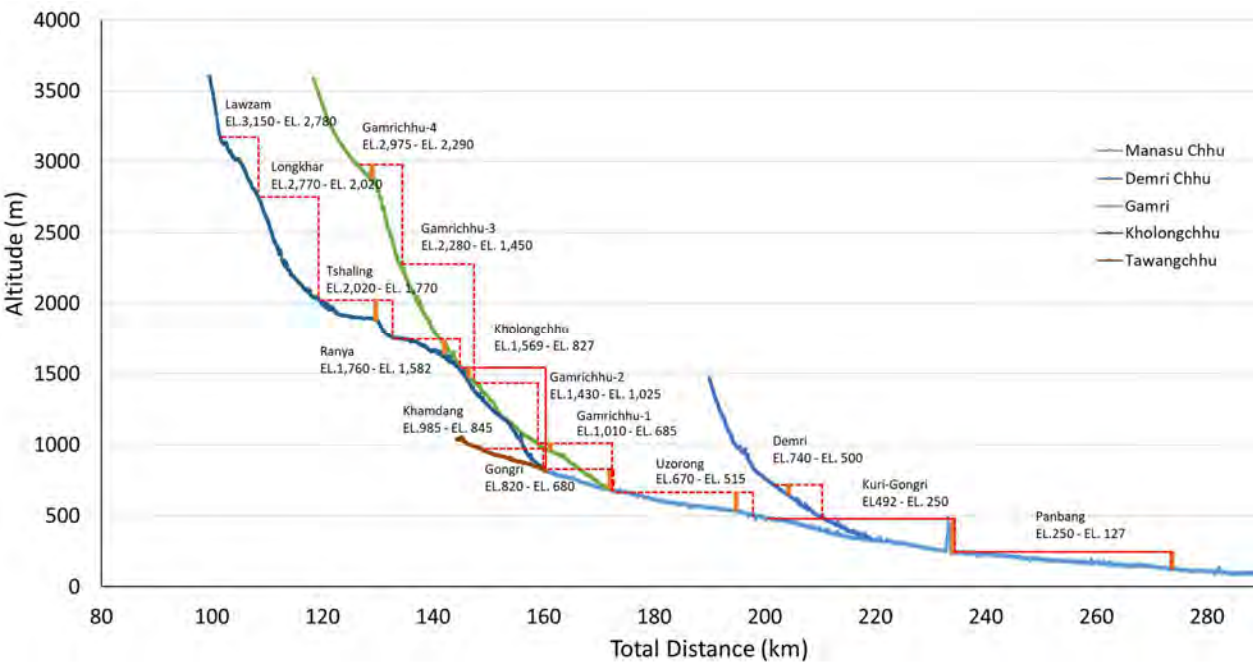
(Source: JICA Survey Team)

Figure 6-14 Elevations of Potential Sites on River Longitudinal Profile (Kurichhu Basin)

Table 6-8 Primary Features of Potential Sites (Kurichhu Basin)

Project code	Tributary	Status	Name of Project/Tributary	Project Type	Features										
					Catchment Area (km2)	Max. Discharge (50% Plant Factor)	RBL at Dam Site	Dam Height from RBL (m)	FRL or IWL	TWL	Gross Head (m)	Effective Head (m)	IC (MW)	Mean Annual/ Design Energy	PLF
Kurichhu Basin															
K-1	Kurichhu	Protected area	Kurichhu-2	ROR+Pond	6,200	237.1	2,550	55	2,600	2,250	350	325.5	666	2,915	50%
K-2	Kurichhu	Protected area	Kurichhu-1	ROR+Pond	6,500	248.6	2,190	55	2,240	1,850	390	362.7	777	3,405	50%
K-3	Kurichhu	Protected area	Chagdzom	ROR+Pond	6,800	260.0	1,800	55	1,850	1,580	270	251.1	563	2,466	50%
K-4	Bazaguruchhu	Protected area	Bazaguruchhu-2	ROR	250	9.6	2,872	13	2,880	2,230	650	604.5	50	218	50%
K-5	Bazaguruchhu	Protected area	Bazaguruchhu-1	ROR	310	11.9	2,210	15	2,220	1,620	600	558.0	57	250	50%
K-6	Nangrigang	Protected area	Nangrigang-2	ROR	203	7.8	2,830	15	2,840	2,180	660	613.8	41	180	50%
K-7	Nangrigang	Protected area	Nangrigang-1	ROR	308	11.8	2,160	15	2,170	1,570	600	558.0	57	248	50%
K-8	Kurichhu	Protected area	Ugenphu	Pondage	7,699	294.4	1,435	130	1,560	1,410	150	139.5	354	1,551	50%
K-9	Kurichhu	Protected area	Nimshong	Pondage	7,974	304.9	1,231	154	1,380	1,230	150	139.5	367	1,607	50%
K-10	Khomachhu	Protected area	Khomachhu-1	ROR	282	10.8	3,039	15	3,049	2,556	493	458.5	43	187	50%
K-11	Khomachhu	Protected area	Khomagang	ROR	370	14.1	2,546	5	2,546	2,103	443	412.0	50	220	50%
K-12	Khomachhu	Protected area	Khomachhu	ROR	450	17.2	2,093	15	2,103	1,350	753	700.3	104	455	50%
K-13	Kurichhu		Minjey	Pondage	8,926	381.5	1,075	150	1,220	1,060	160	148.8	490	2,144	50%
K-14	Khomachhu		Unggarchhu	ROR	132	5.0	1,600	5	1,600	950	650	604.5	26	115	50%
K-15	Kurichhu		Phawan	Pondage	9,388	401.2	905	155	1,055	900	155	144.2	499	2,185	50%
K-16	Khomachhu	<25MW	Wabrangchhu	ROR	124	5.3	1,218	15	1,228	892	336	312.5	14	63	50%
K-17	Kurichhu	In Progress	Dorjilung	Pondage	8,782	451.2	768	87	850	542	308		1,125	4,558	46%
K-19	Shongarchhu		Shongarchhu	ROR	124	5.3	1,300	5	1,300	540	760	706.8	32	141	50%
K-20	Kurichhu	Existing	Kurichhu HPP	ROR+Pond		194.4					35		60	400	76%
Total Kurichhu Basin:			19	19									5,375	23,310	

(Source: JICA Survey Team)



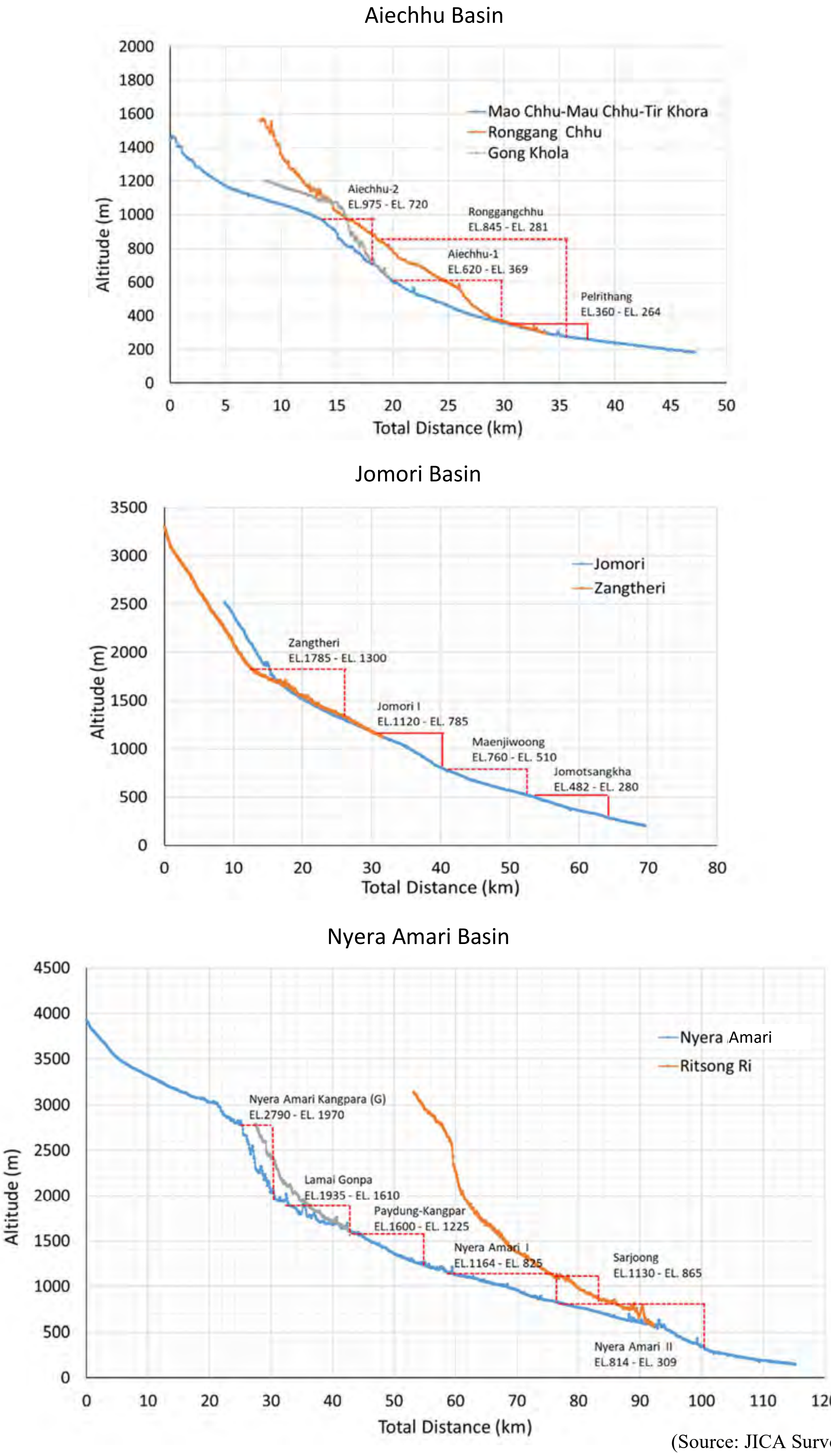
(Source: JICA Survey Team)

Figure 6-15 Elevations of Potential Sites on River Longitudinal Profile (Drangmechhu Basin)

Table 6-9 Primary Features of Potential Sites (Drangmechhu Basin)

Project code	Tributary	Status	Name of Project/Tributary	Project Type	Features										
					Catchment Area (km2)	Max. Discharge (50% Plant Factor)	RBL at Dam Site	Dam Height from RBL (m)	FRL or IWL	TWL	Gross Head (m)	Effective Head (m)	IC (MW)	Mean Annual/ Design Energy	PLF
Drangmechhu Basin															
G-1	Kholongchhu	<25MW	Lawzam	ROR	60	8.0	3,140	15	3,150	2,780	370	344.1	24	104	50%
G-2	Kholongchhu	Protected area	Longkhar	ROR	185	24.8	2,760	15	2,770	2,020	750	697.5	149	653	50%
G-3	Kholongchhu		Tshaling	Pondage	760	101.8	1,893	132	2,020	1,770	250	232.5	204	894	50%
G-4	Kholongchhu		Ranya	Pondage	848	113.5	1,645	120	1,760	1,582	178	165.5	162	710	50%
G-5	Kholongchhu	GOI	Kholongchhu	Pondage	1,044	88.6	1,512	62	1,569	827	742		600	2,209	42%
G-6	Tawangchhu		Khamdang	ROR+Pond	7,286	440.1	957	33	985	845	140	130.2	494	2,165	50%
G-7	Gongri		Gongri	Pondage	8,691	525.0	697	128	820	680	140	130.2	590	2,582	50%
G-8	Gamri	Protected area	Gamrichhu-4	Pondage	115	9.7	2,880	100	2,975	2,290	685	637.1	53	234	50%
G-9	Gamri		Gamrichhu-3	ROR	214	18.4	2,280	5	2,280	1,450	830	771.9	123	538	50%
G-10	Gamri		Gamrichhu-2	ROR	416	32.2	1,410	25	1,430	1,025	405	376.7	104	458	50%
G-11	Gamri		Gamrichhu-1	Pondage	573	41.5	940	75	1,010	685	325	302.3	108	474	50%
G-12	Scherichhu		Rotpa	ROR	208	12.6	1,500	5	1,500	1,100	400	372.0	40	177	50%
G-13	Scherichhu		Sherichhu	ROR	278	16.8	1,060	5	1,060	670	390	362.7	53	230	50%
G-14	Gongri		Uzorong	Pondage	10,164	614.0	540	135	670	515	155	144.2	763	3,343	50%
G-15	Jeri ri	<25MW	Leypheri	ROR	126	7.6	1,285	80	1,360	1,050	310	288.3	19	83	50%
G-16	Jeri ri		Jerichhu	ROR	153	9.2	1,020	5	1,020	500	520	483.6	39	169	50%
G-17	Demri	<25MW	Demri	ROR	178	10.8	660	85	740	500	240	223.2	21	91	50%
G-18	Drangmechhu	GOI	Kuri-Gongri	Reservoir		1,300.0	248	249	492	250	242		2,640	10,056	43%
G-19	Gangchatpu		Nagor	ROR	146	10.9	875	55	925	250	675	627.8	59	258	50%
G-20	Dingrungchhu		Pramaling	ROR	120	12.8	530	5	530	250	280	260.4	29	126	50%
G-21	Kurung-Kirung	<25MW	Norbugang	ROR	74	9.4	490	15	500	250	250	232.5	19	83	50%
G-22	Manas		Panbang	Pondage	20,944	1,006.4	121	134	250	127	122	119.3	1,100	4,640	47%
Total Drangmechhu Basin:			22	22									7,392	30,274	

(Source: JICA Survey Team)



(Source: JICA Survey Team)

Figure 6-16 Elevations of Potential Sites on River Longitudinal Profile (Other Basins)

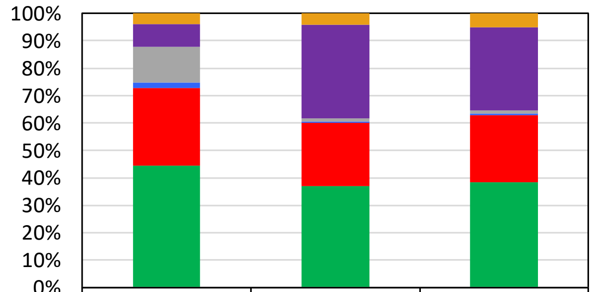
Table 6-10 Primary Features of Potential Sites (Other Basins)

Project Code	Tributary	Status	Name of Project/Tributary	Project Type	Features										
					Catchment Area (km2)	Max. Discharge (50% Plant Factor)	RBL at Dam Site	Dam Height from RBL (m)	FRL or IWL	TWL	Gross Head (m)	Effective Head (m)	IC (MW)	Mean Annual/ Design Energy	PLF
Aiechhu															
Ai-1	Mauchhu		Aiechhu 2	ROR	223	16.7	975	5	975	720	255	237.2	34	150	50%
Ai-2	Aiechhu	Protected area	Aiechhu 1	ROR+Pond	398	29.8	597	28	620	369	251	233.4	60	263	50%
Ai-3	Aiechhu		Pelrithang	ROR+Pond	512	38.3	337	28	360	264	96	89.3	30	129	50%
Ai-4	Ronggang		Ronggangchhu	ROR	149	11.2	845	5	845	281	564	524.5	51	221	50%
Total Maochhu:			4	4									174	763	
Jomori															
J-1	Zangtheri		Zangtheri	ROR	119	7.3	1,785	5	1,785	1,300	485	451.1	29	125	50%
J-2	Jomori		Jomori-I	ROR+Pond	495	30.6	1,100	25	1,120	785	335	311.6	82	360	50%
J-3	Jomori		Maenjiwoong	ROR+Pond	564	34.8	740	25	760	510	250	232.5	70	306	50%
J-4	Jomori		Jomotsangkha	ROR+Pond	685	42.3	462	25	482	280	202	187.9	68	300	50%
Total Jomori:			4	4									249	1,090	
Nyera Amari															
N-1	Nyera Amari		Nyera Amari Kangpara (G)	ROR	145	10.8	2,790	5	2,790	1,970	820	762.6	71	312	50%
N-2	Nyera Amari		Lamai Gonpa	ROR	188	14.1	1,935	5	1,935	1,610	325	302.3	37	161	50%
N-3	Nyera Amari		Paydung-Kangpar	ROR+Pond	379	28.4	1,575	30	1,600	1,225	375	348.8	85	374	50%
N-4	Nyera Amari	ADB	Nyera Amari I&II	Pondage							346	321.3	442	1,700	44%
N-5	Ritsong Ri	<25MW	Sarjoong	ROR	125	9.4	1,119	16	1,130	865	265	246.5	20	87	50%
Total Nyera Amari:			5	5									655	2,633	

(Source: JICA Survey Team)

6.2.3 Initial Screening

The total number of potential sites is 155, installed capacity is 36.9GW, and design energy is 154.1TWh.
Excluding the 6 existing power plants, 13 earmarked projects and 20 sites with an installed capacity of less than 25MW, the remaining potential totals to 116 sites with an installed capacity of 22.4GW.
.
Furthermore, there are 3 project sites (0.2GW) in which many resettlements are required and 44 project sites (8.6GW) in which all the project's components (dam, reservoir, waterway, powerhouse) are located within protected areas. These projects are deemed very difficult to develop. Excluding these sites, there remain 69 potential sites, totaling 13.6GW, 59.5TWh.



	Site NO.	Installed Capacity (MW)	Design Energy (GWh)
Existing	6	1,606	7,957
Earmarked	13	12,510	46,612
<25MW	20	381	1,671
Many relocations	3	202	884
Protected area	44	8,575	37,560
Longlist Sites	69	13,614	59,461
Total	155	36,888	154,145

(Source: JICA Survey Team)

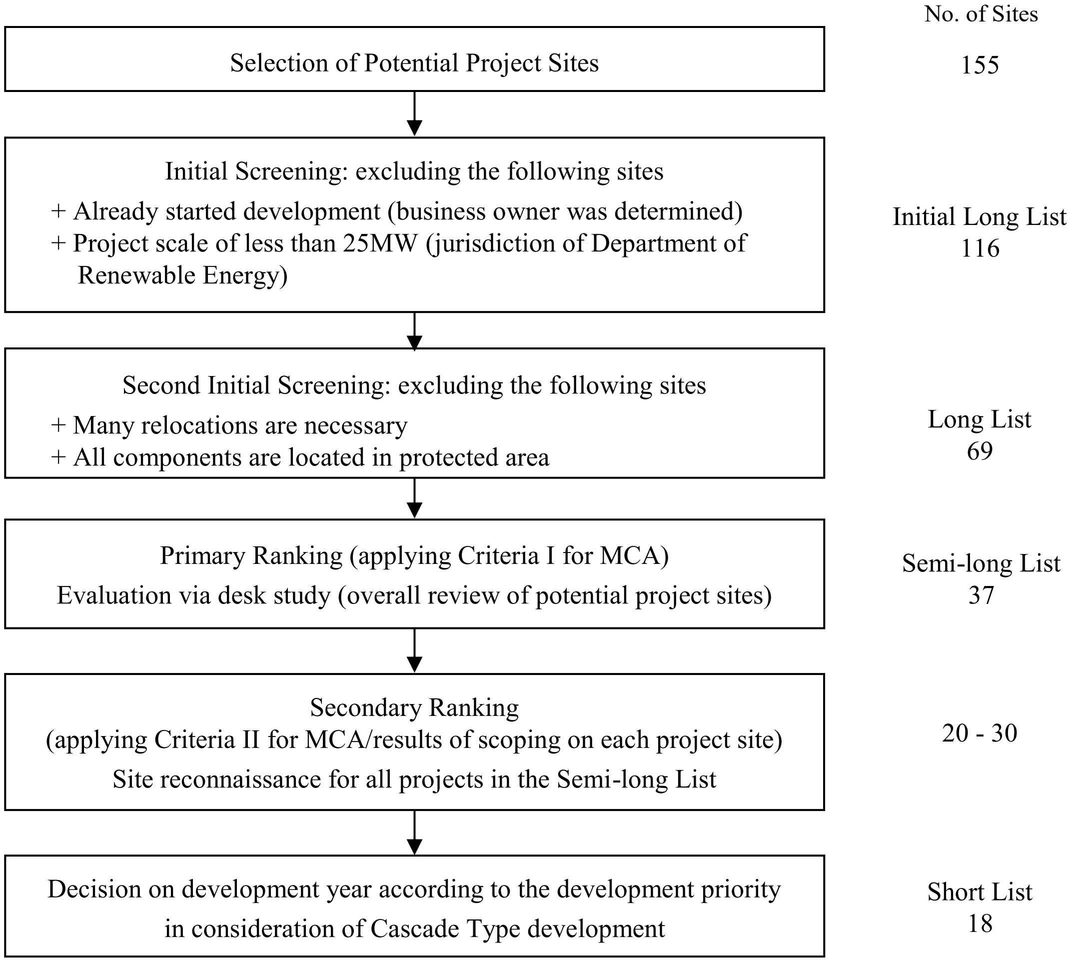
Figure 6-17 Breakdown of Potential Sites

Chapter 7. Evaluation of the Potential Project Sites

7.1 Evaluation Method for the Potential Project Sites

7.1.1 Screening Method

Screening was carried out for the potential project sites in line with the following work flow.



(Source: JICA Survey Team)

Figure 7-1 Screening Method

The primary ranking is carried out to screen out the sites with lower development priority. Since the primary ranking is evaluated via desk study, it is impossible to accurately reflect the site conditions. Accordingly, criteria I for MCA are basically those that can be judged on the desk and the evaluation is put on hold for items for which the presence or absence of a problem cannot be confirmed. However, since the secondary ranking is evaluated after checking the site conditions for every project via site reconnaissance, criteria II for MCA are to be those that can take into account the detailed conditions of the site. In addition, detailed confirmation was carried out on the items that are put on hold in the evaluation of the primary ranking.

7.1.2 Evaluation Criteria for MCA

(1) Criteria for MCA Applied by DHPS

The evaluation criteria and weights for MCA applied by the DHPS are shown in the following table.

Table 7-1 Criteria and Weights for MCA Applied by DHPS (Summary)

No.	Criteria	Sub-criteria	Weights			
1.1	Technical	Hydrological quality	22%	40%	55%	4.8%
1.2		Geological risk	25%			5.5%
1.3		Dam cost risk	15%			3.3%
1.4		GLOF risk	6%			1.3%
1.5		Site accessibility	14%			3.1%
1.6		Transmission line risk	14%			3.1%
1.7		Reservoir sedimentation	4%			0.9%
--		Sub-total	100%			22.0%
2.1	Economic	Economic merit	65%	60%		21.5%
2.2		Transmission line cost	20%			6.6%
2.3		Finance ability	15%			5.0%
--		Sub-total	100%			33.0%
3.1	Social	Improved access	35%	50%	30%	5.3%
3.2		Access to reliable power supply	10%			1.5%
3.3		Employment benefits	25%			3.8%
3.4		Rehabilitation and Resettlement	20%			3.0%
3.5		Tourism	10%			1.5%
--		Sub-total	100%			15.0%
4.1	Environmental	Intrusion into protected areas	40%	50%		6.0%
4.2		Loss of primary forest	35%			5.3%
4.3		Dewatering impacts	10%			1.5%
4.4		Access road erosion	10%			1.5%
4.5		Fish migration	5%			0.8%
--		Sub-total	100%			15.0%
5.1	Development	Balanced regional development	100%	100%	15%	15.0%
		Overall				100.0%

(Source: DHPS)

(2) Issues regarding Scoping Items Applied by DHPS

Technical	There are no large problems, but evaluation result of geological risk is low.
Economic	There is no generation cost evaluation for seasonal variation and each generation time.
Environment in General	According to international practices, an examination in order to avoid or minimize adverse impacts on the environment must be considered prior to the examination of alternatives and mitigation measures. However, the sub-criteria adopted in earlier MCA do not reflect such international practices. Adverse impacts on the environment caused by projects are not well recognized or evaluated.
Natural Environment	Scoping items that evaluate ecologically important areas are missing.
Social Environment	Adverse impacts regarding social issues caused by projects are not well considered, whereas positive impacts are highly emphasized.

(3) Original Draft Agreed between the JICA Survey Team and DHPS

A counterproposal was submitted to make improvements regarding the above issues and had a discussion with DHPS. The following criteria and weights was basically agreed between the JICA Survey Team and DHPS.

Table 7-2 Original Draft Agreed between the JICA Survey Team and DHPS (Summary)

No.	Criteria	Sub-criteria		Weights	
1.1	Technical	Hydrological quality	30%	50%	40%
1.2		Geological risk	50%		
1.3		GLOF risk	5%		
1.4		Sedimentation risk	5%		
1.5		Site accessibility	5%		
1.6		Transmission line risk	5%		
2.1	Economic	Economic efficiency		50%	
3.1	Impact on Social environment	Land Acquisition	25%	50%	40%
3.2		Resettlement and Asset Loss	25%		
3.3		Living and Livelihood	20%		
3.4		Cultural Heritage	30%		
4.1	Impact on Natural Environment	Protected areas	40%	50%	
4.2		Loss of primary forest	35%		
4.3		Loss of wetland	10%		
4.4		Aquatic creatures (including Fish migration)	5%		
4.5		Access road/dam site erosion	5%		
4.6		Impact on Landscape	5%		
5.1	Social Development	Improved access to socioeconomic benefits	50%	100%	20%
5.2		Employment and potential for income opportunities	50%		

(Source: JICA Survey Team)

Evaluation items are divided into three areas.

(a) Technical & Economic

Technical (Technical & Economic) criteria show the economic efficiency of the project as a whole. The "Economic" aspect is evaluated based on total project construction costs (including power transmission facilities), operation and maintenance (O&M) expenses, and electric energy expected to be generated. However, the numerical values, such as construction costs, O&M expenses, and generated electric energy, contain many uncertainties, and the variation risk is evaluated via "Technical" items based on the probability of variation and the impact when variation occurs.

(b) Impact on environment

When promoting large projects, adverse impacts caused by the development must be minimized as much as possible. If the adverse impacts are large, there is a possibility that the development will have to be abandoned. For this reason, with regard to environmental items, impediment factors in promoting hydropower development were evaluated from the viewpoint of the natural and social environment, and projects with fewer impediments were preferentially selected.

(c) Social Development

In Bhutan, which is in the process of development, the effect of promoting social development along with hydropower development can be expected. Such an effect can be thought of as an indirect benefit for the country. In selecting the priority projects, evaluating such effects is also an important factor, and this is evaluated as an additional benefit along with hydropower development.

For a base case, the weights of "Technical & Economic" and "Impact on Environment" are evaluated equally, and the weights of the above three items are 40% for "Technical & Economic", 40% for "Impact on Environment", and 20% for "Social Development". Projects to be evaluated include not only hydropower plants but also access roads and related power transmission facilities to be constructed in connection with the construction of power plants.

(4) Evaluation method (Scoring)

Scoring for each item is evaluated with 5 grades, from 1 to 5, as shown below. In order to avoid differences in evaluations by different evaluators, evaluation scores are prepared based on numericalized data as much as possible. For items that are difficult to numericalize, standards for each score are expressed in concrete and detailed words.

For items with an adverse impact, the evaluation score is set to 0 points which leads to abandonment of the site. In such situations, the plan is re-evaluated in an attempt to avoid all 0 point items.

Table 7-3 Evaluation Method (Scoring)

Score	Items with an advantageous impact	General items	Items with an adverse impact
5	Very big impact	Very good	No impact
4	Big impact	Good	Slight impact
3	Some impact	Average	A little impact
2	Slight impact	Bad	Some impact
1	No impact	Very bad	Irreversible impact
0	--	--	Abandon development

(Source: JICA Survey Team)

(5) Scenario Analysis for Alternative Plans

In prioritizing the potential sites, as a base case, "Technical & Economic" and "Impact on environment" are evaluated equally. Whether to emphasize "Technical & Economic" or "Impact on environment" in developing future potential sites depends largely on the intentions of decision makers. The following three scenarios, with different weights, are studied for the purpose of providing decision makers with reference materials.

Table 7-4 Scenario Analysis for Alternative Plans

Evaluation item	Scenario		
	Base	Emphasizing Environment	Emphasizing Economy
Technical & Economic	40%	20%	60%
Impact on Environment	40%	60%	20%
Social Development	20%	20%	20%
Total	100%	100%	100%

(Source: JICA Survey Team)

7.2 MCA for Primary Ranking

Since the primary ranking is evaluated via desk study, the items that can be judged at a desk are identified and weighed.

7.2.1 Technical Items

In the Technical items, uncertainties included in numerical values such as construction costs, generated electric energy, O&M expenses, etc. are taken as a variation risk and these risks are evaluated based on the variable probability and the impact when variation occurs. The evaluation results for each item, based on the variable probability and the impact when variation occurs, are shown below.

Table 7-5 Risk Evaluation for Technical Items

No.	Sub-criteria	Risk	Probability	Impact	Weight
1.1	Hydrological risk	Decrease in generated energy	High	Big	30%
1.2	Geological risk	Increase in construction cost	High	Very big	50%
1.3	Glacial lake outburst flood (GLOF) risk	Decrease in generated energy Increase in O&M expenses	Very low	Very big	5%
1.4	Sedimentation risk	Increase in O&M expenses	Middle	Small	5%
1.5	Site accessibility	Increase in construction cost	Middle	Small	5%
1.6	Transmission line risk	Increase in T/L construction cost	Middle	Small	5%
--					100%

(Source: JICA Survey Team)

Since geological risk has a high variable probability and creates a very big impact when variation occurs, the weight is set to 50%. The uncertainty risk for hydrological data has a high variable probability and creates a big impact when variation occurs, so its weight is set to 30%. For the other risks, weights are set at 5%, because either the variable probability or the impact when the variation occurs is small and the expectation of the risk is small.

Table 7-6 Evaluation Items for Technical Risks

Sub-criteria	Weight	Assessment of Sub-criteria
Hydrological risk	30%	Ratio catchment area (at gauging station and dam site) Recorded period (year) Density of primary gauging stations in river system basin Density of secondary gauging stations in river system basin
Geological risk	50%	Earthquake Intensity Slope stability (landslide risk) Weak zones (faults, weathering, and alteration) Permeable and anisotropic rocks Construction material risk
GLOF risk	5%	Distance from the nearest Glacial Lake
Sedimentation risk	5%	Annual sedimentation volume
Site accessibility	5%	Distance from existing roadway Distance from nearest railway station
Transmission line risk	5%	Distance to nearest pooling station
Sub-total	100%	

(Source: JICA Survey Team)

(1) Hydrological risk (Weight: 30%)

The annual generated energy in each project is estimated from the catchment area ratio at the water intake point vs. that at the gauging station using the river flow data measured at the nearest gauging station. Annual generated energy is an important factor, which is directly linked to economic efficiency.

If the distance to the gauging station being referenced is not close or the measurement accuracy of the river flow data itself is low, there is a risk that the actual annual generated energy will be estimated at lower than the actual value.
Evaluation weights are 30% on the catchment area ratio at gauging station vs. dam site, 30% on the recorded year at gauging station, and 40% on the density of gauging stations in a river system basin (Primary: 30%, Secondary: 10%).

(a) Catchment area ratio at gauging station vs. dam site (Weight: 30%)
Evaluation scores for catchment area ratio at gauging station vs. dam site are shown below. The measurements data from the nearest gauging station to the intake point of each project are used and the river flow at the water intake point is estimated by the catchment area ratio of the intake point vs. the gauging station. However, if the distance between the gauging station being referenced and the intake point is far, the estimation error risk becomes large. If the catchment area ratio of the intake point vs. the gauging station is 0.5 to 2.0 the score is 5 points, and if it is over 5.0 or less than 0.2 the score is 1 point. This presupposes that the quality of the data for the gauging station being referenced in this evaluation is to be verified beforehand.

Table 7-7 Evaluation Scores for Ratio Catchment Area at Gauging Station and Dam Site

Ratio (Dam Site/Gauging St.)	Score
Over 5.0 / below 0.2	1
From 4.0 to 5.0 / From 0.2 to 0.25	2
From 3.0 to 4.0 / From 0.25 to 0.33	3
From 2.0 to 3.0 / From 0.33 to 0.5	4
From 1.0 to 2.0 / From 0.5 to 1.0	5

(Source: JICA Survey Team)

When using the data from the gauging station located in the same place as the intake point, the above ratio is 1.0. When using the data from a gauging station located in the upstream from the intake point, it becomes more than 1.0. When using the data from a gauging station located in the downstream from the intake point, it becomes less than 1.0.

(b) Recorded year (Weight: 30%)
Evaluation scores for recorded year are shown below. River flow varies greatly according to the season, and it also varies depending on climatic conditions of that year. Therefore, it is possible to estimate the annual generated energy with high accuracy and low risk by using measurement data over a longer period. Considering this point, if the recorded period of the reference gauging station is 20 years or more the score is 5 points, and if it is less than 5 years the score is 1 point.

Table 7-8 Evaluation Scores for Recorded Year

Recorded Period	Score
Less than 5 years	1
Less than 10 years	2
More than 10 years	3
More than 15 years	4
More than 20 years	5

(Source: JICA Survey Team)

(c) Density of gauging stations in a river system basin (Primary: 30%, Secondary: 10%)
Evaluation scores for density of gauging stations in a river system basin are shown below. If there are many gauging stations in the same river basin, the accuracy of estimation for precipitation in the basin

improves, and by investigating the correlation among the gauging stations it is possible to ascertain the measurement accuracy of every gauging station.

Table 7-9 Evaluation Scores for Density of Gauging Stations in a River System Basin

Density of Gauging Stations	Score
Less than 1/4,000 km^2	1
From 1/4,000 km^2 to 1/3,000 km^2	2
From 1/3,000 km^2 to 1/2,000 km^2	3
From 1/2,000 km^2 to 1/1,000 km^2	4
More than 1/1,000 km^2	5

(Source: JICA Survey Team)

(2) Geological risks (Weight: 50%)

Construction of a hydropower plant at a place with geological problems leads to an increase in construction costs and a large opportunity loss due to delays in the construction work, which is a very large risk.

(a) Earthquake Intensity (Weight: 15%)

Evaluation scores for earthquake intensity are shown below. This item is evaluated based on the zoning of the four risk levels described in the hazard map.

Table 7-10 Evaluation Score for Earthquake Intensity

Zone	Score
Very high hazard	1
High hazard	2
Moderate hazard	3
Low hazard	5

(Source: JICA Survey Team)

(b) Construction material risk (Weight: 10%)

Evaluation score for construction material risk is shown below. Especially for construction materials such as concrete aggregate, the possibility of procurement at site is evaluated.

Table 7-11 Evaluation Score for Construction Material Risk

Grade	Score
High	1
Moderate	3
Low	5

(Source: JICA Survey Team)

(c) Geological risk (Weight: 75%)

Evaluation score for geological risk is shown below. The evaluation at the primary ranking stage is based on literature-based desk study. Therefore, the existing literature such as Long et al., 2010, etc., is used and geological risk is estimated by three items of slope stability risk, weak zone, permeability and anisotropic rock based on the geological classification and the location relationship with the MCT (Main Central Trust) which is the essential part of the geological structure in this country.

Table 7-12 Evaluation Score for Geological Risk

Geological Condition	Weight	Negative Impacts on the Project		
		Large	Medium	Small
Slope Stability Risk	25%	1	3	5
Weak Zone	25%	1	3	5
Permeability and Anisotropic Rock	25%	1	3	5

(Source: JICA Survey Team)

(3) GLOF risk (Weight: 5%)

Evaluation scores for GLOF risk are shown below. Due to the occurrence of GLOF, a large amount of debris flows into the downstream. When this debris flows into the dam reservoir/pond of the hydropower plant, due to mass sediment accumulation in the dam reservoir/pond power generation must be stopped temporarily in order to avoid damage to the turbines, creating the a risk of a decrease in generated energy. Moreover, since a large amount of debris flows and accumulates in a short period and the water storage capacity of the dam reservoir/pond decreases, it is necessary to remove the sediment that has accumulated by dredging, creating the risk of an increase in O&M expenses.

The impact due to the occurrence of GLOF depends on the distance from the glacial lake. According to the report on the GLOF that occurred in 1994, the GLOF affected up to 200 km downstream. Based on this fact, if the distance from the glacial lake is 200 km or more the score is 5 points, and if it is less than 50 km the score is 1 point.

Table 7-13 Evaluation Scores for GLOF risk

Elongation from Nearest Glacial Lake	Score
Less than 50km	1
From 50km to 100km	2
From 100km to 150km	3
From 150km to 200km	4
More than 200km	5

(Source: JICA Survey Team)

(4) Sedimentation risk (Weight: 5%)

Evaluation scores for sedimentation risk are shown below. The sedimentation risk is influenced by topography, such as slope gradient, in addition to the vegetation and geology in the upper stream of river. The concentration of suspended solids has been measured for each river. The amount of sediment is to be estimated from this, and the annual sedimentation volume at each project site will be estimated.

Table 7-14 Evaluation Scores for Sedimentation Risk

Annual sedimentation volume	Score
More than 2,000ton/km^2	1
From 1,500ton/km^2 to 2,000ton/km^2	2
From 1,000ton/km^2 to 1,500ton/km^2	3
From 500ton/km^2 to 1,000ton/km^2	4
Less than 500ton/km^2	5

(Source: JICA Survey Team)

(5) Site accessibility (Weight: 5%)

Site accessibility is evaluated via the distance from the existing road to the intake dam site and the distance from the railway station to the power plant. When constructing the water intake dam, the access road is constructed from the existing road at first. There is a possibility that the newly constructed access road may have to be changed to a detour route due to geological risks etc., with the construction costs for the access road then increasing.
Major facilities and construction materials for power plants are imported from India. Upon arrival they are transported by vehicle from the nearest railway station. If the distance between these points is long, there is a risk of cost increase for the transportation of facilities and materials.

Considering the possibility and magnitude of the increase in construction costs, the evaluation weight for the distance to the access road is 80%, and that for the distance to the railway station is 20%.

(a) Distance from existing roadway (Weight: 80%)

Evaluation scores for distance from existing roadway are shown below. The score is 5 points when the distance from the existing roadway is less than 5km, and 1 point when the distance is more than 20km.

Table 7-15 Evaluation Scores for Distance from Existing Roadway

Distance from Existing Road	Score
More than 20km	1
From 15km to 20km	2
From 10km to 15km	3
From 5km to 10km	4
Less than 5km	5

(Source: JICA Survey Team)

(b) Distance from nearest railway station (Weight: 20%)

Evaluation scores for distance from nearest railway station are shown below. The score is 5 points when the distance from the nearest railway station is less than 100km, and 1 point when the distance is more than 250km.

Table 7-16 Evaluation Scores for Distance from Nearest Railway Station

Distance from Railway Station	Score
More than 250 km	1
From 200 km to 250 km	2
From 150 km to 200 km	3
From 100 km to 150 km	4
Less than 100 km	5

(Source: JICA Survey Team)

(6) Transmission line risk (Weight: 5%)

Evaluation scores for transmission line risk are shown below. Transmission line construction is carried out by BPC, but the funds are provided by the project. The new transmission lines may be changed with a route detour due to difficulties in site negotiations or geological risks on the line's route, and there is a risk that the construction costs for the transmission line will increase. Since this becomes a large risk when the transmission line distance is long, the score is 5 points when the transmission line distance is less than 10km, and 1 point when the distance is more than 100km.

Table 7-17 Evaluation Scores for Transmission Line Risk

Distance from Nearest Pooling station/Substation	Score
More than 100km	1
From 50km to 100km	2
From 20km to 50km	3
From 10km to 20km	4
Less than 10km	5

(Source: JICA Survey Team)

7.2.2 Economic Items

Economic items are evaluated based on economic efficiency. It is conceivable that financing ability will become an issue during development of the project. It is not necessary to evaluate financing ability for each project, but the debt situation in Bhutan (Debt servicing capacity) is to be considered when creating the overall power development plan.

(1) Evaluation score for Economic efficiency

Economic efficiency is evaluated via B/C (Benefit/Cost). The score for economic efficiency shall be 1 point if B/C is 1.0 or less and 5 points if B/C is 1.8 or more. In other words, the following calculation formula is used, rounding to the first decimal place.

Formula of Score = (B/C – 0.8) x 5

(2) Conditions for Benefit calculation

Benefits generated by hydropower development are produced by converting river flow into electricity and selling the electric power.

(a) Calculation of generated electric energy (see 4.3.1)

The amount of generated electric energy at each site is estimated based on the river flow measurement data from the neighboring gauging station. 10% of the river flow during the drought period is discharged downstream at all times as E-flow.

(b) Sales of generated electric energy (see 4.3.3)

Regardless of season or time zone, the value of electricity sales is Nu. 4.2/kWh. The amount of electricity to be sold is the value obtained by subtracting the electricity consumption amount in the powerhouse and the power transmission losses.

(c) Value of Firm capacity (see 4.4)

The value of Firm capacity lies in the fact that it can enable postponement of thermal power plant developments in India. It is evaluated as Nu. 9,775/kW annually.

(d) Value of provision of ancillary services (see 4.5)

As shown in 4.5.1, hydropower plants with adjustment ponds seem to have some value in providing ancillary services. However, considering that the amount that can be offered is not that much, that the market is incomplete in the Indian system, that certain value cannot be anticipated and that the specific unit price is difficult to estimate, the value of providing ancillary services is not considered in primary screening.

In the secondary screening, in order to properly evaluate the value of hydropower with a regulating pond, the benefits of ancillary service provision are evaluated at Nu. 3.3/kWh.

(3) Conditions for Cost calculation

(a) Expenses related to the construction of hydropower stations (including transmission and transformation facilities)

This is calculated according to the following conditions.

- Construction costs for power generation facilities: Calculated via construction cost estimation kit (see 5.4)
- Construction costs for transmission and transformation facilities: Calculated based on unit construction costs for each voltage level (see 5.5)
- Life: 30 years
- Discount rate: 10% (Equivalent to borrowing rate from India)

When calculated under the above conditions, the annual capital cost is 10.6% of the construction cost.

(b) Operation and Maintenance (O&M) expenses

O&M expenses for power generation facilities are calculated based on actual data from existing hydropower plants. The O&M expenses data for hydropower stations in DGPC, which is operating and maintaining existing hydropower stations, are shown below.

Table 7-18 O&M Expenses of Existing Hydropower Stations

(Unit: million Nu.)

	2011	2012	2013	2014	2015	Average
Insurance	128.3	126.3	118.7	113.8	114.5	120.3
Running & maintenance	241.2	201.6	390.4	339.4	335.1	301.5
Employee remuneration	608.1	677.4	690.2	649.2	802.9	685.6
Other expenses	331.1	196.0	337.1	153.2	245.4	252.6
Total	1,308.7	1,201.3	1,536.4	1,255.6	1,497.9	1,360.0

(Source: DGPC annual report)

The total amount for power generation facilities that were operated and maintained during 2011-2015 was 1,480MW, and the O&M cost per kW was Nu. 919/kW on average for 5 years. Calculating the unit construction cost of a hydropower plant as Nu. 90,000/kW, the O&M cost is equivalent to 1.0%[9] of the construction cost.

Regarding O&M expenses for the transmission and transformation facilities, in the "Bhutan Power Corporation 2016 - 2019 Tariff Review Report" published by BEA in January 2017, 1% of the current replacement cost is set to Benchmark. Considering this point, O&M expenses for transmission and transformation facilities are to be set as 1.0% of the construction cost.

[9] According to the "Druk Green Power Corporation 2016 - 2019 Tariff Review Report" published by BEA in January 2017, O&M expenses proposed by DGPC are 1.02% of the current replacement cost.

7.2.3 Items for Impact on Social Environment

In the items for impact on social environment, the factors that impede the development of hydropower were evaluated from the viewpoint of the social environment. There are four evaluation items: land acquisition, resettlement & asset loss, living and livelihood means, and cultural heritage. The weight of each item is considered to be about the same degree. However, considering Bhutan's situation, the weight of the impact on cultural heritage is slightly increased, and that of the impact on living and livelihood means is slightly decreased. In Bhutan, many cultural heritage sites are related to Buddhist facilities, closely linked to people's lives and thoughts, and with "Gross National Happiness" (GNH), a unique national development concept in Bhutan. In addition, the Department of Culture (DOC) insisted that this weight should be placed higher, and this was determined via an agreement at a meeting by SEA Task Force members of other relevant government agencies including GNH Commission in charge of assuring and improving livelihood of the nation.

It should be noted that there are many items regarding the social environment which cannot be evaluated precisely without the definitive information collected through site surveys. Thus, in the first MCA screening, impacts due to power station and reservoir sites are primarily evaluated judging from existing documents.

Table 7-19 Items for Impact on Social Environment

Sub-criteria	Weight	Assessment of sub-criteria
Land Acquisition	25%	Area of state land acquired (including forest land) Area of private land acquired
Resettlement & asset loss	25%	No. of affected houses
Living and livelihood means	20%	Negative impacts on non-agricultural livelihood activities (handicrafts, etc.) Damage to crops (paddy, vegetables, wheat, cash crops, etc.) Negative impacts on forest products (NTFPs) Negative impacts on timber products Negative impacts on livestock Negative impacts on fishing activities Negative impacts on water supply Negative impacts on irrigation
Cultural Heritage	30%	Negative impacts on nationally important cultural heritage sites
Total	100%	

(Source: JICA Survey Team)

(1) Land acquisition (Weight: 25%)

Evaluation scores for land acquisition are shown below. No problems arise if the acquisition is state-owned land, but when acquiring privately-owned land, even if providing substitute land this directly affects landowners. For this reason, if acquiring only state-owned land the score is 5 points, and in the case of acquiring more than 200 acres of privately-owned land the score is 1 point.

In the first MCA screening, however, since there are some power stations and surrounding sites where land size has not been identified although there is private land, such cases are tentatively evaluated to be 3 points.

Table 7-20 Evaluation Scores for Land Acquisition

Land size	State	Private
200 acres or more	5	1
25 acres - less than 200 acres		3
Under 25 acres		4
Nothing (0)		5

(Source: JICA Survey Team)

(2) Resettlement & asset loss (Weight: 25%)

Evaluation scores for resettlement & asset loss are shown below. Resettlement of residence has a very significant impact on residents. Therefore, if there is no resettlement of residence the score is 5 points; if there are more than 100 houses to be resettled the score is 1 point.

In the first MCA screening, there were some power station sites where the number of facilities and houses had not been identified although it seemed there would be some impact on them. The score for these sites is tentatively set at 3 points.

Table 7-21 Evaluation Scores for Resettlement & Asset Loss

No. of Houses	Score
100 or more	1
10 - less than 100	2
Less than 10	3
Nothing (0)	5

(Source: JICA Survey Team)

(3) Living and livelihood means (Weight: 20%)

Evaluation scores for living and livelihood means are shown below. The evaluation score is lowered if there is an adverse impact on non-agricultural livelihood activities, agricultural products, forest products, timber products, livestock, fishing activities, water supply or irrigation. Particular emphasis is placed on the impact on fishing activities, water supply and irrigation as these impact more directly on people's life, and if one item is applicable the score is 1 point.

In the first MCA screening, such items which can be confirmed from existing data and information are agricultural land, community forests, commercial timber production areas, traditional communities where fishing is officially permitted (Rocha - Wangdue Phodrang Dzongkhag, Throng - Zhemgang Dzongkhag, Ganzur- Lhuntse Dzongkhag) and existing irrigation systems. Thus, these items are evaluated.

Table 7-22 Evaluation Scores for Living and Livelihood Means

Affected activities	Score
- No.4 or No.5 - all items from No.1 to No.3	1
- 1 to 2 items from No.1 to No.3	3
None	5

List of sub criteria on activities related to living and livelihood means

1	Damages to crops (paddy, vegetables, wheat, cash crops, etc.)
2	Negative impacts on forest products (NTFPs)
3	Negative impacts on timber products
4	Negative impacts on fishing activities
5	Negative impacts on irrigation

(Source: JICA Survey Team)

(4) Cultural Heritage (Weight: 30%)

Evaluation scores for cultural heritage are shown below. Cultural heritage is very important in Bhutan. Therefore, if there is even one influential cultural heritage site representing significant cultural heritage value[10], the score is 1 point.

[10] According to the DOC, the Cultural Heritage Bill 2016 mandates registration and designation of cultural heritage sites based on their values: those sites built before 1960 represent "significant" cultural heritage values and those after 1960 represent "exceptional" values. Based on their values, they are designated as "important heritages sites" or "heritage sites of special importance."

In the first MCA screening, if there is more than one cultural heritage site, it is scored as 1 point for all sites.

Table 7-23 Evaluation Scores for Cultural Heritage

No. of Affected Heritage Sites	Score
1 or more	1
None	5

(Source: JICA Survey Team)

7.2.4 Items for Impact on Natural Environment

In the items for impact on natural environment, the factors that impede the development of hydropower from the viewpoint of the natural environment were evaluated. There are six evaluation items: located in protected areas, loss of forest, loss of wetland, aquatic creatures (including fish migration), erosion caused by access road/dam site, and impact on landscape. Regarding the water quality and waste, it was judged as “In this project, polluted water from construction work is discharged rather than a specific pollutant, so there is no difference in water quality between projects and in addition, the waste associated with the construction of dams, power plants, ground-waterways, etc. is large and there is no difference between projects.” at the SEA Task Force meeting. Based on this result, these two items were excluded from the evaluation items under the team member agreement. As for the item "Endangered species", considering that habitats of endangered species are designated as protected areas, and since they are evaluated in the same way as "Located in protected areas"[11], "Endangered species" was excluded and the evaluation weight of "Located in protected areas" was increased.
Furthermore, with regard to development in protected areas, it is assumed that all of the following five conditions will be fulfilled based on the "Frequently asked questions" (July 20, 2011, revised February 5, 2016, JICA Guideline) in the environmental and social considerations guidelines.

i) There are no viable alternatives that can be implemented within the region other than the areas that the government has specifically designated for protection of nature and cultural heritage via laws and regulations (hereinafter "the area").
ii) Development activities in such areas are to be legally permitted under the domestic law of the partner country.
iii) The executing agency etc. for the project shall comply with laws and ordinances concerning the area and management plan for protected areas, etc.
iv) The executing agency for the project has consulted with the management responsible for organization in the area, the local community in the vicinity and other appropriate stakeholders, and an agreement with them has been obtained regarding the project’s implementation.
v) In order for the area to be effectively managed according to the purpose of its conservation, the executing agency for the project, etc. will implement additional programs as necessary.

Considering the magnitude of the impact on the natural environment, the weights are 40% for located in protected areas, 35% for loss of forest, 10% for loss of wetland and 5% for all other items.

Table 7-24 Items for Impact on Natural Environment

Sub-criteria	Weight	Assessment of sub-criteria
Located in protected areas	40%	Affected area in core zone Affected area in buffer zone Affected area in multiple-use zone
Loss of forest	35%	Loss of forest area Degree of affected biodiversity
Loss of wetland	10%	Loss of wetland area, Degree of importance
Aquatic creatures (including Fish migration)	5%	Type of stream, Possibility of mitigation
Access road/dam site erosion	5%	Possibility of mitigation
Impact on landscape	5%	Length of transmission line
Total	100%	-

(Source: JICA Survey Team)

(1) Located in protected areas (Weight: 40%)

Evaluation scores for located in protected areas are shown below. Development in protected areas shall be avoided as far as possible in the planning process, but if this is inevitable, the score is 1 or 2 points according to the level of the protected area. The development of hydropower is abandoned if major

[11] Indicated by DoFPS at the second SEA Task force Meeting

facilities such as power stations and dams are located in the core zone of a protected area. Regarding the transmission line, there are no transmission lines cross over core zone of protected area and a detour route is sought so as not to pass through protected areas as much as possible, but if this cannot be avoided by any means the route employs the shortest distance.

Table 7-25 Evaluation Scores for Located in Protected Areas

Protected area		Main component	Sub component	Transmission line
Protected area	Core	0	0.1	1
	Buffer	1	1	2
	Multiple-use	2	2	3
Biological corridor		2	2	3
Not located in protected area		5	5	5

(Source: JICA Survey Team)

(2) Loss of forest (Weight: 35%)

Evaluation scores for loss of forest are shown below. Forest is more greatly affected as the loss area increases, and from the viewpoint of biodiversity, loss of forests in the lower altitude zone, which is considered to have plentiful species, is regarded as having a greater impact. Considering this, if the area of loss in subtropical broad-leaved areas with an altitude of less than 1,000m is large, the score is 1 point.

Table 7-26 Evaluation Scores for Loss of Forest

Forest type	Deforestation		
	Large	Medium	Small
Subtropical broad-leaved (to 1,000m)	1	2	3
Warm broad-leaved (1,000m - 2,000m)	1	2	3
Cool broad-leaved (2,000m - 2,900m)	2	3	4
Chir Pine (900 - 1,800m)	3	4	5
Blue Pine (2,100 - 3,000m)	3	4	5
Spruce (2,700 - 3,000m)	3	4	5

(Source: JICA Survey Team)

(3) Loss of wetland (Weight: 10%)

Evaluation scores for loss of wetland are shown below. For important wetland designated by the Ramsar Convention, even if the area of loss is small, development is abandoned. For other wetlands, development is abandoned if the loss area is 20% or more of the wetland, and the score is 4 points if the loss area is less than 5%.

Table 7-27 Evaluation Score for Loss of wetland

Affected area	Important wetland designated by Ramsar Convention	Other Wetland
Over 20% of wetland	0	0
15% - 20% of wetland		1
10% - 15% of wetland		2
5% - 10% of wetland		3
Under 5% of wetland		4
Nothing	5	5

(Source: JICA Survey Team)

(4) Aquatic creatures (including Fish migration) (Weight: 5%)

Evaluation scores for aquatic creatures (including fish migration) are shown below. The impact on fish migration etc. is evaluated by considering the size of the river blocked by the dam or weir. In each case, if mitigation measures such as the installation of fishways are possible, the evaluation score is raised by one point.

Table 7-28 Evaluation Scores for Aquatic Creatures (including Fish Migration)

Affected area	Located in the lower part of the stream	There is a dam/weir in the downstream
Main Stream	1	3
Tributary Stream	2	4

(Source: JICA Survey Team)

(5) Erosion caused by Access road/Dam site (Weight: 5%)

Evaluation scores for erosion caused by access road/dam site are shown below. Land erosion is inevitable due to the construction of access roads and dams, but if mitigation measures such as the planting of trees/bushes are possible no major problems will occur, so the score is 5 points. If mitigation measures are difficult, the score is 3 points.

Table 7-29 Evaluation Scores for Erosion caused by Access road/Dam site

Type of erosion	Caused by construction of access roads, cutting for dam/weir
No possibility of Mitigation	3
Possibility of Mitigation, such as planting of trees/bushes	5

(Source: JICA Survey Team)

(6) Impact on landscape (Weight: 5%)

Evaluation scores for impact on landscape are shown below. Dams and transmission lines are assumed as items that influence the landscape along with hydropower development. The dams were excluded from the target items because there are many Bhutanese who think that reservoirs being formed has a good impact on the landscape. For transmission lines, it is considered that the impact on the landscape will become considerable as the transmission line distance increases. Therefore, the score is 5 points when the transmission line distance is less than 10km, and 1 point if the transmission line distance is 100km or more.

Table 7-30 Evaluation Scores for Impact on landscape due to Transmission Line

Distance from Nearest Pooling station/Substation	Score
More than 100km	1
From 50km to 100km	2
From 20km to 50km	3
From 10km to 20km	4
Less than 10km	5

(Source: JICA Survey Team)

7.2.5 Social Development Items

In the items for social development, the factors that promote social development along with hydropower development were evaluated. There are two evaluation items: improved access to socio-economic benefits, and employment and potential for income opportunities. The weight of each item is considered to be about the same, at 50% each.
In the first MCA screening, these criteria are evaluated through items which can be judged based on a desk study.

Table 7-31 Social Development Items

Sub-criteria	Weight	Assessment of sub-criteria
Improved Access to socio-economic benefits	50%	Positive impacts on road access and network
Employment and potential for income opportunities	50%	Poverty Rate Potential for increased sales of local products
Total	100%	

(Source: JICA Survey Team)

(1) Improved Access to socio-economic benefits (Weight: 50%)

Evaluation scores for improved access to socio-economic benefits are shown below. For local residents, socio-economic benefits, such as road access and network, access to educational facilities and services, and access to health facilities and services, can be expected to improve along with the development of hydropower plants.
In the first MCA screening, since it is difficult to judge the improvement in access to education and health facilities, if there is a community near the project site without a national or Dzongkhag road in the surrounding area, it is considered to be a positive impact. Such cases are scored as 5 points, while other cases are evaluated as 2 points.

Table 7-32 Evaluation Scores for Improved Access to Socio-economic Benefits

Sub criteria	Score
No Particular Positive impacts on road access and network	2
Positive impacts on road access and network	5

(Source: JICA Survey Team)

(2) Employment and potential for income opportunities (Weight: 50%)

Evaluation scores for employment and potential for income opportunities are shown below. Along with the development of hydropower plants, benefits can be expected for local residents by ensuring employment and increasing income. Considering that the impacts of these benefits are large in areas with high poverty rates, the evaluation score is high for Dzongkhags with the household poverty rate of 10% or more.
In the first MCA screening, however, it is considered that there will be employment opportunities at any project site during the construction period and it is difficult to assess tourism potential based on existing information gained through desk study. Thus, this item is evaluated based on the importance placed on employment opportunities in poor Dzongkhags, and the possibility of increased local product sales is evaluated via improved road access. In other words, if the household poverty rate in a Dzongkhag is higher than 10%, it is scored as 5 points. If it is lower than 10% without an existing national or Dzongkhag road nearby it is scored as 3 points. The same case with a national or Dzongkhag road is scored as 1 point.

Table 7-33 Evaluation Scores for Employment and Potential for Income Opportunities

Sub criteria	Score	
	High Household Poverty Rate Areas	Other areas
None	5	1
Potential for increased sales of local products	5	3

Note: High household poverty rate area = Approx. 10% and more at Dzongkhag in 2017

(Source: JICA Survey Team)

7.3 Primary Screening

7.3.1 Project Sites for which Development is to be avoided

Out of the 116 potential sites identified in Chapter 6, 3 project sites in which many resettlements are required, and 44 project sites in which all the components of the project are located within a protected area are considered very difficult to realize, even if plans are revised. Therefore, development of these projects is to be avoided and they are excluded from the potential project sites.
The project sites in question are listed in the table below.

Table 7-34 Project Sites in which many Resettlements are required

Project Code	Tributary	Name	Capacity (MW)	Energy (GWh)
W-5	Wangchhu	Thimphu Reservoir	46	201
W-10	Parochhu	Paro Reservoir	54	237
C-6	Chamkharchhu	Bumtang	102	447
Total		3 sites	202	884

(Source: JICA Survey Team)

Table 7-35 Project Sites that are Located within Protected Areas

Project Code	Tributary	Name	Capacity (MW)	Energy (GWh)
A-2	Amochhu	Amochhu-2	453	1,985
A-3	Tima Lum Chhu	Timalumchhu	38	165
W-2	Tangochhu	Chhanda-gang	37	164
P-1	Mochhu	Taksti Makhang	177	775
P-2	Mochhu	Chhogley	257	1,125
P-3	Samechhu	Chhuzarkha	165	721
P-4	Samechhu	Rimi	189	830
P-5	Mochhu	Daushing	495	2,167
P-6	Mochhu	Sechednang	330	1,445
P-8	Phochhu	Phochhu-2	59	260
P-9	Phochhu	Uesana	97	425
P-10	Tangchhu	Wachey	81	354
P-11	Tr-Phochhu-3	Threlga	124	543
P-12	Tr-Phochhu-3	Phochhu-Tr-2	431	1,886
P-13	Phochhu	Phochhu-1	597	2,615
P-14	Tr-Phochhu-2	Phochhu-Tr-1	62	271
P-16	Sichhu	Tshachuphu	58	255
P-27	Machhu	Kago-2	40	174
P-32	Harachhu	Rukha	81	356
M-1	Mangdechhu	Mangdechhu-2	69	301
M-2	Duigang chhu	Duigang chhu	62	273
M-3	Mangdechhu	Mangdechhu-1	186	813
M-4	Thampochhu	Thampochhu	59	259
M-9	Wachichhu	Wachichhu	29	127
M-12	Rimjigangchhu	Rimjigangchhu	29	126
M-13	Shergarchhu	Shergarchhu	28	121
C-1	Chamkharchhu	Gumthangchhu	125	548
C-2	Chamkharchhu	Chamkharchhu-V	72	317
C-9	Chamkharchhu	Chamkharchhu-III	755	3,307
K-1	Kurichhu	Kurichhu-2	666	2,915
K-2	Kurichhu	Kurichhu-1	777	3,405
K-3	Kurichhu	Chagdzom	563	2,466
K-4	Bazaguruchhu	Bazaguruchhu-2	50	218

K-5	Bazaguruchhu	Bazaguruchhu-1	57	250
K-6	Nangrigang	Nangrigang-2	41	180
K-7	Nangrigang	Nangrigang-1	57	248
K-8	Kurichhu	Ugenphu	354	1,551
K-9	Kurichhu	Nimshong	367	1,607
K-10	Khomachhu	Khomachhu-1	43	187
K-11	Khomachhu	Khomagang	50	220
K-12	Khomachhu	Khomachhu	104	455
G-2	Kholongchhu	Longkhar	149	653
G-8	Gamri	Gamrichhu-4	53	234
Ai-2	Aiechhu	Aiechhu 1	60	263
Total		44 sites	8,576	37,560

(Source: JICA Survey Team)

As a result, 47 project sites with 8,778MW for which development is to be avoided are excluded from the potential project sites. Primary scoring by MCA is carried out for the remaining 69 potential projects.

7.3.2 Power Transmission Plan for each Potential Project Site

In order to calculate the power transmission and transformation facility construction costs at each potential site, a power transmission plan for each potential site is created in the following manner.

- Considering the capacity of transmission lines at the planning stage in addition to existing and under construction transmission lines, a power transmission plan that can transmit electricity generated at each potential site to the Indian system is formulated.
- Since the priority of each site is unknown when determining the priority order, a power transmission plan for each potential site that enables transmission of the power generated at each site independently is formulated. Once the priority order has been determined, the plan is reviewed to consolidate the generated power from the sites extracted and the power is transmitted together.
- The transmission line is a two-circuit line, and the voltage of the transmission line is determined by considering the transmission capacity (considering one-line accidents) shown below and the voltage at the neighboring substation.
  Base on 40 degree of ambient temperature, 85 degree of maximum conductor temperature and 0.9 of power factor.
  - 400kV, Moose, Twin: $\sqrt{3}$*400kV*850A*0.9*2=1,060MW
  - 220kV, Zebra, Single: $\sqrt{3}$*220kV*750A*0.9=257MW
  - 132kV, Panther, Single: $\sqrt{3}$*132kV*490A*0.9=101MW

Table 7-36 Transmission Capacity of each Transmission Line

Voltage	Type	Capacity (1 cct)
400kV	Moose, Twin	1,060MW
220kV	Zebra, Single	257MW
132kV	Panther, Single	101MW

(Source: JICA Survey Team)

The power transmission plans for each potential project site are as follows.

Table 7-37 Power Transmission Plan for each Potential Project Site

Project Code	Name of project	Installed capacity (MW)	Voltage (kV)	From	To	Distance (km)
A-4	Kunzangling	897	400	Kunzangling	Amochhu Res.	59.0
A-5	Tingma	567	400	Tingma	Amochhu Res.	45.2
A-8	Dorokha	573	400	Dorokha	Amochhu Res.	27.4
A-9	Ngatse	44	132	Ngatse	Amochhu Res.	25.8
A-10	Sanglum	178	400	Sanglum	Amochhu Res.	16.3
A-11	Dojengkha	25	132	Dojengkha	Amochhu Res.	22.0
A-12	Dolepchen	41	132	Dolepchen	Amochhu Res.	15.2
W-3	Dodennang	61	220	Dodennang	Semtokha	21.2
W-6	Chuzom	152	220	Chuzom	Chhukha	34.4
W-7	Getsa	37	220	Getsa	Chhukha	97.0
W-8	Zangkhepa	73	220	Zangkhepa	Chhukha	81.0
W-13	Singkhar	38	220	Singkhar	Chhukha	41.3
W-14	Tsendu Goenpa	75	220	Tsendu Goenpa	Chhukha	24.2
W-19	Pipingchhu	100	132	Pipingchhu	Wangchhu	0.6
P-7	Puna Gom	127	220	Puna Gom	Punatsangchhu-I	38.8
P-15	Tamigdamchu	188	220	Tamigdamchu	Punatsangchhu-I	52.7
P-17	Tseykha	170	220	Tseykha	Punatsangchhu-I	38.2
P-18	Jarona	43	132	Jarona	Punatsangchhu-I	42.8
P-19	Dangchhu	101	132	Dangchhu	Punatsangchhu-I	28.7

Project Code	Name of project	Installed capacity (MW)	Voltage (kV)	From	To	Distance (km)
P-20	Rabuna	33	132	Rabuna	Punatsangchhu-I	22.2
P-26	Thasa	680	400	Thasa	LILO	2.3
P-28	Kago-1	102	132	Kago-1	Punatsangchhu-II	15.8
P-29	Kago	58	132	Kago	Punatsangchhu-II	9.6
P-30	Pinsa	151	132	Pinsa	Punatsangchhu-II	5.9
P-33	Burichhu	40	220	Burichhu	LILO	0.4
P-34	Darachhu	61	220	Darachhu	Dagachhu	17.5
P-35	Dagachhu-II	94	220	Dagachhu-II	Dagachhu	9.8
P-36	Pelichhu	52	220	Pelichhu	Dagachhu	16.4
P-38	Tashiding	81	220	Tashiding	Dagapela	9.1
M-5	Bemji	333	400	Bemji	Mangdechhu	39.5
M-6	Jongthang	170	400	Jongthang	Mangdechhu	22.7
M-11	Wangdigang	446	400	Wangdigang	LILO	4.4
M-14	Tingtibi	181	400	Tingtibi	LILO	2.6
M-15	Gomphu	488	400	Gomphu	Goling	20.8
M-17	Buli	67	132	Buli	Goling	10.4
M-18	Nyekhar	43	132	Nyekhar	Goling	6.1
M-19	Sermaling	496	400	Sermaling	Yangbari	39.2
C-3	Kurjey	89	132	Kurjey	Bumthang	17.3
C-4	Chhutoe	29	132	Chhutoe	Bumthang	22.1
C-7	Chamkharchhu-IV	451	400	Chamkharchhu-IV	Goling	46.3
C-10	Chamkharchhu-II	456	400	Chamkharchhu-II	Goling	29.4
K-13	Minjey	490	400	Minjey	Yangbari	82.4
K-14	Unggarchhu	28	132	Unggarchhu	Tangmachhu	14.2
K-15	Phawan	502	400	Phawan	Yangbari	68.8
K-19	Shongarchhu	32	132	Shongarchhu	Kurichhu	15.1
G-3	Tshaling	204	220	Tshaling	Kholongchhu	27.4
G-4	Ranya	162	220	Ranya	Kholongchhu	17.9
G-6	Khamdang	494	400	Khamdang	Kholongchhu	1.0
G-7	Gongri	590	400	Gongri	Yangbari	69.0
G-9	Gamrichhu-3	123	220	Gamrichhu-3	Kholongchhu	24.1
G-10	Gamrichhu-2	104	220	Gamrichhu-2	Kholongchhu	15.8
G-11	Gamrichhu-1	108	220	Gamrichhu-1	Kholongchhu	12.7
G-12	Rotpa	40	132	Rotpa	Kilikhar	22.6
G-13	Sherichhu	53	132	Sherichhu	Kilikhar	17.2
G-14	Uzorong	763	400	Uzorong	Yangbari	44.6
G-16	Jerichhu	40	132	Jerichhu	Nangkhor	11.3
G-19	Nagor	53	132	Nagor	Nganglam	23.0
G-20	Pramaling	29	132	Pramaling	Nganglam	14.2
G-22	Panbang	1,100	400	Panbang	Yangbari	27.8
Ai-1	Aiechhu 2	34	132	Aiechhu 2	Jigmeling	13.2
Ai-3	Pelrithang	30	132	Pelrithang	Jigmeling	13.1
Ai-4	Ronggangchhu	51	132	Ronggangchhu	Jigmeling	15.4
J-1	Zangtheri	29	132	Zangtheri	Phuentshogthang	54.0
J-2	Jomori-I	82	132	Jomori-I	Phuentshogthang	48.0
J-3	Maenjiwoong	70	132	Maenjiwoong	Phuentshogthang	51.8
J-4	Jomotsangkha	68	132	Jomotsangkha	Phuentshogthang	61.8
N-1	NA Kangpara (G)	71	132	NA Kangpara (G)	Phuentshogthang	57.6
N-2	Lamai Gonpa	37	132	Lamai Gonpa	Phuentshogthang	43.9
N-3	Paydung-Kangpar	85	132	Paydung-Kangpar	Phuentshogthang	28.9

(Source: JICA Survey Team)

7.3.3 Scoring of Potential Project Sites (Technical)

(1) Evaluation of Hydrological Risks

(a) Catchment area ratio at gauging station vs. dam site (Weight: 30%)

A river gauging station closest to the intake dam of each potential project was selected. However, river gauging stations whose data quality were confirmed in advance by the Study Team were selected. For instance, if a gauging station has too short observation period to be verified, or if the data quality of a station is significantly inconsistent, then such data is eliminated from the selection. The evaluation based on the catchment ratio of the gauging station and intake dam site is shown in the table below.

Table 7-38 Evaluation of Catchment Area Ratio of Gauging Station vs. Dam Site

Project Code	Name of Project	Catchment area ratio				
		Catchment area (dam site) km^2	Catchment area (station) km^2	Station selected	Catchment area ratio	Score
Amochhu Basin						
A-4	Kunzangling	2,100	3,055	Dorokha	0.69	5
A-5	Tingma	2,252	3,055	Dorokha	0.74	5
A-8	Dorokha	2,602	3,055	Dorokha	0.85	5
A-9	Ngatse	237	3,055	Dorokha	0.08	1
A-10	Sanglum	3,112	3,055	Dorokha	1.02	5
A-11	Dojengkha	95	3,650	Doyagang	0.03	1
A-12	Dolepchen	235	3,650	Doyagang	0.06	1
Wangchhu Basin						
W-3	Dodennang	410	663	Lungtenphu	0.62	5
W-6	Chuzom	2,483	2,520	Damchhu/Tamchu	0.99	5
W-7	Getsa	175	1,101	Paro (closed)	0.16	1
W-8	Zangkhepa	325	1,101	Paro (closed)	0.29	3
W-13	Singkhar	380	2,520	Damchhu/Tamchu	0.15	1
W-14	Tsendu Goenpa	646	2,520	Damchhu/Tamchu	0.26	3
W-19	Pipingchhu	217	3,573	Chukha/Chimakoti	0.06	1
Punatsangchhu Basin						
P-7	Puna Gom	2,145	2,320	Yebesa	0.92	5
P-15	Tamigdamchu	2,120	6,271	Wangdue/Wangdirapids	0.34	4
P-17	Tseykha	2,205	6,271	Wangdue/Wangdirapids	0.35	4
P-18	Jarona	219	6,271	Wangdue/Wangdirapids	0.03	1
P-19	Dangchhu	404	6,271	Wangdue/Wangdirapids	0.06	1
P-20	Rabuna	561	6,271	Wangdue/Wangdirapids	0.09	1
P-26	Thasa	6,102	8,593	Sankosh/Toritar	0.71	5
P-28	Kago-1	250	6,271	Wangdue/Wangdirapids	0.04	1
P-29	Kago	377	6,271	Wangdue/Wangdirapids	0.06	1
P-30	Pinsa	427	6,271	Wangdue/Wangdirapids	0.07	1
P-33	Burichhu	190	8,593	Sankosh/Toritar	0.02	1
P-34	Darachhu	220	8,593	Sankosh/Toritar	0.03	1
P-35	Dagachhu-II	593	8,593	Sankosh/Toritar	0.07	1
P-36	Pelichhu	211	8,593	Sankosh/Toritar	0.02	1
P-38	Tashiding	778	8,593	Sankosh/Toritar	0.09	1
Mangdechhu Basin						
M-5	Bemji	1,010	1,390	Bjizam	0.73	5
M-6	Jongthang	1,298	1,390	Bjizam	0.93	5
M-11	Wangdigang	2,490	3,322	Tingtibi	0.75	5
M-14	Tingtibi	2,878	3,322	Tingtibi	0.87	5
M-15	Gomphu	3,328	3,322	Tingtibi	1.00	5
M-17	Buli	216	3,322	Tingtibi	0.07	1

Project Code	Name of Project	Catchment area ratio				
		Catchment area (dam site) km^2	Catchment area (station) km^2	Station selected	Catchment area ratio	Score
M-18	Nyekhar	244	3,322	Tingtibi	0.07	1
M-19	Sermaling	7,281	3,322	Tingtibi	2.19	4
Chamkharchhu Basin						
C-3	Kurjey	804	1,350	Kurjey	0.60	5
C-4	Chhutoe	146	1,350	Kurjey	0.11	1
C-7	Chamkharchhu-IV	2,080	2,728	Shingkhar/Bemethang	0.76	5
C-10	Chamkharchhu-II	2,525	2,728	Shingkhar/Bemethang	0.93	5
Kurichhu Basin						
K-13	Minjey	8,926	7,270	Sumpa	1.23	5
K-14	Unggarchhu	132	611	Lhuentse (Khoma)	0.22	2
K-15	Phawan	9,445	8,547	Autsho	1.11	5
K-19	Shongarchhu	124	320	Lingmethang	0.39	4
Drangmechhu Basin						
G-3	Tshaling	760	905	Muktrap	0.84	5
G-4	Ranya	848	905	Muktrap	0.94	5
G-6	Khamdang	7,286	8,560	Uzorong	0.85	5
G-7	Gongri	8,691	8,560	Uzorong	1.02	5
G-9	Gamrichhu-3	214	905	Muktrap	0.24	2
G-10	Gamrichhu-2	416	905	Muktrap	0.46	4
G-11	Gamrichhu-1	573	905	Muktrap	0.63	5
G-12	Rotpa	208	437	Sherichu	0.48	4
G-13	Sherichhu	278	437	Sherichu	0.64	5
G-14	Uzorong	10,164	8,560	Uzorong	1.19	5
G-16	Jerichhu	153	320	Lingmethang	0.48	4
G-19	Nagor	150	320	Lingmethang	0.47	4
G-20	Pramaling	120	320	Lingmethang	0.37	4
G-22	Panbang	20,944	20,925	Panbang	1.00	5
Aiechhu Basin						
Ai-1	Aiechhu 2	223	3,322	Tingtibi	0.07	1
Ai-3	Pelrithang	512	3,322	Tingtibi	0.15	1
Ai-4	Ronggangchhu	149	3,322	Tingtibi	0.04	1
Jomori Basin						
J-1	Zangtheri	119	437	Sherichu	0.27	3
J-2	Jomori-I	495	437	Sherichu	1.13	5
J-3	Maenjiwoong	564	437	Sherichu	1.29	5
J-4	Jomotsangkha	685	437	Sherichu	1.57	5
Nyera Amari Basin						
N-1	NA Kangpara (G)	145	437	Sherichu	0.33	4
N-2	Lamai Gonpa	188	437	Sherichu	0.43	4
N-3	Paydung-Kangpar	379	437	Sherichu	0.87	5

(Source: JICA Survey Team)

(b) Recorded Period (Weight: 30%)

The recorded period is evaluated for the gauging stations selected in (a). The results are shown in the table below.

Table 7-39 Evaluation of Recorded Period

Project Code	Name of Project	Recorded period (years)	Score
Amochhu Basin			
A-4	Kunzangling	19	4

Project Code	Name of Project	Recorded period (years)	Score
A-5	Tingma	19	4
A-8	Dorokha	19	4
A-9	Ngatse	19	4
A-10	Sanglum	19	4
A-11	Dojengkha	9	2
A-12	Dolepchen	9	2
Wangchhu Basin			
W-3	Dodennang	24	5
W-6	Chuzom	14	3
W-7	Getsa	24	5
W-8	Zangkhepa	24	5
W-13	Singkhar	14	3
W-14	Tsendu Goenpa	14	3
W-19	Pipingchhu	39	5
Punatsangchhu Basin			
P-7	Puna Gom	24	5
P-15	Tamigdamchu	25	5
P-17	Tseykha	25	5
P-18	Jarona	25	5
P-19	Dangchhu	25	5
P-20	Rabuna	25	5
P-26	Thasa	8	2
P-28	Kago-1	25	5
P-29	Kago	25	5
P-30	Pinsa	25	5
P-33	Burichhu	8	2
P-34	Darachhu	8	2
P-35	Dagachhu-II	8	2
P-36	Pelichhu	8	2
P-38	Tashiding	8	2
Mangdechhu Basin			
M-5	Bemji	21	5
M-6	Jongthang	21	5
M-11	Wangdigang	11	3
M-14	Tingtibi	11	3
M-15	Gomphu	11	3
M-17	Buli	11	3
M-18	Nyekhar	11	3
M-19	Sermaling	11	3
Chamkharchhu Basin			
C-3	Kurjey	25	5
C-4	Chhutoe	25	5
C-7	Chamkharchhu-IV	6	2
C-10	Chamkharchhu-II	6	2
Kurichhu Basin			
K-13	Minjey	8	2
K-14	Unggarchhu	27	5
K-15	Phawan	24	5
K-19	Shongarchhu	12	3
Drangmechhu Basin			
G-3	Tshaling	15	4
G-4	Ranya	15	4
G-6	Khamdang	21	5
G-7	Gongri	21	5
G-9	Gamrichhu-3	15	4

Project Code	Name of Project	Recorded period (years)	Score
G-10	Gamrichhu-2	15	4
G-11	Gamrichhu-1	15	4
G-12	Rotpa	23	5
G-13	Sherichhu	23	5
G-14	Uzorong	21	5
G-16	Jerichhu	12	3
G-19	Nagor	12	3
G-20	Pramaling	12	3
G-22	Panbang	6	2
Aiechhu Basin			
Ai-1	Aiechhu 2	11	3
Ai-3	Pelrithang	11	3
Ai-4	Ronggangchhu	11	3
Jomori Basin			
J-1	Zangtheri	23	5
J-2	Jomori-I	23	5
J-3	Maenjiwoong	23	5
J-4	Jomotsangkha	23	5
Nyera Amari Basin			
N-1	NA Kangpara (G)	23	5
N-2	Lamai Gonpa	23	5
N-3	Paydung-Kangpar	23	5

(Source: JICA Survey Team)

(c) Density of gauging stations in a river system basin (Primary: 30%, Secondary: 10%)

The density of the primary and secondary gauging stations are evaluated as shown in the table below.

Table 7-40 Evaluation of Density of the Gauging Stations

Project Code	Name of Project	Basin Area km^2 (inside Bhutan)	Primary stations			Secondary stations		
			No. of stations	Density	Score	No. of stations	Density	Score
Amochhu Basin								
A-4	Kunzangling	2,323	1	0.0004	3	1	0.0004	3
A-5	Tingma	2,323	1	0.0004	3	1	0.0004	3
A-8	Dorokha	2,323	1	0.0004	3	1	0.0004	3
A-9	Ngatse	2,323	1	0.0004	3	1	0.0004	3
A-10	Sanglum	2,323	1	0.0004	3	1	0.0004	3
A-11	Dojengkha	2,323	1	0.0004	3	1	0.0004	3
A-12	Dolepchen	2,323	1	0.0004	3	1	0.0004	3
Wangchhu Basin								
W-3	Dodennang	4,644	2	0.0004	3	0	0.0000	1
W-6	Chuzom	4,644	2	0.0004	3	0	0.0000	1
W-7	Getsa	4,644	2	0.0004	3	0	0.0000	1
W-8	Zangkhepa	4,644	2	0.0004	3	0	0.0000	1
W-13	Singkhar	4,644	2	0.0004	3	0	0.0000	1
W-14	Tsendu Goenpa	4,644	2	0.0004	3	0	0.0000	1
W-19	Pipingchhu	4,644	2	0.0004	3	0	0.0000	1
Punatsangchhu Basin								
P-7	Puna Gom	9,748	4	0.0004	3	3	0.0003	2
P-15	Tamigdamchu	9,748	4	0.0004	3	3	0.0003	2
P-17	Tseykha	9,748	4	0.0004	3	3	0.0003	2
P-18	Jarona	9,748	4	0.0004	3	3	0.0003	2
P-19	Dangchhu	9,748	4	0.0004	3	3	0.0003	2
P-20	Rabuna	9,748	4	0.0004	3	3	0.0003	2

Project Code	Name of Project	Basin Area km^2 (inside Bhutan)	Primary stations			Secondary stations		
			No. of stations	Density	Score	No. of stations	Density	Score
P-26	Thasa	9,748	4	0.0004	3	3	0.0003	2
P-28	Kago-1	9,748	4	0.0004	3	3	0.0003	2
P-29	Kago	9,748	4	0.0004	3	3	0.0003	2
P-30	Pinsa	9,748	4	0.0004	3	3	0.0003	2
P-33	Burichhu	9,748	4	0.0004	3	3	0.0003	2
P-34	Darachhu	9,748	4	0.0004	3	3	0.0003	2
P-35	Dagachhu-II	9,748	4	0.0004	3	3	0.0003	2
P-36	Pelichhu	9,748	4	0.0004	3	3	0.0003	2
P-38	Tashiding	9,748	4	0.0004	3	3	0.0003	2
Mangdechhu Basin								
M-5	Bemji	4,085	2	0.0005	3	1	0.0002	1
M-6	Jongthang	4,085	2	0.0005	3	1	0.0002	1
M-11	Wangdigang	4,085	2	0.0005	3	1	0.0002	1
M-14	Tingtibi	4,085	2	0.0005	3	1	0.0002	1
M-15	Gomphu	4,085	2	0.0005	3	1	0.0002	1
M-17	Buli	4,085	2	0.0005	3	1	0.0002	1
M-18	Nyekhar	4,085	2	0.0005	3	1	0.0002	1
M-19	Sermaling	4,085	2	0.0005	3	1	0.0002	1
Chamkharchhu Basin								
C-3	Kurjey	3,178	2	0.0006	4	0	0.0000	1
C-4	Chhutoe	3,178	2	0.0006	4	0	0.0000	1
C-7	Chamkharchhu-IV	3,178	2	0.0006	4	0	0.0000	1
C-10	Chamkharchhu-II	3,178	2	0.0006	4	0	0.0000	1
Kurichhu Basin								
K-13	Minjey	3,837	2	0.0005	4	3	0.0008	4
K-14	Unggarchhu	3,837	2	0.0005	4	3	0.0008	4
K-15	Phawan	3,837	2	0.0005	4	3	0.0008	4
K-19	Shongarchhu	3,837	2	0.0005	4	3	0.0008	4
Drangmechhu Basin								
G-3	Tshaling	9,785	3	0.0003	2	1	0.0001	1
G-4	Ranya	9,785	3	0.0003	2	1	0.0001	1
G-6	Khamdang	9,785	3	0.0003	2	1	0.0001	1
G-7	Gongri	9,785	3	0.0003	2	1	0.0001	1
G-9	Gamrichhu-3	9,785	3	0.0003	2	1	0.0001	1
G-10	Gamrichhu-2	9,785	3	0.0003	2	1	0.0001	1
G-11	Gamrichhu-1	9,785	3	0.0003	2	1	0.0001	1
G-12	Rotpa	9,785	3	0.0003	2	1	0.0001	1
G-13	Sherichhu	9,785	3	0.0003	2	1	0.0001	1
G-14	Uzorong	9,785	3	0.0003	2	1	0.0001	1
G-16	Jerichhu	9,785	3	0.0003	2	1	0.0001	1
G-19	Nagor	9,785	3	0.0003	2	1	0.0001	1
G-20	Pramaling	9,785	3	0.0003	2	1	0.0001	1
G-22	Panbang	9,785	3	0.0003	2	1	0.0001	1
Aiechhu Basin								
Ai-1	Aiechhu 2	1,956	0	0.0000	1	0	0.0000	1
Ai-3	Pelrithang	1,956	0	0.0000	1	0	0.0000	1
Ai-4	Ronggangchhu	1,956	0	0.0000	1	0	0.0000	1
Jomori Basin								
J-1	Zangtheri	731	0	0.0000	1	0	0.0000	1
J-2	Jomori-I	731	0	0.0000	1	0	0.0000	1
J-3	Maenjiwoong	731	0	0.0000	1	0	0.0000	1
J-4	Jomotsangkha	731	0	0.0000	1	0	0.0000	1
Nyera Amari Basin								

Project Code	Name of Project	Basin Area km^2 (inside Bhutan)	Primary stations			Secondary stations		
			No. of stations	Density	Score	No. of stations	Density	Score
N-1	NA Kangpara (G)	2,289	0	0.0000	1	0	0.0000	1
N-2	Lamai Gonpa	2,289	0	0.0000	1	0	0.0000	1
N-3	Paydung-Kangpar	2,289	0	0.0000	1	0	0.0000	1

Note; Basin area in above table referes to the area within Bhutan

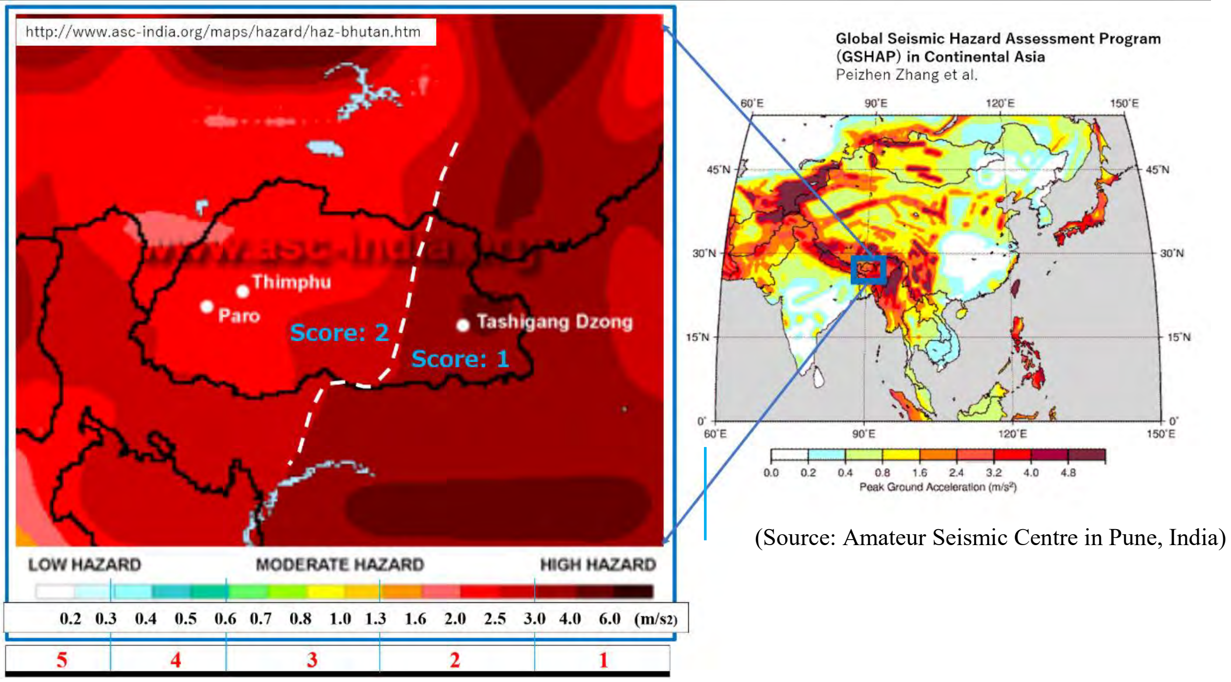
(Source: JICA Survey Team)

(2) Evaluation of Geological Risks

(a) Earthquake intensity

"The Global Seismic Hazard Assessment Project" (GSHAP) produced a global seismic hazard map covering Bhutan (Giardini et al., 1999), which was re-generated by the Amateur Seismic Centre in Pune, India. Much of Bhutan is mapped within high seismic hazard zone.

The following siesmic zoning map of Bhutan as shown in Figure 7-2 is being used for ranking seismic intensity of the project areas as one of the criteria.



(Source: Amateur Seismic Centre in Pune, India)

(Source: JICA Survey Team compiled from Amateur Seismic Centre in Pune, India and GSHAP)

Figure 7-2 Earthquake Intensity score in Bhutan based on the GSHAP Seismic Hazard Map

(b) Construction material risks

It is desirable that riverbed materials such as gravel and sand, which are easy to collect, are widely distributed near the planned site. The distribution and volume are evaluated through Google Earth images. If such materials are scarce along the riverbed, Google Earth images are checked to confirm whether or not any protruding mountains suitable for the quarry site can be found around the project area. Riverbed materials/the quarry site are evaluated from the aspects of availability and ease of collection.

(c) Evaluation of topographical/geological risks

Three major risks - 1) Slope Stability, 2) Weak Zones, and 3) Permeable and Anisotropic Rocks - are evaluated as follows:

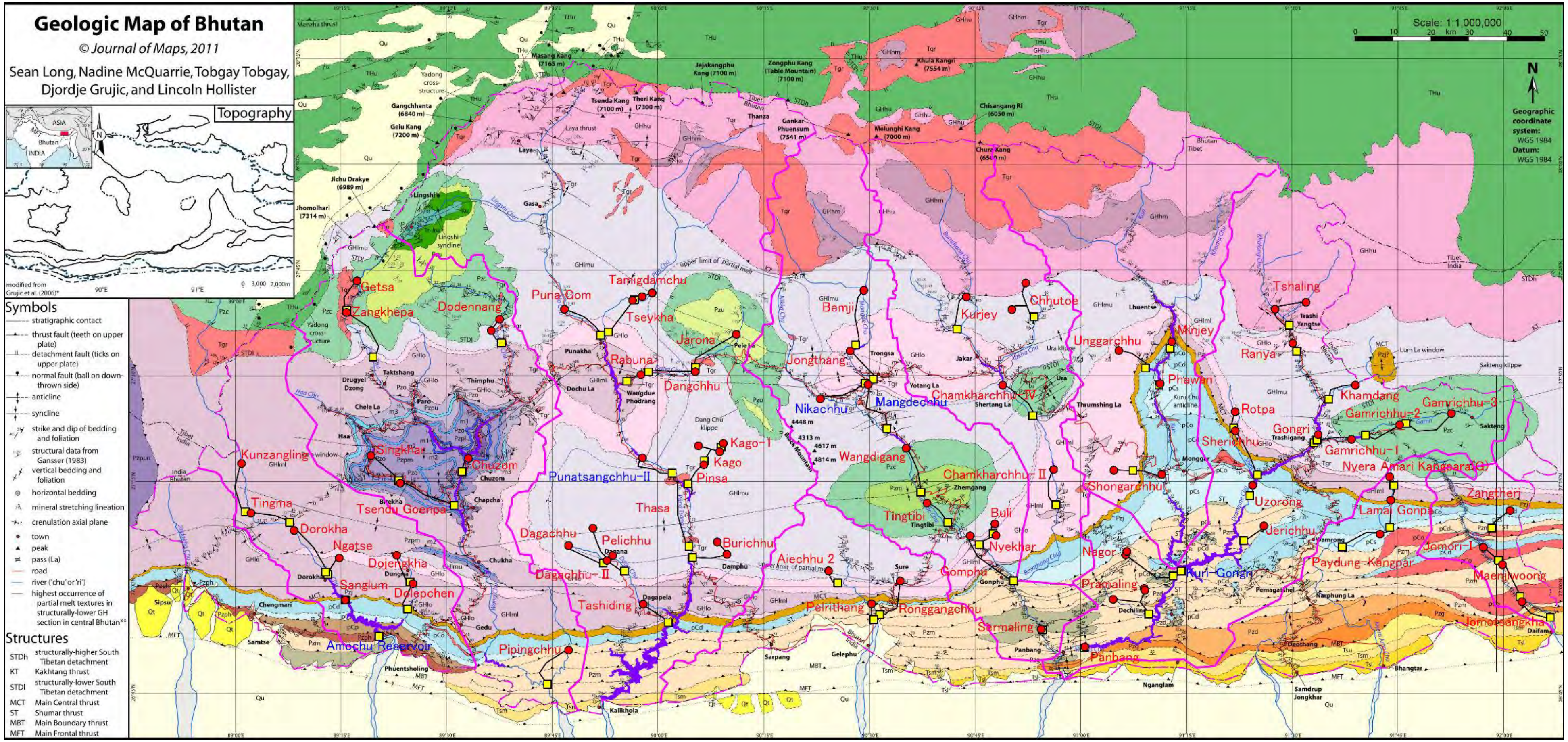
1) Slope Stability is evaluated comprehensively from both Topographical and Geological aspects. Whether or not unstable blocks can be seen on the Google Earth images is evaluated from the aspect

of topography. Further, whether or not the dip direction of the bedding plane is parallel to the land slope around the reservoir in a wide range is evaluated through existing geological maps. This is classified relatively into five levels.

2) With regard to Weak Zones, whether or not there are structural faults such as lineaments or MCT around the project area is evaluated on Google Earth images and through existing geological maps. Their scores are as follows:
1: lineaments/structural faults pass within the project area; 3: they are distributed within 5 km of the project area; 5: other.

3) With regard to Permeable and Anisotropic Rocks, we evaluate whether or not calcareous rocks which have adverse impact on impermeability are distributed around the pond and dam site, and whether or not anisotropic rocks are distributed around the waterway route and/or underground powerhouse cavern based on the geologic map shown below.

69 numbers of candidate location are plotted on the following geologic map.



(Source: Long et al., 2011)

Figure 7-3 Potential Project Sites on the Geological Plan of Bhutan

Scoring is as follows:
1: If there is a high possibility that the main structures are to be planned in the same strata of such problematic rocks; 3: If there is a possibility that the main structures are to be planned near the strata of such problematic rocks; 5: If there is little possibility that the main structures are to be planned near the strata of such problematic rocks.

The scores for topographical/geological risks are shown in the table below.

Table 7-41 Geological Risk Scores

Project Code	Name of Project	Slope stability Risk	Weak zone	Permeable & anisotropic rocks	Construction material risk
A-4	Kunzangling	3	5	5	4
A-5	Tingma	3	5	5	2
A-8	Dorokha	4	4	5	4
A-9	Ngatse	4	5	5	2
A-10	Sanglum	4	3	1	4
A-11	Dojengkha	4	4	5	3
A-12	Dolepchen	3	3	3	4
W-3	Dodennang	4	3	4	1
W-6	Chuzom	4	5	5	3
W-7	Getsa	4	5	3	2
W-8	Zangkhepa	4	4	3	2
W-13	Singkhar	4	5	5	2
W-14	Tsendu Goenpa	4	5	5	2
W-19	Pipingchhu	4	5	5	3
P-7	Puna Gom	4	5	5	3
P-15	Tamigdamchu	4	5	5	2
P-17	Tseykha	4	5	5	5
P-18	Jarona	4	3	1	2
P-19	Dangchhu	4	5	5	3
P-20	Rabuna	2	5	5	3
P-26	Thasa	3	5	5	2
P-28	Kago-1	4	5	5	2
P-29	Kago	4	4	5	2
P-30	Pinsa	2	4	5	2
P-33	Burichhu	4	5	5	2
P-34	Darachhu	4	5	5	3
P-35	Dagachhu-II	4	5	5	2
P-36	Pelichhu	4	5	5	2
P-38	Tashiding	3	3	5	2
M-5	Bemji	4	5	5	3
M-6	Jongthang	4	5	5	3
M-11	Wangdigang	4	5	3	3
M-14	Tingtibi	4	5	3	5
M-15	Gomphu	4	3	2	5
M-17	Buli	4	5	5	5
M-18	Nyekhar	4	5	5	5
M-19	Sermaling	5	3	2	5
C-3	Kurjey	3	3	5	4
C-4	Chhutoe	3	4	5	4
C-7	Chamkharchhu-IV	4	3	3	3
C-10	Chamkharchhu-II	4	3	5	4
K-13	Minjey	4	4	1	3
K-14	Unggarchhu	4	3	3	2

Project Code	Name of Project	Slope stability Risk	Weak zone	Permeable & anisotropic rocks	Construction material risk
K-15	Phawan	4	5	3	2
K-19	Shongarchhu	4	4	5	2
G-3	Tshaling	4	4	5	2
G-4	Ranya	4	5	5	3
G-6	Khamdang	4	5	5	4
G-7	Gongri	4	5	5	5
G-9	Gamrichhu-3	4	4	3	3
G-10	Gamrichhu-2	3	5	3	3
G-11	Gamrichhu-1	3	3	3	3
G-12	Rotpa	4	3	5	2
G-13	Sherichhu	3	3	1	2
G-14	Uzorong	3	5	1	2
G-16	Jerichhu	4	4	3	2
G-19	Nagor	4	4	1	2
G-20	Pramaling	4	4	3	2
G-22	Panbang	4	4	3	4
Ai-1	Aiechhu 2	3	5	5	1
Ai-3	Pelrithang	3	4	2	3
Ai-4	Ronggangchhu	3	3	2	2
J-1	Zangtheri	3	3	1	2
J-2	Jomori-I	3	3	3	2
J-3	Maenjiwoong	4	4	3	3
J-4	Jomotsangkha	4	2	4	3
N-1	NA Kangpara (G)	4	3	5	1
N-2	Lamai Gonpa	4	2	1	1
N-3	Paydung-Kangpar	4	4	3	3

(Source: JICA Survey Team)

(3) GLOF Risk

The elongation along the river from the glacial lake to the dam (weir) was calculated on QGIS and the GLOF risk for each potential site was scored according to the evaluation score for GLOF risk described in 7.2.1 (3).

(4) Sedimentation Risk

The specific yield of the river gauging stations is assigned from the nearest sediment monitoring station discussed in section 5.3.9. The assigned sediment specific yield for each of the gauging stations is shown in the table below.

Table 7-42 Assignment of Sediment Specific Yield to River Gauging Station

Sl. No.	*Station Name*	*Catchment Name*	*Altitude (m)*	*Catchment Area (km²)*	*Sediment Specific Yield (ton/km²)*	*Reference Station*
Principal River Gauging Stations						
1	Doyagang	Amochhu	253	3,650	516	Wandurapids
2	Lungtenphu	Wangchhu	2280	663	516	Wandurapids
3	Damchhu/Tamchu	Wangchhu	2019	2,520	516	Wandurapids
4	Kerabari	Punatsangchhu	145	10,355	964.75	Sankosh
5	Sunkosh/Turitar	Punatsangchhu	324	8,593	964.75	Sankosh
6	Wangdue/Wangdirapids	Punatsangchhu	1204	6,271	516	Wandurapids
7	Yebesa	Punatsangchhu	1255	2,320	437.25	Yebesa
8	Bjizam	Mangdechhu	1921	1,390	152.5	Mangdechhu
9	Tingtibi	Mangdechhu	546	3,322	152.5	Mangdechhu
10	Kurjey	Chamkharchhu	2625	1,350	56	Kurjey

Sl. No.	*Station Name*	*Catchment Name*	*Altitude (m)*	*Catchment Area (km²)*	*Sediment Specific Yield (ton/km²)*	*Reference Station*
11	Shingkhar/Bemethang	Chamkharchhu	1465	2,728	56	Kurjey
12	Kurizampa	Kurichhu	559	8,600	551.75	Kurizampa
13	Panbang	Drangmechhu	133	20,925	551.75	Kurizampa
14	Sumpa	Kurichhu	1178	7,270	551.75	Kurizampa
15	Muktrap	Drangmechhu	1691	905	551.75	Kurizampa
16	Uzorong	Drangmechhu	573	8,560	551.75	Kurizampa
Secondary River Gauging Stations						
1	Dorokha	Amochhu	479	3055	516	Wandurapids
2	Chukha/Chimakoti	Wangchhu	1376	3573	516	Wandurapids
3	Paro (closed)	Wangchhu	2220	1101	516	Wandurapids
10	Autsho	Kurichhu	850	8547	551.75	Kurizampa
11	Lhuentse(Khoma)	Kurichhu	1178	611	551.75	Kurizampa
12	Lingmethang	Kurichhu	562	320	551.75	Kurizampa
13	Sherichu	Drangmechhu	573	437	551.75	Kurizampa

(Source: JICA Survey Team)

The sediment risk of the potential projects is evaluated via the specific yield of the reference gauging station assigned by the above table. The results of the sediment risk evaluation are shown in the table below.

Table 7-43 Results of the Sediment Risk Evaluation

Project Code	Name of Project	Annual sediment volume ton/km²	Score
Amochhu Basin			
A-4	Kunzangling	516	4
A-5	Tingma	516	4
A-8	Dorokha	516	4
A-9	Ngatse	516	4
A-10	Sanglum	516	4
A-11	Dojengkha	516	4
A-12	Dolepchen	516	4
Wangchhu Basin			
W-3	Dodennang	516	4
W-6	Chuzom	516	4
W-7	Getsa	516	4
W-8	Zangkhepa	516	4
W-13	Singkhar	516	4
W-14	Tsendu Goenpa	516	4
W-19	Pipingchhu	516	4
Punatsangchhu Basin			
P-7	Puna Gom	437	5
P-15	Tamigdamchu	516	4
P-17	Tseykha	516	4
P-18	Jarona	516	4
P-19	Dangchhu	516	4
P-20	Rabuna	516	4
P-26	Thasa	965	4
P-28	Kago-1	516	4
P-29	Kago	516	4
P-30	Pinsa	516	4
P-33	Burichhu	965	4
P-34	Darachhu	965	4

Project Code	Name of Project	Annual sediment volume ton/km^2	Score
P-35	Dagachhu-II	965	4
P-36	Pelichhu	965	4
P-38	Tashiding	965	4
Mangdechhu Basin			
M-5	Bemji	153	5
M-6	Jongthang	153	5
M-11	Wangdigang	153	5
M-14	Tingtibi	153	5
M-15	Gomphu	153	5
M-17	Buli	153	5
M-18	Nyekhar	153	5
M-19	Sermaling	153	5
Chamkharchhu Basin			
C-3	Kurjey	56	5
C-4	Chhutoe	56	5
C-7	Chamkharchhu-IV	56	5
C-10	Chamkharchhu-II	56	5
Kurichhu Basin			
K-13	Minjey	552	4
K-14	Unggarchhu	552	4
K-15	Phawan	552	4
K-19	Shongarchhu	552	4
Drangmechhu Basin			
G-3	Tshaling	552	4
G-4	Ranya	552	4
G-6	Khamdang	552	4
G-7	Gongri	552	4
G-9	Gamrichhu-3	552	4
G-10	Gamrichhu-2	552	4
G-11	Gamrichhu-1	552	4
G-12	Rotpa	552	4
G-13	Sherichhu	552	4
G-14	Uzorong	552	4
G-16	Jerichhu	552	4
G-19	Nagor	552	4
G-20	Pramaling	552	4
G-22	Panbang	552	4
Aiechhu Basin			
Ai-1	Aiechhu 2	153	5
Ai-3	Pelrithang	153	5
Ai-4	Ronggangchhu	153	5
Jomori Basin			
J-1	Zangtheri	552	4
J-2	Jomori-I	552	4
J-3	Maenjiwoong	552	4
J-4	Jomotsangkha	552	4
Nyera Amari Basin			
N-1	NA Kangpara (G)	552	4
N-2	Lamai Gonpa	552	4
N-3	Paydung-Kangpar	552	4

(Source: JICA Survey Team)

7.3.4 Scoring for Potential Project Sites (Economic)

The economic evaluation for each potential site is shown below.

Table 7-44 Economic Evaluation for each Potential Site

Project Code	Name of project	Installed capacity (MW)	Annual energy (GWh)	Construction cost (million Nu.)		Unit price		Cost	Benefit	B/C	Score
				Plant	System	10^3Nu./kW	Nu./kWh	million Nu./annum			
A-4	Kunzangling	897	3,816	43,519	6,024	55.2	13.0	5,751	16,183	2.81	5.0
A-5	Tingma	567	2,413	35,579	5,225	72.0	16.9	4,736	10,230	2.16	5.0
A-8	Dorokha	573	2,439	46,103	4,351	88.0	20.7	5,857	10,364	1.77	4.8
A-9	Ngatse	44	170	5,569	1,252	155.1	40.1	792	716	0.90	1.0
A-10	Sanglum	178	779	36,778	2,579	221.2	50.5	4,569	3,475	0.76	1.0
A-11	Dojengkha	25	105	4,979	1,168	250.2	58.8	714	440	0.62	1.0
A-12	Dolepchen	41	172	6,663	1,069	190.9	44.8	898	726	0.81	1.0
W-3	Dodennang	61	275	8,719	1,497	166.6	37.1	1,186	1,188	1.00	1.0
W-6	Chuzom	152	645	22,813	1,822	162.5	38.2	2,860	3,370	1.18	1.9
W-7	Getsa	37	152	6,260	3,151	255.6	61.9	1,092	656	0.60	1.0
W-8	Zangkhepa	73	305	6,720	2,817	130.7	31.2	1,107	1,318	1.19	2.0
W-13	Singkhar	38	165	7,084	1,926	234.2	54.8	1,046	722	0.69	1.0
W-14	Tsendu Goenpa	75	321	12,559	1,569	188.0	43.9	1,640	1,388	0.85	1.0
W-19	Pipingchhu	100	424	12,486	864	134.1	31.5	1,550	1,849	1.19	2.0
P-7	Puna Gom	127	543	25,896	2,296	222.1	51.9	3,273	2,347	0.72	1.0
P-15	Tamigdamchu	188	805	24,033	2,643	141.7	33.1	3,097	3,480	1.12	1.6
P-17	Tseykha	170	726	26,279	2,312	168.5	39.4	3,319	3,138	0.95	1.0
P-18	Jarona	43	179	8,484	1,540	234.9	55.9	1,164	783	0.67	1.0
P-19	Dangchhu	101	432	11,155	1,343	123.3	28.9	1,451	1,887	1.30	2.5
P-20	Rabuna	33	140	6,635	1,180	237.9	55.8	907	612	0.67	1.0
P-26	Thasa	680	3,277	73,644	2,842	112.4	23.3	8,878	14,561	1.64	4.2
P-28	Kago-1	102	436	6,275	1,125	72.4	17.0	859	1,896	2.21	5.0
P-29	Kago	58	249	8,214	988	157.7	37.0	1,068	1,082	1.01	1.1
P-30	Pinsa	151	644	10,341	985	75.0	17.6	1,315	2,801	2.13	5.0
P-33	Burichhu	40	170	8,912	840	244.3	57.3	1,132	749	0.66	1.0
P-34	Darachhu	61	259	7,765	1,415	151.2	35.5	1,066	1,130	1.06	1.3
P-35	Dagachhu-II	94	402	11,953	1,260	140.3	32.9	1,534	1,754	1.14	1.7
P-36	Pelichhu	52	222	7,260	1,387	166.7	38.9	1,004	970	0.97	1.0
P-38	Tashiding	81	347	10,927	1,239	149.7	35.1	1,412	1,530	1.08	1.4
M-5	Bemji	333	1,425	30,700	3,779	103.6	24.2	4,002	6,202	1.55	3.7
M-6	Jongthang	170	726	30,409	2,887	196.3	45.9	3,865	3,174	0.82	1.0
M-11	Wangdigang	446	1,907	49,274	1,782	114.6	26.8	5,927	8,348	1.41	3.0
M-14	Tingtibi	181	770	33,064	1,589	191.6	45.0	4,022	3,403	0.85	1.0
M-15	Gomphu	488	2,076	72,525	2,918	154.6	36.3	8,757	9,492	1.08	1.4
M-17	Buli	67	262	5,793	1,009	101.9	25.9	790	1,164	1.47	3.4
M-18	Nyekhar	43	183	6,032	916	161.8	38.0	807	795	0.99	1.0
M-19	Sermaling	496	2,171	69,107	3,826	147.1	33.6	8,466	9,849	1.16	1.8
C-3	Kurjey	89	381	24,942	767	288.6	67.4	2,984	1,676	0.56	1.0
C-4	Chhutoe	29	126	6,518	828	249.7	58.4	853	543	0.64	1.0
C-7	Chamkharchhu-IV	451	1,928	37,916	4,157	93.4	21.8	4,884	8,494	1.74	4.7
C-10	Chamkharchhu-II	456	1,936	36,121	3,330	86.5	20.4	4,579	8,669	1.89	5.0
K-13	Minjey	490	2,091	81,444	5,941	178.5	41.8	10,144	9,306	0.92	1.0
K-14	Unggarchhu	28	119	4,010	693	168.4	39.4	546	517	0.95	1.0
K-15	Phawan	502	2,185	88,255	6,350	188.5	43.3	10,982	9,744	0.89	1.0
K-19	Shongarchhu	32	138	4,926	711	174.5	40.8	654	595	0.91	1.0
G-3	Tshaling	204	876	66,800	2,096	337.7	78.7	7,997	4,145	0.52	1.0
G-4	Ranya	162	696	45,141	1,861	290.0	67.6	5,456	3,050	0.56	1.0
G-6	Khamdang	494	2,109	56,594	1,950	118.5	27.8	6,796	9,269	1.36	2.8
G-7	Gongri	590	2,515	87,004	6,398	158.4	37.1	10,842	11,174	1.03	1.2
G-9	Gamrichhu-3	123	524	10,952	1,971	105.3	24.7	1,500	2,276	1.52	3.6
G-10	Gamrichhu-2	104	446	11,666	1,776	128.6	30.2	1,560	1,966	1.26	2.3
G-11	Gamrichhu-1	108	462	23,844	1,710	236.0	55.3	2,966	2,074	0.70	1.0
G-12	Rotpa	40	172	5,280	841	151.8	35.6	710	748	1.05	1.3
G-13	Sherichhu	53	227	8,293	753	172.2	39.8	1,050	987	0.94	1.0

Project Code	Name of project	Installed capacity (MW)	Annual energy (GWh)	Construction cost (million Nu.)		Unit price		Cost	Benefit	B/C	Score
				Plant	System	10^3Nu./kW	Nu./kWh	million Nu./annum			
G-14	Uzorong	763	3,257	84,990	5,271	118.3	27.7	10,477	14,600	1.39	3.0
G-16	Jerichhu	40	164	5,143	649	144.7	35.2	672	715	1.06	1.3
G-19	Nagor	53	252	7,774	853	162.8	34.3	1,001	1,084	1.08	1.4
G-20	Pramaling	29	123	6,760	693	259.9	60.8	865	528	0.61	1.0
G-22	Panbang	1,100	4,640	113,900	4,563	107.7	25.5	13,751	20,901	1.52	3.6
Ai-1	Aiechhu 2	34	146	4,842	1,029	171.9	40.3	681	630	0.92	1.0
Ai-3	Pelrithang	30	126	9,680	1,022	362.7	85.0	1,242	552	0.44	1.0
Ai-4	Ronggangchhu	51	216	7,729	1,080	174.2	40.8	1,023	933	0.91	1.0
J-1	Zangtheri	29	121	4,699	1,717	224.8	52.9	745	530	0.71	1.0
J-2	Jomori-I	82	349	9,703	1,658	138.3	32.6	1,319	1,548	1.17	1.9
J-3	Maenjiwoong	70	296	11,496	1,715	189.3	44.6	1,533	1,315	0.86	1.0
J-4	Jomotsangkha	68	291	12,498	1,883	210.1	49.5	1,669	1,290	0.77	1.0
N-1	NA Kangpara (G)	71	304	6,134	1,814	111.7	26.2	923	1,313	1.42	3.1
N-2	Lamai Gonpa	37	156	6,438	1,553	218.1	51.1	928	676	0.73	1.0
N-3	Paydung-Kangpar	85	364	13,253	1,336	170.9	40.1	1,693	1,597	0.94	1.0

Note) [green] : B/C is 1.5 or more, [orange] : B/C is 0.8 or less

(Source: JICA Survey Team)

As a result, 11 sites have a B/C of 1.5 or more, a high evaluation of 3.5 points or more. 18 sites have a B/C of 0.8 or less. Many of these sites are small with a capacity of less than 50 MW.

<Techno-Economical Potential>

The total number of potential sites and total installed capacities are 155 sites and 36.9GW, respectively. Of these sites, for 44 sites, all components are located in protected areas, and it is difficult to change to a plan that can be avoided development in protected areas. Therefore, development of these sites is avoided, and these are excluded from potential sites. Including these sites, potential sites that can be developed technically and economically (B/C is 1.0 or more) are as follows.

	Techno-Economical Potential		Others		Total	
	Site No.	Capacity (GW)	Site No.	Capacity (GW)	Site No.	Capacity (GW)
Existing	6	1.6			6	1.6
Earmarked	13	12.5			13	12.5
Less than 25MW			20	0.4	20	0.4
Many relocations			3	0.2	3	0.2
Inside of Protected area	37	8.3	7	0.3	44	8.6
Long list	34	10.2	35	3.4	69	13.6
Total	90	32.6	65	4.3	155	36.9

(Source: JICA Survey Team)

Potential sites that can be developed technically and economically are 90 sites and 32.6GW.

7.3.5 Evaluation of each potential site (Natural and Social Environment)

(1) Natural Environment

Evaluation at each candidate point for “Development in Protected Area”, “Loss of Forest”, “Loss of Wetland”, “Impact on Aquatic culture”, “Access road/dam site erosion” and “Impact on Landscape”, extracted as impediments to promoting hydraulic development, is as follows.

(a) Development in Protected Area

All protected areas (excluding biological corridors) in Bhutan are divided into the three zonings of “Core-Zone”, “Buffer-Zone” and “Multiple use-Zone” (as per interview with DoFPS).
However, as of May 2018, as zoning related to each protected area is undergoing legal preparations, it was not possible to obtain zoning maps. The zonation maps for Jigme Dorji N.P., Sakteng W.S., and Manas N.P. were obtained from DoFPS, while for the rest of the protected area the “unknown” category was applied and a score of 2 points given, similar to that of “Multiple use Zone”.
The definitions and designation purposes of protected areas (including biological corridors) and zones are described in Chapter 10, Tables 10-3 and 10-4.

Table 7-45 Relationship between Construction Site for Hydroelectric Components and Protected Areas

Project Code	Name		Component in Zoning site			Score
	Project	Protected area	Dam	Waterway	Powerhouse	
A-4	Kunzangling	Jigme Khesar SNR.	Unknown	Unknown	-	2
W-3	Dodennang	Jigme Dorji N.P.	Multiple	Multiple	-	2
W-7	Getsa	Jigme Dorji N.P.	Core	Buffer	-	0
W-8	Zangkhepa	Jigme Dorji N.P.	Multiple	Multiple	-	2
P-7	Puna Gom	Jigme Dorji N.P.	Multiple	-	-	2
P-15	Tamigdamchu	Jigme Dorji N.P.	Multiple	Multiple	-	2
P-17	Tseykha	Jigme Dorji N.P.	Multiple	-	-	2
P-18	Jarona	-	Corridor	Corridor	-	2
P-19	Dangchhu	-	Corridor	-	-	2
P-28	Kago-1	Jigme Singye N.P.	Unknown	Unknown	-	2
P-29	Kago	Jigme Singye N.P.	Unknown	-	-	2
P-30	Pinsa	Jigme Singye N.P.	Unknown	-	-	2
M-5	Bemji	Wangchuck C.P.	Unknown	Unknown	-	2
M-11	Wangdigang	Jigme Singye N.P.	Unknown	-	Unknown	2
M-14	Tingtibi	Jigme Singye N.P.	Unknown	-	-	2
M-15	Gomphu	Manas N.P.	Multiple	Multiple	-	2
M-19	Sermaling	Manas N.P.	Multiple	Multiple	-	2
C-3	Kurjey	Wangchuck C.P.	Unknown	Unknown	-	2
C-4	Chhutoe	Wangchuck C.P.	Unknown	Unknown	-	2
K-13	Minjey	-	Corridor	-	Corridor	2
K-19	Shongarchhu	Phrumsengla N.P.	Unknown	-	-	2
G-3	Tshaling	Bumdeling W.S.	Unknown	-	-	2
G-9	Gamrichu-3	Sakteng W.S	Core	Multiple	-	0
G-12	Rotpa	Bumdeling W.S.	Unknown	-	-	2
Ai-1	Aiechhu 2	-	-	Corridor	Corridor	2
Ai-3	Pelrithang	-	Corridor	Corridor	-	2
Ai-4	Ronggangchhu	-	-	Corridor	Corridor	2
J-1	Zangtheri	Sakteng W.S.	Multiple	Multiple	-	2
J-4	Jomotsangkha	Khaling W.S.	-	Unknown	Unknown	2

(Source: JICA Survey Team)

(b) Loss of Forest

Forest types in the project sites, where logging activities and submersion of forest due to backflow of water from dam are based on aerial photographs (Google Earth images) and forest vegetation maps

(Major land cover types in Bhutan MOAF 2014-). Interpretation is carried out by dividing the forest types into the six types of "Subtropical broad-leaved", "Warm broad-leaved", "Cool broad-leaved", "Chir Pine", "Blue Pine", and "Spruce" and the forest area assumed to be affected is rated as Small (1 ha or less), Medium (1 ha ~ 5 ha), and Large (over 5 ha).

Table 7-46 Construction of Hydroelectric Power Components and the Ratio of Forest Vegetation and Forest Loss

Project Code	Project	Type of Forest	Deforestation			Score
			L.	M.	S.	
A-4	Kunzangling	Cool broad-leaved		○		3
A-5	Tingma	Warm broad-leaved			○	3
A-8	Dorokha	Subtropical broad-leaved			○	3
A-9	Ngatse	Subtropical broad-leaved			○	3
A-10	Sanglum	Subtropical broad-leaved			○	3
A-11	Dojengkha	Warm broad-leaved			○	3
A-12	Dolepchen	Warm broad-leaved			○	3
W-3	Dodennang	Spruce			○	5
W-6	Chuzom	Cool broad-leaved		○		3
W-7	Getsa	Spruce			○	5
W-8	Zangkhepa	Spruce			○	5
W-13	Singkhar	Cool broad-leaved			○	4
W-14	Tsendu Goenpa	Cool broad-leaved			○	4
W-19	Pipingchhu	Subtropical broad-leaved			○	3
P-7	Puna Gom	Warm broad-leaved			○	3
P-15	Tamigdamchu	Warm broad-leaved			○	3
P-17	Tseykha	Warm broad-leaved			○	3
P-18	Jarona	Cool broad-leaved			○	4
P-19	Dangchhu	Warm broad-leaved			○	3
P-20	Rabuna	Warm broad-leaved			○	3
P-26	Thasa	Subtropical broad-leaved			○	3
P-28	Kago-1	Cool broad-leaved		○		3
P-29	Kago	Warm broad-leaved			○	3
P-30	Pinsa	Warm broad-leaved			○	3
P-33	Burichhu	Subtropical broad-leaved			○	3
P-34	Darachhu	Warm broad-leaved			○	3
P-35	Dagachhu-II	Warm broad-leaved			○	3
P-36	Pelichhu	Warm broad-leaved			○	3
P-38	Tashiding	Subtropical broad-leaved			○	3
M-5	Bemji	Blue Pine		○		4
M-6	Jongthang	Warm broad-leaved			○	3
M-11	Wangdigang	Subtropical broad-leaved			○	3
M-14	Tingtibi	Subtropical broad-leaved			○	3
M-15	Gomphu	Subtropical broad-leaved			○	3
M-17	Buli	Warm broad-leaved			○	3
M-18	Nyekhar	Subtropical broad-leaved			○	3
M-19	Sermaling	Subtropical broad-leaved			○	3
C-3	Kurjey	Spruce			○	5
C-4	Chhutoe	Spruce			○	5
C-7	Chamkharchhu-IV	Blue Pine		○		4
C-10	Chamkharchhu-II	Warm broad-leaved			○	3
K-13	Minjey	Warm broad-leaved			○	3
K-14	Unggarchhu	Warm broad-leaved			○	3
K-15	Phawan	Subtropical broad-leaved			○	3
K-19	Shongarchhu	Warm broad-leaved			○	3
G-3	Tshaling	Cool broad-leaved		○		3

Project Code	Project	Type of Forest	Deforestation			Score
			L.	M.	S.	
G-4	Ranya	Warm broad-leaved			○	3
G-6	Khamdang	Subtropical broad-leaved			○	3
G-7	Gongri	Subtropical broad-leaved			○	3
G-9	Gamrichhu-3	Cool broad-leaved		○		3
G-10	Gamrichhu-2	Warm broad-leaved			○	3
G-11	Gamrichhu-1	Subtropical broad-leaved			○	3
G-12	Rotpa	Warm broad-leaved			○	3
G-13	Sherichhu	Warm broad-leaved			○	3
G-14	Uzorong	Subtropical broad-leaved			○	3
G-16	Jerichhu	Subtropical broad-leaved			○	3
G-19	Nagor	Subtropical broad-leaved			○	3
G-20	Pramaling	Subtropical broad-leaved			○	3
G-22	Panbang	Subtropical broad-leaved			○	3
Ai-1	Aiechhu 2	Subtropical broad-leaved			○	3
Ai-3	Pelrithang	Subtropical broad-leaved			○	3
Ai-4	Ronggangchhu	Subtropical broad-leaved			○	3
J-1	Zangtheri	Warm broad-leaved			○	3
J-2	Jomori-I	Warm broad-leaved			○	3
J-3	Maenjiwoong	Subtropical broad-leaved			○	3
J-4	Jomotsangkha	Subtropical broad-leaved			○	3
N-1	NA Kangpara (G)	Cool broad-leaved		○		3
N-2	Lamai Gonpa	Cool broad-leaved		○		3
N-3	Paydung-Kangpar	Warm broad-leaved			○	3

(Source: JICA Survey Team)

(c) Loss of Wetland

In terms of wetland which are likely to be affected by the project, Ramsar Convention-registered wetlands and IBIS (Important Bird and Biodiversity Areas) wetlands designated by BLI (Birdlife International) are examined. There is concern about the influence on wetlands at the two sites in the table below.

Table 7-47 Construction of Hydroelectric Components and Influence on Important Wetlands

Project Code	Project	Type of Wetland		Affected Size (%)	Score
		Ramsar	IBAs		
K-13	Minjey	-	○	Less than 5%	4
G-3	Tshaling	○	-	More than 20%	0

(Source: JICA Survey Team)

(d) Impact on Aquatic culture

In order to ascertain the effect on migratory aquatic culture (mainly fish) upstream, the following items are checked for each water system (main stream, tributary) in dam construction planning: i) Presence or absence of existing dams in the downstream area, ii) Possibility of installation of fish way etc. based on dam height to be constructed. In terms of mitigation measures, in principle, when the dam height is 25 m or less, technical mitigation measures can be implemented.

Table 7-48 Influence of dam on aquatic culture and possibility of mitigation measures

Project Code	River Basin	Project	Class of River		Dam Down -stream	Possibility. of Mitigation	Score
			Main	Tributary			
A-4	Amochhu	Kunzangling	○	-	×	×	1
A-5	Amochhu	Tingma	○	-	×	×	1
A-8	Amochhu	Dorokha	○	-	×	×	1
A-9	Amochhu	Ngatse		○	×	○	3
A-10	Amochhu	Sanglum	○	-	×	×	1
A-11	Amochhu	Dojengkha	○	-	×	○	2
A-12	Amochhu	Dolepchen	○	-	×	○	2
W-3	Wangchhu	Dodennang	○		○	×	3
W-6	Wangchhu	Chuzom	○		○	×	3
W-7	Wangchhu	Getsa	○		○	×	3
W-8	Wangchhu	Zangkhepa	○		○	○	4
W-13	Wangchhu	Singkhar	○		○	×	3
W-14	Wangchhu	Tsendu Goenpa	○		○	○	4
W-19	Wangchhu	Pipingchhu	○		×	○	2
P-7	Punatsangchhu	Puna Gom	○		○	○	4
P-15	Punatsangchhu	Tamigdamchu	○		○	○	4
P-17	Punatsangchhu	Tseykha	○		○	○	4
P-18	Punatsangchhu	Jarona	○		○	○	4
P-19	Punatsangchhu	Dangchhu	○		○	○	4
P-20	Punatsangchhu	Rabuna	○		○	○	4
P-26	Punatsangchhu	Thasa	○		○	○	4
P-28	Punatsangchhu	Kago-1		○	○	○	5
P-29	Punatsangchhu	Kago		○	○	○	5
P-30	Punatsangchhu	Pinsa		○	○	○	5
P-33	Punatsangchhu	Burichhu		○	○	×	4
P-34	Punatsangchhu	Darachhu	○		○	○	4
P-35	Punatsangchhu	Dagachhu-II	○		○	○	4
P-36	Punatsangchhu	Pelichhu	○		○	○	4
P-38	Punatsangchhu	Tashiding	○		○	×	3
M-5	Mangdechhu	Bemji	○		○	×	3
M-6	Mangdechhu	Jongthang	○		○	×	3
M-11	Mangdechhu	Wangdigang	○		×	×	1
M-14	Mangdechhu	Tingtibi	○		×	×	1
M-15	Mangdechhu	Gomphu	○		×	×	1
M-17	Mangdechhu	Buli	○		×	×	1
M-18	Mangdechhu	Nyekhar	○		×	○	2
M-19	Mangdechhu	Sermaling	○		×	×	1
C-3	Chamkharchhu	Kurjey	○		○	×	3
C-4	Chamkharchhu	Chhutoe	○		○	○	4
C-7	Chamkharchhu	Chamkharchhu-IV	○		○	×	3
C-10	Chamkharchhu	Chamkharchhu-II	○		○	×	3
K-13	Kurichhu	Minjey	○		○	×	3
K-14	Kurichhu	Unggarchhu		○	○	○	5
K-15	Kurichhu	Phawan		○	○	×	4
K-19	Kurichhu	Shongarchhu		○	○	×	4
G-3	Drangmechhu	Tshaling	○		○	×	3
G-4	Drangmechhu	Ranya	○		○	×	3
G-6	Drangmechhu	Khamdang	○		○	○	4
G-7	Drangmechhu	Gongri	○		○	×	3
G-9	Drangmechhu	Gamrichhu-3	○		○	○	4
G-10	Drangmechhu	Gamrichhu-2	○		○	○	4
G-11	Drangmechhu	Gamrichhu-1	○		○	×	3

Project Code	River Basin	Project	Class of River		Dam Down -stream	Possibility. of Mitigation	Score
			Main	Tributary			
G-12	Drangmechhu	Rotpa		○	○	○	5
G-13	Drangmechhu	Sherichhu		○	○	○	5
G-14	Drangmechhu	Uzorong	○		○	×	3
G-16	Drangmechhu	Jerichhu		○	○	×	4
G-19	Drangmechhu	Nagor	○		×	×	1
G-20	Drangmechhu	Pramaling		○	×	○	3
G-22	Drangmechhu	Panbang	○		×	×	1
Ai-1	Aiechhu	Aiechhu 2	○		×	○	2
Ai-3	Aiechhu	Pelrithang	○		×	×	1
Ai-4	Aiechhu	Ronggangchhu	○		×	○	2
J-1	Jomori	Zangtheri	○		×	○	2
J-2	Jomori	Jomori-I	○		×	○	2
J-3	Jomori	Maenjiwoong	○		×	○	2
J-4	Jomori	Jomotsangkha	○		×	○	2
N-1	Nyera	NA Kangpara (G)	○		○	×	3
N-2	Nyera	Lamai Gonpa	○		○	○	4
N-3	Nyera	Paydung-Kangpar	○		○	×	3

(Source: JICA Survey Team)

(e) Access road/dam site erosion

The possibility of soil erosion due to the project development and its mitigation measures (including construction of road) is checked by using aerial photographs (Google Earth images).
Since any project candidate site is covered with rock and fragile ground, mitigation measures via greening/planting of natural vegetation etc. are difficult. For this reason, all sites receive a score of 3 in the evaluation.

(f) Impact on Landscape

The distance from the project site to the nearest substation was calculated, where the transmission line is laid down and ascertained the influence on the landscape in terms of its distance. The influence is evaluated by dividing the distance of the transmission lines into the five stages of 100 km or more, 50 km to 100 km, 20 km to 50 km, 10 km to 20 km, and 10 km or less.

Table 7-49 Transmission line distance and impact on landscape

Project Code	Project	Distance (km)	Score	Project Code	Project	Distance (km)	Score
A-4	Kunzangling	59.0	2	C-3	Kurjey	17.3	4
A-5	Tingma	45.2	3	C-4	Chhutoe	22.1	3
A-8	Dorokha	27.4	3	C-7	Chamkharchhu-IV	46.3	3
A-9	Ngatse	25.8	3	C-10	Chamkharchhu-II	29.4	3
A-10	Sanglum	16.3	4	K-13	Minjey	82.4	2
A-11	Dojengkha	22.0	3	K-14	Unggarchhu	14.2	4
A-12	Dolepchen	15.2	4	K-15	Phawan	68.8	2
W-3	Dodennang	21.2	3	K-19	Shongarchhu	15.1	4
W-6	Chuzom	34.4	3	G-3	Tshaling	27.4	3
W-7	Getsa	97.0	2	G-4	Ranya	17.9	4
W-8	Zangkhepa	81.0	2	G-6	Khamdang	1.0	5
W-13	Singkhar	41.3	3	G-7	Gongri	69.0	2
W-14	Tsendu Goenpa	24.2	3	G-9	Gamrichhu-3	24.1	3
W-19	Pipingchhu	0.6	5	G-10	Gamrichhu-2	15.8	4
P-7	Puna Gom	38.8	3	G-11	Gamrichhu-1	12.7	4
P-15	Tamigdamchu	52.7	2	G-12	Rotpa	22.6	3

Project Code	Project	Distance (km)	Score	Project Code	Project	Distance (km)	Score
P-17	Tseykha	38.2	3	G-13	Sherichhu	17.2	4
P-18	Jarona	42.8	3	G-14	Uzorong	44.6	3
P-19	Dangchhu	28.7	3	G-16	Jerichhu	11.3	4
P-20	Rabuna	22.2	3	G-19	Nagor	23.0	3
P-26	Thasa	2.3	5	G-20	Pramaling	14.2	4
P-28	Kago-1	15.8	4	G-22	Panbang	27.8	3
P-29	Kago	9.6	5	Ai-1	Aiechhu 2	13.2	4
P-30	Pinsa	5.9	5	Ai-3	Pelrithang	13.1	4
P-33	Burichhu	0.4	5	Ai-4	Ronggangchhu	15.4	4
P-34	Darachhu	17.5	4	J-1	Zangtheri	54.0	2
P-35	Dagachhu-II	9.8	5	J-2	Jomori-I	48.0	3
P-36	Pelichhu	16.4	4	J-3	Maenjiwoong	51.8	2
P-38	Tashiding	9.1	5	J-4	Jomotsangkha	61.8	2
M-5	Bemji	39.5	3	N-1	NA Kangpara (G)	57.6	2
M-6	Jongthang	22.7	3	N-2	Lamai Gonpa	43.9	3
M-11	Wangdigang	4.4	5	N-3	Paydung-Kangpar	28.9	3
M-14	Tingtibi	2.6	5				
M-15	Gomphu	20.8	3				
M-17	Buli	10.4	5				
M-18	Nyekhar	6.1	5				
M-19	Sermaling	39.2	3				

(Source: JICA Survey Team)

(2) Social Environment

In the items for impact on the social environment, the factors that impede the development of hydropower were evaluated from the viewpoint of the social environment, based on four evaluation items: land acquisition, resettlement & asset loss, living and livelihood means, and cultural heritage. In the first screening, per the evaluation policy indicated in 7.2.3, it is evaluated from sub-criteria which can be judged to some extent through desk evaluation and the score is reduced if there are concerns about negative impacts. Evaluation is conducted within a range that can be judged based on the desk information and it is considered that there will be social environment factors which would be revealed upon the site survey. Therefore, it cannot be concluded that there are no concerns regarding social environment impacts even at sites with no points deducted at the time of the first MCA screening.

In each candidate project site, information should be collected during site surveys regarding whether or not the site is an area where people are economically vulnerable or depend on traditional resources, on what points and to what extent the project may affect the living and livelihood means of such people. Then, its results should then be considered in the secondary screening. If there is any candidate site where the project can have serious negative impacts on such people, it will be possibly reconsidered and exclude them from the candidate sites.

(a) Land Acquisition and Resettlement

The number of project sites which may include residential and agricultural areas is 28 out of 69 sites, as shown in Table 7-50. Among such sites, 17 have impacts due to the reservoir and 11 have impacts due to the power station and its surroundings. Land size of the power station area is unknown, so such cases are evaluated as 3 points.

In addition, the number of houses and facilities which may be impacted by the project is evaluated based on the Google Earth images. As for the power station and its surrounding area, if there are no houses or facilities, such sites are evaluated as 5 points; if houses or facilities are there apparently but a number of them are unconfirmed, such sites are evaluated as 3 points.

Table 7-50 Impacts on Land Acquisition and Resettlement

Project Code	Project name	Private land acquisition (Acre)	Score	No. of houses/facilities	Score
A-10	Sanglum	73.8	**3**	17	**2**
W-6	Chuzom	14.8	**4**	220	**1**
W-13	Singkhar	P/S	**3**	3	**3**
W-14	Tsendu Goenpa	P/S	**3**	0	**5**
P-19	Dangchhu	P/S	**3**	0	**5**
P-35	Dagachhu-II	P/S	**3**	-	**3**
P-36	Pelichhu	P/S	**3**	-	**3**
M-6	Jongthang	17.0	**4**	2	**3**
M-11	Wangdigang	9.6	**4**	3	**3**
M-15	Gomphu	277.0	**1**	43	**2**
M-17	Buli	P/S	**3**	-	**3**
M-19	Sermaling	136.0	**3**	1	**3**
C-3	Kurjey	42.5	**3**	17	**2**
C-7	Chamkharchhu-IV	38.1	**3**	-	**3**
C-10	Chamkharchhu-II	P/S	**3**	-	**3**
K-13	Minjey	86.0	**3**	31	**2**
K-15	Unggarchhu	64.5	**3**	-	**3**
G-3	Tshaling	376.0	**1**	37	**2**
G-4	Ranya	47.4	**3**	2	**3**
G-6	Khamdang	P/S	**3**	0	**5**
G-7	Gongri	108.3	**3**	6	**3**
G-10	Gamrichu-2	P/S	**3**	-	**3**
G-11	Gamrichu-1	105.3	**3**	73	**2**
G-12	Rotpa	P/S	**3**	0	**5**
G-14	Uzorong	110.0	**3**	28	**2**
G-22	Panbang	700.1	**1**	45	**2**
Ai-3	Pelrithang	P/S	**3**	3	**3**
N-3	Paydung-Kangpar	2.4	**4**	2	**3**

Note: ☐ : sites affected by the reservoir
P/S = there may be private areas within the power station site.
Private land acquisition is evaluated after calculating in acres, the unit used by NLC, converting by dividing by 0.4, from the result calculated in hectares.
No. of houses/facilities includes all facilities other than residences, because it was difficult to judge precisely houses and other cases upon checking in Google Earth images in the first MCA screening.

(Source: JICA Survey Team)

(b) Living and Livelihood Means

In terms of living and livelihood means, as indicated in Table 7-51 the number of project sites which may have impacts on any of agricultural products, forest products, fishing, or irrigation is 30 out of 69. Among all of these, there were no impacts on traditional communities which have official permission for fishing, the area which falls into the definition of the location where economically vulnerable people and people who depend on traditional resources. 10 project sites may have impacts on the irrigation system.

Table 7-51 Impacts on Living and Livelihood Means

Project Code	Project name	Living and livelihood means					
		1. Damage to crops	2. Forest products	3. Timber products	4. Fishing activities	5. Irrigation	**Score**
A-10	Sanglum	○					**3**
W-6	Chuzom	○				○	**1**

Project Code	Project name	Living and livelihood means					
		1. Damage to crops	2. Forest products	3. Timber products	4. Fishing activities	5. Irrigation	**Score**
W-13	Singkhar	○					**3**
W-14	Tsendu Goenpa	○					**3**
P-17	Tseykha					○	**1**
P-19	Dangchhu	○				○	**1**
P-20	Rabuna					○	**1**
P-35	Dagachhu-II	○					**3**
P-36	Pelichhu	○					**3**
M-6	Jongthang	○					**3**
M-11	Wangdigang	○					**3**
M-15	Gomphu	○				○	**1**
M-17	Buli	○					**3**
M-19	Sermaling	○				○	**1**
C-3	Kurjey	○					**3**
C-7	Chamkharchhu-IV	○					**3**
C-10	Chamkharchhu-II	○					**3**
K-13	Minjey	○					**3**
K-15	Phawan	○					**3**
K-19	Shongarchhu	○					**3**
G-3	Tshaling	○				○	**1**
G-4	Ranya	○					**3**
G-7	Gongri	○	○				**3**
G-10	Gamrichu-2	○				○	**1**
G-11	Gamrichu-1	○					**3**
G-12	Sherichhu-2	○					**3**
G-14	Uzorong	○	○	○		○	**1**
G-22	Panbang	○				○	**1**
Ai-3	Pelrithang	○					**3**
N-3	Paydung-Kangpar	○					**3**

○＝Negative impacts can occur.

(Source: JICA Survey Team)

(c) Cultural Heritage

The number of project sites which may have impacts on one or more cultural heritage sites is 19 out of 69 sites, as shown in Table 7-52. Items of cultural heritage are Buddhism-related facilities such as Chorten (pagoda), Lhakang (temple), and Prayer-wheels.

Table 7-52 Impacts on Cultural Heritage Sites

Project Code	Project name	No. of affected heritage sites	Heritage Sites	Score
A-10	Sanglum	2	Bailey Bridge and Chorten beside Toorsa river	**1**
W-6	Chuzom	27	4 Lhakhang, 3 Prayer-wheels, 2 Dangrim, 20 Chorten	**1**
W-13	Singkhar	1	Chorten	**1**
W-14	Tsendu Goenpa	1	Chorten	**1**
P-36	Pelichhu	8	7 Chorten, Lhakhang	**1**
M-15	Gomphu	1	Chorten	**1**
M-19	Sermaling	3	Pantang Lhakhang, 2 Chorten	**1**

Project Code	Project name	No. of affected heritage sites	Heritage Sites	Score
C-3	Kurjey	2	Chorten , Prayer-wheel	**1**
K-13	Minjey	3	3 Chorten, Nye, Prayer-wheel	**1**
K-15	Phawan	1	Chorten	**1**
G-3	Tshaling	9	4 Prayer-wheels, 2 Lhakhang, 2 Chorten, Dangrim	**1**
G-4	Ranya	6	4 Chorten, 2 Prayer-wheels	**1**
G-7	Gongri	2	Gomphu kora Lhakhang, Chorten	**1**
G-9	Gamrichu-3	1	Dangrim	**1**
G-10	Gamrichu-2	3	Ranjung Lhakhang, Chorten, Prayer-wheel	**1**
G-11	Gamrichu-1	3	2 Prayer-wheels, Chorten	**1**
G-12	Rotpa	1	Chorten	**1**
G-22	Panbang	2	Phuntsho choling Lhakhang, Chorten	**1**
J-2	Jomori-I	1	Chorten	**1**

(Source: JICA Survey Team)

(3) Social Development

The Social Development Criteria "Improved Access to Socio-economic Benefits" and "Employment and Potential for Income Opportunities" are positive impact evaluation items. "Improved Access to Socio-economic Benefits" is for communities surrounding the project site without national or Dzongkhag roads nearby. The number of such sites is 24. Placing a higher evaluation score on poor Dzongkhags which have a poverty rate of more than 10%, there are 21 such sites.

Table 7-53 "Improved Access to Socio-economic Benefits" and "Employment and Potential for Income Opportunities"

Project Code	Project name	Improved Access to Socio-economic Benefits		Employment and potential for income opportunities			
		Positive impacts on road access and network	Score	Dzongkhag	Dzongkhag Poverty rate	Potential for increased sales of local products	Score
A-4	Kunzangling		2	Haa	1.1%		1
A-5	Tingma		2	Haa	1.1%		1
A-8	Dorokha	○	5	Haa	1.1%	○	3
A-9	Ngatse		2	Samtse	8.5%		1
A-10	Sanglum	○	5	Samtse	8.5%	○	3
A-11	Dojengkha	○	5	Chhukha	2.2%	○	3
A-12	Dolepchen	○	5	Chhukha	2.2%	○	3
W-3	Dodennang		2	Thimphu	0.3%		1
W-6	Chuzom		2	Paro	0.2%		1
W-7	Getsa	○	5	Paro	0.2%	○	3
W-8	Zangkhepa	○	5	Paro	0.2%	○	3
W-13	Singkhar		2	Haa	1.1%		1
W-14	Tsendu Goenpa		2	Paro	0.2%		1
W-19	Pipingchhu	○	5	Chhukha	2.2%	○	3
P-7	Puna Gom		2	Punakha	1.8%		1
P-15	Tamigdamchu	○	5	Punakha	1.8%	○	3
P-17	Tseykha	○	5	Punakha	1.8%	○	3
P-18	Jarona		2	Wanduphodrang	3.0%		1
P-19	Dangchhu		2	Wanduphodrang	3.0%		1
P-20	Rabuna		2	Wanduphodrang	3.0%		1
P-26	Thasa		2	Wanduphodrang	3.0%		1
P-28	Kago-1	○	5	Wanduphodrang	3.0%	○	3
P-29	Kago		2	Wanduphodrang	3.0%		1
P-30	Pinsa		2	Wanduphodrang	3.0%		1
P-33	Burichhu	○	5	Tsirang	2.6%	○	3
P-34	Darachhu		2	Dagana	23.7%		5

Project Code	Project name	Improved Access to Socio-economic Benefits		Employment and potential for income opportunities			
		Positive impacts on road access and network	Score	Dzongkhag	Dzongkhag Poverty rate	Potential for increased sales of local products	Score
P-35	Dagachhu-II		2	Dagana	23.7%		5
P-36	Pelichhu		2	Dagana	23.7%		5
P-38	Tashiding		2	Dagana	23.7%		5
M-5	Bemji		2	Trongsa	9.6%		5
M-6	Jongthang	○	5	Trongsa	9.6%	○	5
M-11	Wangdigang		2	Trongsa	9.6%		5
M-14	Tingtibi		2	Zhemgang	16.3%		5
M-15	Gomphu		2	Zhemgang	16.3%		5
M-17	Buli		2	Zhemgang	16.3%		5
M-18	Nyekhar		2	Zhemgang	16.3%		5
M-19	Sermaling	○	5	Zhemgang	16.3%	○	5
C-3	Kurjey	○	5	Bhumtang	1.7%	○	3
C-4	Chhutoe		2	Bhumtang	1.7%		1
C-7	Chamkharchhu-IV		2	Bhumtang	1.7%		1
C-10	Chamkharchhu-II	○	5	Zhemgang	16.3%	○	5
K-13	Minjey		2	Lhuentse	5.2%		1
K-14	Unggarchhu		2	Lhuentse	5.2%		1
K-15	Phawan		2	Lhuentse	5.2%		1
K-19	Shongarchhu		2	Mongar	14.0%		5
G-3	Tshaling	○	5	Tashi Yantse	8.7%	○	3
G-4	Ranya		2	Tashi Yantse	8.7%		1
G-6	Khamdang		2	Tashi Yantse	8.7%		1
G-7	Gongri		2	Trashigang	7.8%		1
G-9	Gamrichhu-3		2	Trashigang	7.8%		1
G-10	Gamrichhu-2		2	Trashigang	7.8%		1
G-11	Gamrichhu-1	○	5	Trashigang	7.8%	○	3
G-12	Rotpa		2	Mongar	14.0%		5
G-13	Sherichhu		2	Mongar	14.0%		5
G-14	Uzorong		2	Mongar	14.0%		5
G-16	Jerichhu		2	Pemagatsel	10.0%		5
G-19	Nagor		2	Mongar	14.0%		5
G-20	Pramaling		2	Zhemgang	16.3%		5
G-22	Panbang	○	5	Zhemgang	16.3%	○	5
Ai-1	Aiechhu 2		2	Sarpang	8.4%		1
Ai-3	Pelrithang	○	5	Sarpang	8.4%	○	3
Ai-4	Ronggangchhu		2	Sarpang	8.4%		1
J-1	Zangtheri		2	Trashigang	7.8%		1
J-2	Jomori-I		2	Samdrup jongkhar	4.5%		1
J-3	Maenjiwoong	○	5	Samdrup jongkhar	4.5%	○	3
J-4	Jomotsangkha	○	5	Samdrup jongkhar	4.5%	○	3
N-1	NA Kangpara (G)	○	5	Trashigang	7.8%	○	3
N-2	Lamai Gonpa	○	5	Trashigang	7.8%	○	3
N-3	Paydung-Kangpar	○	5	Trashigang	7.8%	○	3

○: Project site which may have positive impacts. If the household poverty rate reaches 10% by rounding up, it is evaluated as 10%. If the project site covers two Dzongkhags, the higher household poverty rate of the two is evaluated.

(Source: JICA Survey Team)

7.3.6 Comprehensive Evaluation

A comprehensive evaluation that summarizes the above results is shown below.

Table 7-54 Comprehensive Evaluation (Base Case)

Project Code	Name of Project	Installed Capacity (MW)	Annual Energy (GWh)	Technical	Economic	Impact on Social environ-ment	Impact on Natural environ-ment	Social develop-ment	Total	Rank
A-4	Kunzangling	897	3,816	15.3	20.0	20.0	10.6	6.0	71.9	9
A-5	Tingma	567	2,413	15.0	20.0	20.0	15.6	6.0	76.6	6
A-8	Dorokha	573	2,439	15.4	19.2	20.0	15.6	16.0	86.2	1
A-9	Ngatse	44	170	14.5	4.0	20.0	16.0	6.0	60.5	38
A-10	Sanglum	178	779	13.5	4.0	8.6	15.8	16.0	57.9	42
A-11	Dojengkha	25	105	12.9	4.0	20.0	15.8	16.0	68.7	17
A-12	Dolepchen	41	172	11.9	4.0	20.0	16.0	16.0	67.9	22
W-3	Dodennang	61	275	14.1	4.0	20.0	14.0	6.0	58.1	41
W-6	Chuzom	152	645	15.5	7.6	7.0	16.0	6.0	52.1	60
W-7	Getsa	37	152	12.9	4.0	20.0	10.6	16.0	63.5	36
W-8	Zangkhepa	73	305	13.4	8.0	20.0	14.0	16.0	71.4	10
W-13	Singkhar	38	165	14.0	4.0	9.6	17.4	6.0	51.0	65
W-14	Tsendu Goenpa	75	321	14.8	4.0	11.6	17.6	6.0	54.0	56
W-19	Pipingchhu	100	424	13.3	8.0	20.0	16.2	16.0	73.5	8
P-7	Puna Gom	127	543	16.1	4.0	20.0	11.4	6.0	57.5	46
P-15	Tamigdamchu	188	805	14.5	6.4	20.0	11.2	16.0	68.1	20
P-17	Tseykha	170	726	16.2	4.0	16.8	11.4	16.0	64.4	34
P-18	Jarona	43	179	11.6	4.0	20.0	12.8	6.0	54.4	55
P-19	Dangchhu	101	432	14.9	10.0	14.8	11.4	6.0	57.1	48
P-20	Rabuna	33	140	13.8	4.0	16.8	16.2	6.0	56.8	50
P-26	Thasa	680	3,277	15.0	16.8	20.0	16.6	6.0	74.4	7
P-28	Kago-1	102	436	14.6	20.0	20.0	11.8	16.0	82.4	3
P-29	Kago	58	249	13.5	4.4	20.0	12.0	6.0	55.9	54
P-30	Pinsa	151	644	13.2	20.0	20.0	12.0	6.0	71.2	11
P-33	Burichhu	40	170	14.1	4.0	20.0	16.6	16.0	70.7	13
P-34	Darachhu	61	259	13.6	5.2	20.0	16.4	14.0	69.2	16
P-35	Dagachhu-II	94	402	14.0	6.8	14.4	16.6	14.0	65.8	32
P-36	Pelichhu	52	222	13.7	4.0	9.6	16.4	14.0	57.7	45
P-38	Tashiding	81	347	12.0	5.6	20.0	16.4	14.0	68.0	21
M-5	Bemji	333	1,425	15.2	14.8	20.0	12.6	14.0	76.6	5
M-6	Jongthang	170	726	15.6	4.0	15.4	16.0	20.0	71.0	12
M-11	Wangdigang	446	1,907	14.5	12.0	15.4	11.2	14.0	67.1	24
M-14	Tingtibi	181	770	15.1	4.0	20.0	11.2	14.0	64.3	35
M-15	Gomphu	488	2,076	12.5	5.6	5.0	10.8	14.0	47.9	67
M-17	Buli	67	262	15.0	13.6	14.4	12.6	14.0	69.6	14
M-18	Nyekhar	43	183	15.2	4.0	20.0	13.0	14.0	66.2	30
M-19	Sermaling	496	2,171	13.7	7.2	8.0	10.8	20.0	59.7	40
C-3	Kurjey	89	381	14.5	4.0	8.6	14.2	16.0	57.3	47
C-4	Chhutoe	29	126	13.6	4.0	20.0	14.2	6.0	57.8	44
C-7	Chamkharchhu-IV	451	1,928	12.9	18.8	14.4	17.4	6.0	69.5	15
C-10	Chamkharchhu-II	456	1,936	14.7	20.0	14.4	16.0	20.0	85.1	2
K-13	Minjey	490	2,091	12.0	4.0	8.6	10.6	6.0	41.2	69
K-14	Unggarchhu	28	119	13.5	4.0	20.0	13.4	6.0	56.9	49
K-15	Phawan	502	2,185	14.5	4.0	9.6	12.8	6.0	46.9	68
K-19	Shongarchhu	32	138	12.1	4.0	18.4	11.6	14.0	60.1	39
G-3	Tshaling	204	876	14.4	4.0	5.0	9.2	16.0	48.6	66
G-4	Ranya	162	696	15.5	4.0	9.6	16.2	6.0	51.3	64
G-6	Khamdang	494	2,109	16.1	11.2	18.0	16.6	6.0	67.9	23
G-7	Gongri	590	2,515	15.6	4.8	9.6	15.8	6.0	51.8	61
G-9	Gamrichhu-3	123	524	12.2	14.4	15.2	8.2	6.0	56.0	53
G-10	Gamrichhu-2	104	446	13.5	9.2	8.0	16.4	6.0	53.1	59
G-11	Gamrichhu-1	108	462	13.0	4.0	8.6	16.2	16.0	57.8	43
G-12	Rotpa	40	172	13.9	5.2	11.6	11.6	14.0	56.3	52

Project Code	Name of Project	Installed Capacity (MW)	Annual Energy (GWh)	Technical	Economic	Impact on Social environ-ment	Impact on Natural environ-ment	Social develop-ment	Total	Rank
G-13	Sherichhu	53	227	12.2	4.0	20.0	16.6	14.0	66.8	26
G-14	Uzorong	763	3,257	13.1	12.0	11.8	16.0	14.0	66.9	25
G-16	Jerichhu	40	164	13.0	5.2	20.0	16.4	14.0	68.6	18
G-19	Nagor	53	252	11.2	5.6	20.0	15.6	14.0	66.4	29
G-20	Pramaling	29	123	12.3	4.0	20.0	16.2	14.0	66.5	28
G-22	Panbang	1,100	4,640	13.2	14.4	5.0	15.6	20.0	68.2	19
Ai-1	Aiechhu 2	34	146	12.4	4.0	20.0	11.2	6.0	53.6	58
Ai-3	Pelrithang	30	126	10.9	4.0	14.4	11.0	16.0	56.3	51
Ai-4	Ronggangchhu	51	216	10.5	4.0	20.0	11.2	6.0	51.7	62
J-1	Zangtheri	29	121	10.5	4.0	20.0	10.8	6.0	51.3	63
J-2	Jomori-I	82	349	12.4	7.6	15.2	12.6	6.0	53.8	57
J-3	Maenjiwoong	70	296	13.5	4.0	20.0	12.4	16.0	65.9	31
J-4	Jomotsangkha	68	291	12.7	4.0	20.0	10.8	16.0	63.5	37
N-1	NA Kangpara (G)	71	304	12.7	12.4	20.0	15.8	16.0	76.9	4
N-2	Lamai Gonpa	37	156	10.4	4.0	20.0	16.2	16.0	66.6	27
N-3	Paydung-Kangpar	85	364	13.1	4.0	15.4	16.0	16.0	64.5	33

(Source: JICA Survey Team)

The results of the Base Case are rearranged in descending order of evaluation scores and the results of re-evaluation by changing the weights of economic efficiency and environment are shown below.

Table 7-55 Overall Rank

Rank	Base Case (Technical 40%, Environment 40%)			Emphasizing Economy Case (Technical 60%, Environment 20%)			Emphasizing Environment Case (Technical 20%, Environment 60%)		
	Project Code	Name of Project	Total	Project Code	Name of Project	Total	Project Code	Name of Project	Total
1	A-8	Dorokha	86.2	C-10	Chamkharchhu-II	87.3	A-8	Dorokha	86.7
2	C-10	Chamkharchhu-II	85.1	A-8	Dorokha	85.7	C-10	Chamkharchhu-II	83.0
3	P-28	Kago-1	82.4	P-28	Kago-1	83.8	N-1	NA Kangpara (G)	82.2
4	N-1	NA Kangpara (G)	76.9	A-5	Tingma	76.3	P-28	Kago-1	81.0
5	M-5	Bemji	76.6	M-5	Bemji	75.4	W-19	Pipingchhu	81.0
6	A-5	Tingma	76.6	A-4	Kunzangling	74.2	P-33	Burichhu	79.9
7	P-26	Thasa	74.4	P-26	Thasa	72.1	A-11	Dojengkha	78.1
8	W-19	Pipingchhu	73.5	P-30	Pinsa	71.8	P-34	Darachhu	78.0
9	A-4	Kunzangling	71.9	G-22	Panbang	71.7	A-12	Dolepchen	77.9
10	W-8	Zangkhepa	71.4	N-1	NA Kangpara (G)	71.5	M-5	Bemji	77.9
11	P-30	Pinsa	71.2	M-17	Buli	70.3	W-8	Zangkhepa	77.7
12	M-6	Jongthang	71.0	C-7	Chamkharchhu-IV	69.4	G-16	Jerichhu	77.7
13	P-33	Burichhu	70.7	M-11	Wangdigang	67.1	N-2	Lamai Gonpa	77.5
14	M-17	Buli	69.6	W-19	Pipingchhu	66.1	P-38	Tashiding	77.4
15	C-7	Chamkharchhu-IV	69.5	G-14	Uzorong	65.5	G-13	Sherichhu	77.0
16	P-34	Darachhu	69.2	W-8	Zangkhepa	65.1	A-5	Tingma	76.9
17	A-11	Dojengkha	68.7	M-6	Jongthang	65.1	M-6	Jongthang	76.9
18	G-16	Jerichhu	68.6	G-6	Khamdang	64.2	P-26	Thasa	76.8
19	G-22	Panbang	68.2	P-15	Tamigdamchu	63.0	G-20	Pramaling	76.4
20	P-15	Tamigdamchu	68.1	P-33	Burichhu	61.4	G-19	Nagor	75.8
21	P-38	Tashiding	68.0	P-35	Dagachhu-II	60.8	J-3	Maenjiwoong	73.4
22	A-12	Dolepchen	67.9	M-19	Sermaling	60.7	P-15	Tamigdamchu	73.3
23	G-6	Khamdang	67.9	P-34	Darachhu	60.4	M-18	Nyekhar	73.1
24	M-11	Wangdigang	67.1	P-17	Tseykha	60.4	N-3	Paydung-Kangpar	71.7
25	G-14	Uzorong	66.9	G-16	Jerichhu	59.4	G-6	Khamdang	71.5
26	G-13	Sherichhu	66.8	M-18	Nyekhar	59.2	P-35	Dagachhu-II	70.9
27	N-2	Lamai Gonpa	66.6	A-11	Dojengkha	59.2	P-30	Pinsa	70.6
28	G-20	Pramaling	66.5	P-38	Tashiding	58.6	J-4	Jomotsangkha	70.5
29	G-19	Nagor	66.4	J-3	Maenjiwoong	58.5	M-14	Tingtibi	70.4
30	M-18	Nyekhar	66.2	M-14	Tingtibi	58.3	W-7	Getsa	70.4
31	J-3	Maenjiwoong	65.9	A-12	Dolepchen	57.8	C-7	Chamkharchhu-IV	69.5
32	P-35	Dagachhu-II	65.8	G-9	Gamrichhu-3	57.6	A-4	Kunzangling	69.5

Rank	Base Case (Technical 40%, Environment 40%)			Emphasizing Economy Case (Technical 60%, Environment 20%)			Emphasizing Environment Case (Technical 20%, Environment 60%)		
	Project Code	Name of Project	Total	Project Code	Name of Project	Total	Project Code	Name of Project	Total
33	N-3	Paydung-Kangpar	64.5	N-3	Paydung-Kangpar	57.4	A-9	Ngatse	69.2
34	P-17	Tseykha	64.4	G-19	Nagor	57.0	M-17	Buli	68.8
35	M-14	Tingtibi	64.3	W-7	Getsa	56.7	P-17	Tseykha	68.4
36	W-7	Getsa	63.5	G-13	Sherichhu	56.5	G-14	Uzorong	68.2
37	J-4	Jomotsangkha	63.5	G-20	Pramaling	56.5	M-11	Wangdigang	67.2
38	A-9	Ngatse	60.5	P-19	Dangchhu	56.5	K-19	Shongarchhu	67.0
39	K-19	Shongarchhu	60.1	J-4	Jomotsangkha	56.4	C-4	Chhutoe	66.1
40	M-19	Sermaling	59.7	N-2	Lamai Gonpa	55.6	W-3	Dodennang	66.1
41	W-3	Dodennang	58.1	C-3	Kurjey	55.1	K-14	Unggarchhu	64.8
42	A-10	Sanglum	57.9	A-10	Sanglum	54.5	G-22	Panbang	64.7
43	G-11	Gamrichhu-1	57.8	G-12	Rotpa	54.3	P-20	Rabuna	64.4
44	C-4	Chhutoe	57.8	G-11	Gamrichhu-1	53.9	P-7	Puna Gom	63.2
45	P-36	Pelichhu	57.7	P-36	Pelichhu	53.6	P-18	Jarona	63.0
46	P-7	Puna Gom	57.5	K-19	Shongarchhu	53.1	P-29	Kago	63.0
47	C-3	Kurjey	57.3	G-10	Gamrichhu-2	52.3	P-36	Pelichhu	61.9
48	P-19	Dangchhu	57.1	W-6	Chuzom	52.2	G-11	Gamrichhu-1	61.7
49	K-14	Unggarchhu	56.9	P-7	Puna Gom	51.9	Ai-3	Pelrithang	61.6
50	P-20	Rabuna	56.8	A-9	Ngatse	51.7	A-10	Sanglum	61.4
51	Ai-3	Pelrithang	56.3	Ai-3	Pelrithang	51.1	Ai-1	Aiechhu 2	61.0
52	G-12	Rotpa	56.3	G-3	Tshaling	50.8	Ai-4	Ronggangchhu	60.0
53	G-9	Gamrichhu-3	56.0	W-3	Dodennang	50.2	J-1	Zangtheri	59.5
54	P-29	Kago	55.9	J-2	Jomori-I	49.9	C-3	Kurjey	59.4
55	P-18	Jarona	54.4	C-4	Chhutoe	49.5	W-14	Tsendu Goenpa	59.2
56	W-14	Tsendu Goenpa	54.0	G-7	Gongri	49.4	M-19	Sermaling	58.6
57	J-2	Jomori-I	53.8	P-20	Rabuna	49.2	G-12	Rotpa	58.4
58	Ai-1	Aiechhu 2	53.6	M-15	Gomphu	49.1	P-19	Dangchhu	57.8
59	G-10	Gamrichhu-2	53.1	K-14	Unggarchhu	48.9	J-2	Jomori-I	57.7
60	W-6	Chuzom	52.1	P-29	Kago	48.9	W-13	Singkhar	55.5
61	G-7	Gongri	51.8	W-14	Tsendu Goenpa	48.7	G-4	Ranya	54.4
62	Ai-4	Ronggangchhu	51.7	G-4	Ranya	48.1	G-9	Gamrichhu-3	54.4
63	J-1	Zangtheri	51.3	W-13	Singkhar	46.5	G-7	Gongri	54.3
64	G-4	Ranya	51.3	Ai-1	Aiechhu 2	46.2	G-10	Gamrichhu-2	54.0
65	W-13	Singkhar	51.0	P-18	Jarona	45.8	W-6	Chuzom	52.1
66	G-3	Tshaling	48.6	K-15	Phawan	44.9	K-15	Phawan	48.8
67	M-15	Gomphu	47.9	Ai-4	Ronggangchhu	43.3	M-15	Gomphu	46.8
68	K-15	Phawan	46.9	J-1	Zangtheri	43.2	G-3	Tshaling	46.5
69	K-13	Minjey	41.2	K-13	Minjey	39.6	K-13	Minjey	42.8

(Source: JICA Survey Team)

7.3.7 Result of the 1st Screening

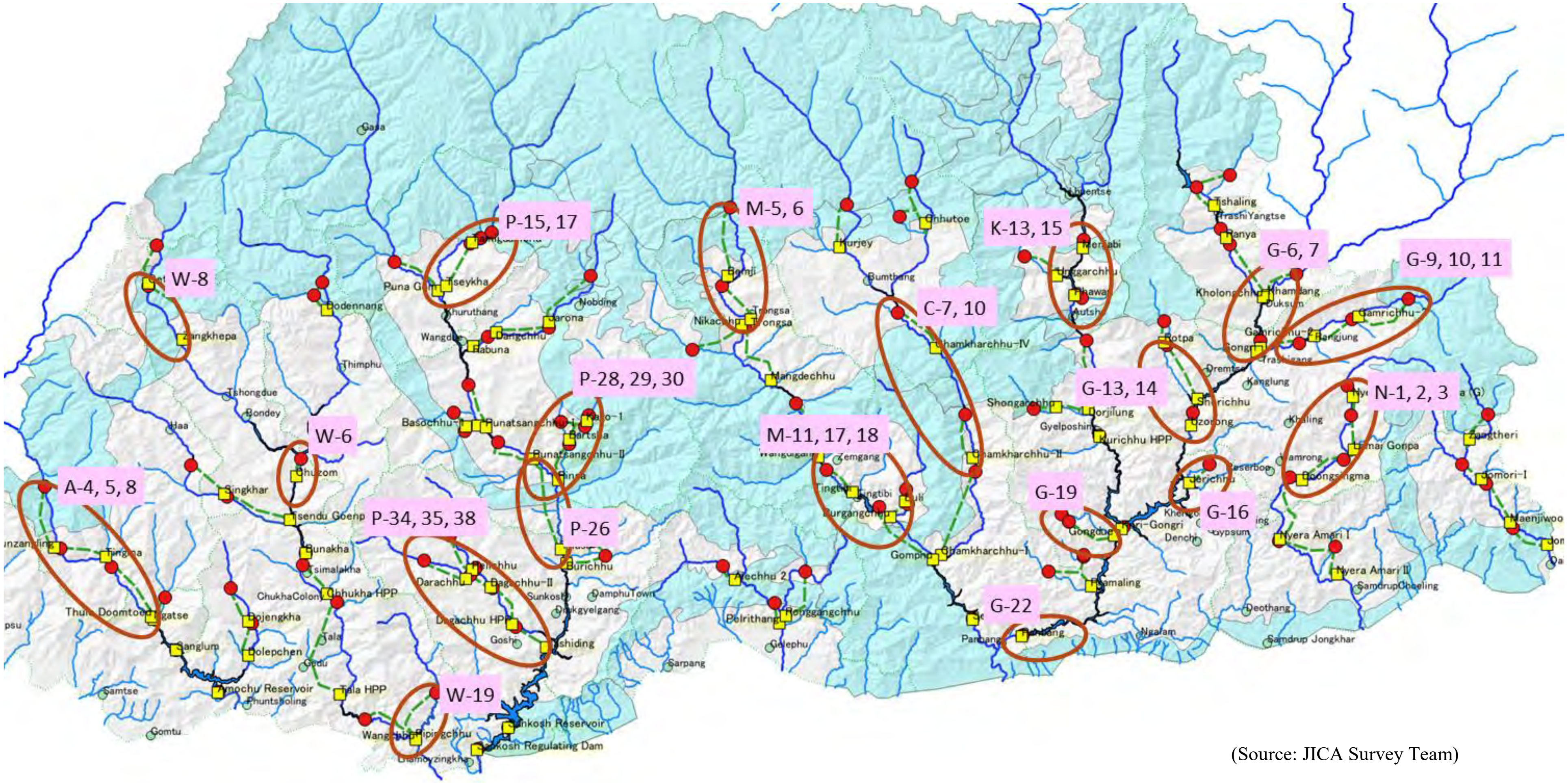
Based on the results of the previous studies, 37 sites are selected for site reconnaissance (Semi-Long List) based on the following.

Table 7-56 Result of the 1st Screening

		Number of sites	Project Code	Project name	Capacity (MW)
(1)	Sites where the evaluation rank in the Base Case (Technical: 40%, Environment: 40%) is within 20th place, except for sites where B/C is less than 0.8 and capacity is less than 50MW	18	A-4	Kunzangling	897
			A-5	Tingma	567
			A-8	Dorokha	573
			W-8	Zangkhepa	73
			W-19	Pipingchhu	100
			P-15	Tamigdamchu	188
			P-26	Thasa	680
			P-28	Kago-1	102
			P-30	Pinsa	151
			P-34	Darachhu	61
			M-5	Bemji	333
			M-6	Jongthang	170
			M-17	Buli	67
			C-7	Chamkharchhu-IV	451
			C-10	Chamkharchhu-II	456
			G-16	Jerichhu	40
			G-22	Panbang	1,100
			N-1	Nyera Amari Kangpara (G)	71
(2)	Sites where the evaluation rank in the Emphasizing Economy Case (Technical: 60%, Environment: 20%) is within 20th place	3	M-11	Wangdigang	446
			G-6	Khamdang	494
			G-14	Uzorong	763
(3)	Sites where the evaluation rank in the Emphasizing Environment Case (Technical: 20%, Environment: 60%) is within 20th place	3	G-13	Sherichhu	53
			G-19	Nagor	53
			N-2	Lamai Gonpa	37
(4)	A site where the B/C is more than 1.5	1	G-9	Gamrichhu-3	123
(5)	Sites located downstream on the same tributary as the sites selected in (1) to (4)	8	P-17	Tseykha	170
			P-29	Kago	58
			P-35	Dagachhu-II	94
			P-38	Tashiding	81
			M-18	Nyekhar	43
			G-10	Gamrichhu-2	104
			G-11	Gamrichhu-1	108
			N-3	Paydung-Kangpar	85
(6)	Sites located upstream of the main river that have a reservoir, where an increase in Firm Power at the power plant located downstream can be expected	4	W-6	Chuzom	152
			K-13	Minjey	490
			K-15	Phawan	502
			G-7	Gongri	590
	Total	37			10,524

(Source: JICA Survey Team)

A map of the 37 sites selected is shown Figure 7-4.



(Source: JICA Survey Team)

Figure 7-4 Sites selected in 1st Screening

7.4 Site Reconnaissance for Semi-long List Projects

7.4.1 Objectives and Methods

(1) Objectives

The objectives of the site reconnaissance are as follows:

1. To verify the location of each major structure (Dam, Waterway, Powerhouse, Outlet and Switchyard) for the 37 sites selected.
2. To verify access conditions, hydrological conditions, topographical and geological conditions, and natural & social environmental conditions.
3. To check whether risk avoidance is possible through a review of plot plans/power development plans, and where there are any serious risks (technical and environmental).

(2) Methods

Site reconnaissance was carried out by two parties (Team A and Team B) in order to conduct an efficient investigation in a short period of time.

One party is basically composed of the following 10 members.

- DHPS Engineers: Two Civil Engineers, One Geologist Total: three people
- JICA Experts: Two Civil Engineers, One Geologist, One Natural Environment Expert, One Social Environment Expert Total: five people
- Local Consultant: One Natural Environment Expert, One Social Environment Expert Total: two people

7.4.2 Check List for Site Reconnaissance

Check lists for the site reconnaissance are shown in the table below

Table 7-57 Check List for Site Reconnaissance (Civil & Geology)

Primary Data	Project Name	A-5 : Tingma		Date	03/09/2018	
	Basin	Amochhu		Tributary	Amochhu	
	Dam (Weir)	Latitude： 27°10'39.27"N		Longitude： 89° 1'58.64"E		
	Powerhouse	Latitude： 27° 9'22.67"N		Longitude： 89° 7'26.88"E		
	Type	ROR+Pond		Salient Features	RBL at Dam	EL 1,280 m
	General Features	Installed Capacity	567 MW		Dam Height	75 (10) m
		Max. Discharge	151 m^3/s		Crest Length	160 m
		Effective Head	434.6 m		Waterway Length	10,371 m
		Catchment Area	2,252 km^2		Live Storage Capacit	1.0 MCM

Category	Items	To be Verified	Results	Application
General	Approach	Current		Elongation from the existing road and its conditions
		Required New Road		To be used during construction / operation
Hydrology	River	River Flow Rate		Difference from assumption (Eye measurement)
		Sediment		Sort of sediment and Average particle diameter
Topography / Geology	Topography	Dam / Desilting Pond		1. Topography suitable for the planned civil structure 2. Thickness of weathering / loosened zone 3. Slope stability (during construction / operation) 4. Flood disaster traces due to GLOF etc.
		Waterway / Penstock		
		Powerhouse / Outlet		
		Switchyard		
		Access Route		
	Geology	Dam / Desilting Pond		1. Existence of noteworthy fault / fracture zone 2. Geological condition suitable for each civil structure planned 3. Highly permeable bedrock (dam / reservoir) 4. Anisotropic rock (Phyllite, etc.) 5. Difficulty in quality and securement of construction material
		Waterway / Penstock		
		Powerhouse / Outlet		
		Switchyard		
		Access Route		
Civil Design	Review of Plot Plan	Dam / Desilting Pond		1. Possibility of reducing topographical / geological risk (Alternative) 2. Possibility of reducing environmental risk (Alternative) 3. Dam type selection in consideration of Spillway, Sluicing sediment, Diversion facilities, Construction material
		Waterway / Penstock		
		Powerhouse / Outlet		
		Switchyard		
		Access Route		
Others	Special Note			

(Source: JICA Survey Team)

Table 7-58 Check List for Site Reconnaissance (Natural Environment)

Project Site Sr. # and Name【 】 Date of Survey ( ) Surveyed by ( )

	Environment Item	Main Check Item		Method of Study: Category*	Method of Study: Source of Data/Interviewer	Confirmation of site/item that will likely have an impact	Cause of Influence: Dam/ Reservoir	Cause of Influence: Water way	Cause of Influence: Power-house	Cause of Influence: Trans-mission	Remarks
Natural Environment	Protected Areas	Is the site located in a Protected area?	Y, N	D, I, L							Mark "○" on cause of influence. Note: Name of Protected area should be cleared
		Is the Protected area divided into Zoning areas?	Y, N	D, I, L		Core					
						Buffer					
						Multiple-use					
		Is the site located in a Corridor?	Y, N	D, I, L							
	Ecosystem	Is forest to be affected ? What size is to be lost if affected?	Y, N	D, I, L		Subtropical broad-leaved Forest					Mark "○" on type and size of forest affected. (under 1ha - S 1ha to 5ha - M over 5ha - L)
						Warm broad-leaved Forest					
						Cool broad-leaved Forest					
						Chir Pine Forest					
						Blue Pine Forest					
						Spruce					
		Will the site affect wetland?	Y, N	D, I, L		Ramsar Site					Mark "○" on type and size of wetland affected. over 20% 15 to 20% 10 to 15% 5 to 10% under 5% no effects expected
						No Ramsar Site					
		Does the site affect the habitat of any endangered species?				Critically Endangered (CR)					
						Endangered (EN)					
						Vulnerable (VU)					
		Does any important aquatic culture designated by local law inhabit the site?				Migratory Fish					
						Aquatic insects					
						Aquatic plants					
	Topography and Geology	Is there a possibility of landslides or erosion?	Y, N	D, I, L							Mark "○" on cause of influence. Including influence caused by construction of access roads.
		If impact is anticipated, are mitigation measures available?	Y, N	D, I, L							
	Hydrology	Is there a possibility that hydrological changes due to installation of the dam/weir will adversely affect the ecosystem downstream?	Y, N	D, I, L		Sufficient water flow from mountain streams can be expected throughout the year.					Mark "○" on main reasons
						Water flow can be expected during the rainy season only.					
						Sufficient water flow from mountain streams cannot be expected throughout the year.					

*D = Direct observation, I = Interview, L = Literature

(Source: JICA Survey Team)

Table 7-59 Check List for Site Reconnaissance (Social Environment)

Project Site Sr. # and Name【 】 Date of Survey ( ) Surveyed by ( )

	Environment Item	Main Check Item		Area of Influence etc.	Cause of Influence: Submerged area	Cause of Influence: Water way	Cause of Influence: Power station	Cause of Influence: Transmission	Notes	Information Source
Social Environment	Land Acquisition	Private land area	Y, N	Approx. private land area for land acquisition ________Acre (_______ha) Purpose of land use:					Mark "○" on cause of influence. Note location and approx. private land area for land acquisition, if it can be estimated.	Site reconnaissance, land officers at Dzongkhag, gewog officers and tsopas, etc.
	Traditional Communities	Existence of traditional communities with unique customs in and around project site	Y, N						Check if traditional communities are in and around project site together with their residential areas, lifestyle and activity areas, to examine the impacts on them.	
	Resettlement and Asset Loss	Houses	Y, N	No. of Houses: Including no. of empty houses: No. of temporary houses:					Mark "○" on cause of influence. Note abandoned empty houses and temporary houses of nomads or people living outside project area, if this information is available. Mainly check power station and submerged areas.	Site reconnaissance, land officers at Dzongkhag, gewog officers and tsopas, etc.
		Huts and livestock, etc.	Y, N	No. of Huts: No. of Livestock by type:						
		Public facilities such as schools and health units	Y, N	Facility name and No.:						
		Any other facilities (including graves)	Y, N	Facility name and No.:						
	Living and livelihood means	Negative impacts on non-agricultural livelihood activities (handicrafts, etc.)	Y, N						Mark "○" on cause of influence. If negative impacts are predicted, note specific, current situation and impacts caused by the project in detail.	Site reconnaissance, environment, land, planning officers at Dzongkhag, gewog officers and tsopas, etc.
		Damage to crops (paddy, vegetables, wheat, cash crops, etc.)	Y, N							
		Negative impacts on forest products (NTFPs)	Y, N							
		Negative impacts on timber products	Y, N							
		Negative impacts on livestock	Y, N							
		Negative impacts on fishing activities	Y, N							
		Negative impacts on water supply	Y, N							
		Negative impacts on irrigation	Y, N							
		Negative impacts on any other activities	Y, N							
	Cultural Heritage	Negative impacts on nationally important cultural heritage sites	Y, N						Mark "○" on cause of influence. Note name of facilities and areas which can be influenced. Upon site survey, note the information given by representatives of local people such as gewog officers and tsopas.	As above
		Any cultural heritage sites for which local residents are strongly against reconstruction	Y, N							
		Any sacred sites for which local residents are strongly against reconstruction	Y, N							

Project Site Sr. # and Name【　　　　　　　　　　　　　　　　　　　】 Date of Survey (　　　　　　　　　) Surveyed by (　　　　　　　　　　　　　)

	Environment Item	Main Check Item		Area of Influence etc.	Cause of Influence: Submerged area	Cause of Influence: Water way	Cause of Influence: Power station	Cause of Influence: Transmission	Notes	Information Source
Social Development	Improved Access to socio-economic benefits	Positive impacts on road access and network	Y, N						Note whether or not it can be predicted if communities around the project site will have better access due to road construction. In addition, judge the possibility of better access to schools and health units by checking whether or not schools (primary or higher level) and health facilities exist near the site (because, if not, it is common for these facilities to be constructed via the project).	As above
		Better access to educational facilities/services	Y, N							
		Better access to health facilities/services	Y, N							
	Employment and potential for income opportunities	Poverty rate in communities in project site area is high	Y, N						Even if the poverty rate at the Dzongkhag level is low, rural communities around the project site can still sometimes have high poverty rates. This is to be confirmed via poverty target programs by the government which cover such areas, or interviews with gewog representatives or tsopas.	As above
		Potential for tourism development (Religious & Cultural Sites, Handicraft Production, Eco-Tourism)	Y, N						Check the potential for tourism and local product development by confirming that communities around the site are included in national or gewog-level development policies and plans.	
		Potential for increased sales of local products	Y, N						Check the potential for an increase in local product sales by, for example, examining if access to urban markets could improve via road construction implemented by the project.	

(Source: JICA Survey Team)

7.4.3 Results of Site Reconnaissance

Based on the results of the site reconnaissance, the development superiority of each site was evaluated. If there are issues on the geological aspect of the development plan, if major facilities are in the protected area, if there are issues in terms of social development, the plan is reviewed and evaluated the development superiority on the revised plan.

Overall evaluation is classified in the following five categories.

- AA: Most Promising
- A: Promising
- B: There is a possibility of becoming promising if the plan is slightly revised
- C: Difficult to develop
- D: Very Difficult to develop

The evaluation results of each site are shown in Table 7-61.

The overall evaluation results are shown in the following table.

Table 7-60 Overall Evaluation Results

	No. of sites	Installed capacity (MW)	Annual Energy (GWh)
AA	5	2,405	10,533
A	9	3,302	14,464
B	4	748	3,277
C	8	931	4,079
D	11	3,673	16,086
Total	37	11,059	48,440

(Source: JICA Survey Team)

Meanwhile, the individual site reconnaissance report is described in Appendix – 1.

Table 7-61 Tentative Evaluation of each Site

Project Code	Name of Project	Project Type	Installed Capacity (MW)	Annual Energy (GWh)	Geological Risk	National Park	Resettlement	Unit Cost (Nu/kWh)	Rank	Remarks
A-4	Kunzangling	ROR+Pond	897	3,928	-	Dam	-	11.1	**D**	+ Both the dam site and powerhouse site are not accessible and cannot be assessed. + Since the dam site is located in the JKSNR, the development is considered to be very difficult.
A-5	Tingma	ROR+Pond	567	2,483	-	Outside	No	14.3	**-**	+ Dam is relocated at the upmost stream outside of National Park (Tingma Rev)
	Tingma Rev	ROR	816	3,574	Middle	Outside	No	10.5	**AA**	+ Since A-4 site was abandoned to develop, the dam site was shifted to the upmost stream outside of JKSNR (a plan to combine the A-4 and A-5 sites) + The dam site is not accessible and cannot be assessed.
A-8	Dorokha	ROR+Pond	573	2,511	Low	Outside	No	18.4	**AA**	+ There is no particular big problem.
W-6	Chuzom	Reservoir	152	664	High	Outside	220 HHs	150.6	**D**	+ This site wouldn't be possible just because of the immense loss of wetlands (paddy field) and also the huge resettlement that would be required
W-8	Zangkhepa	ROR	73	320	Low	Dam	No	21.5	**-**	+ In order to avoid developing in Jigme Dorji National Park
	Zangkhepa Rev	ROR	54	237	Low	Outside	No	35.3	**C**	+ The intake site was selected downstream of the boundary of the National Park. + Therefore, the head decreases and the economic efficiency deteriorates.
W-19	Pipingchhu	ROR	100	436	High	Outside	No	28.6	**D**	+ The dam site is not accessible and cannot be evaluated.
P-15	Tamigdamchu	ROR	188	824	-	Dam, Powerhouse	No	29.2	**D**	+ Since the dam, waterway and powerhouse site is in the core zone of Protected Area (Jigme Dorji National Park), the development is considered to be very difficult.
P-17	Tseykha	ROR	170	743	Middle	Outside	No	35.4	**-**	+ Dam is relocated at the upmost stream outside of National Park (Tseykha Rev)

Project Code	Name of Project	Project Type	Installed Capacity (MW)	Annual Energy (GWh)	Geological Risk	National Park	Resettlement	Unit Cost (Nu/kWh)	Rank	Remarks
	Tseykha Rev	ROR	215	942	Middle	Outside	No	22.8	**A**	+ A Part of Dam and intake (right bank of river) is located on border of Protected Area (Jigme Dorji National Park). + Development work in the buffer zone of cultural sites is difficult in Punakha.
P-26	Thasa	Pondage	768	3,364	Low	Dam	No	21.9	**-**	+ Dam is relocated at the upmost stream outside of National Park (Thasa Rev)
	Thasa Rev	Pondage	706	3,092	Low	A part of the Reservoir	Impact on commercial Facility	25.7	**A**	+ Move the waterway from the right bank side to the left bank side to shorten the length + It is possible to change the power plant an open-air type structure. + Though there is no particular big problem, the comparison study for alternative plans is required. + It is necessary to confirm the impact on the indigenous community living around Harachhu.
P-28	Kago-1	ROR	102	448	Middle	Dam	No	14.0	**C**	+ Both the dam site and powerhouse site are not accessible and cannot be assessed. + Since the dam site is located in the core zone of National Park, the development is considered to be very difficult.
P-29	Kago	ROR	58	256	Low	Dam	No	32.1	**C**	+ The eastern intake, is located on the border of Jigme Singye Wangchuck National Park. + It is possible to change the power plant and penstock an open-air type structure.
P-30	Pinsa Rev	ROR	151	662	Low	Dam (Multiple)	No	15.6	**AA**	+ The intake is located on the border of Jigme Singye Wangchuck National Park.
P-34	Darachhu	ROR	61	266	Middle	Outside	No	29.2	**C**	+ The dam site is not accessible and cannot be evaluated.
P-35	Dagachhu-II	ROR	94	413	Middle	Outside	No	29.0	**B**	+ There is no particular big problem.
P-38	Tashiding	ROR+Pond	81	356	High	Outside	No	30.7	**D**	+ Both dams, waterways, and power station sites have big problems in terms of geology. + The powerhouse site is not accessible.

Project Code	Name of Project	Project Type	Installed Capacity (MW)	Annual Energy (GWh)	Geological Risk	National Park	Resettlement	Unit Cost (Nu/kWh)	Rank	Remarks
M-5	Bemji	ROR+Pond	333	1,458	Middle	Dam	No	21.1	**D**	+ The dam site is not accessible and cannot be evaluated. + Since the dam site is located in the National Park, the development is considered to be very difficult.
M-6	Jongthang	ROR+Pond	170	743	Middle	Outside	No	40.9	-	+ Dam is relocated at the 2km downstream from original plan due to geological condition. (Jongthang Rev) + The original powerhouse and outlet is located near the Trongsa Dzong in Trongsa Town.
	Jongthang Rev2	Pondage	164	718	Low	Outside	No	53.8	**D**	+ Because the location of dam is shifted downstream, the head decreases and the economic efficiency deteriorates.
M-11	Wangdigang	ROR+Pond	446	1,952	Middle	Dam (Multiple) Powerhouse (Corridor)	No	25.2	-	+ Dam is relocated at the outside of National Park (Wangdigang Rev) + Powerhouse is relocated at the outside of corridor
	Wangdigang Rev	ROR+Pond	502	2,199	Middle	Outside	No	22.7	**C**	+ White-bellied Heron is observed regularly along the river. (Around powerhouse, outlet)
M-17	Buli	ROR	62	272	Low	Outside	No	21.5	-	+ Considering that it is possible to construct open-air type de-silting pond and increase the effective head, intake dam is relocated at the 1.5km upstream.
	Buli Rev	ROR	69	302	Low	Outside	No	20.1	**A**	+ There is no particular big problem.
M-18	Nyekhar	ROR	43	188	Low	Outside	No	32.1	**C**	+ As an alternative plan, the headrace could be directly connected with the tailrace of Buli project However, In order to avoid influence of stoppage of operation of one project, additional structures such as connecting chamber, outlet and intake are required. + There is no particular big problem. + White-bellied Heron is observed regularly along the river. (Around powerhouse, outlet)
C-7	Chamkharchhu-IV	Pondage	451	1,974	Low	Outside	No	19.2	**AA**	+ The powerhouse sites planned was not accessible, therefore, that was observed with the drone from a distance.

Project Code	Name of Project	Project Type	Installed Capacity (MW)	Annual Energy (GWh)	Geological Risk	National Park	Resettlement	Unit Cost (Nu/kWh)	Rank	Remarks
C-10	Chamkharchhu-II	ROR+Pond	456	1,997	Low	Part of Reservoir	No	18.1	-	+ It is recommended to shift the dam site 0.3km downstream from the original site + By shifting the dam site, the intake and waterway are recommended at the left bank to reduce impacts to the National Park.
	Chamkharchhu-II Rev	ROR+Pond	414	1,813	Low	Outside	No	15.4	**AA**	+ There is no particular big problem.
K-13	Minjey	Pondage	490	2,144	Middle	Outside	Several HHs, Crematorium	38.0	-	+ An important facility of crematorium is located at the end of reservoir which elevation is EL 1,780m.
	Minjey Rev	Pondage	673	2,948	Middle	Outside	Several HHs	20.8	**A**	+ In order to avoid submergence of the crematorium, the FRL of Dam was reduced from EL.1,820m to EL. 1,770m
K-15	Phawan	Pondage	499	2,185	High	Outside	Several HHs	40.4	**D**	+ It is difficult to construct dams exceeding 150 m in terms of geology, and the present economic efficiency is also quite low, accordingly, this project has to be abandoned to develop. + 2 MOAL facilities (poultry farm and dairy farm) and 6 acres of barren land (1), paddy field (5 partly) and orange orchard (1 partly) will be inundated.
G-6	Khamdang	ROR+Pond	494	2,165	Middle	Outside	No	26.1	-	+ Penstock and Powerhouse were shifted to the slight downstream where outcrops of Gnisse / Schist were observes.
	Khamdang Rev	ROR+Pond	512	2,243	Middle	Outside	Near border with India	24.8	**B**	+ The upstream end of pond is located in the vicinity of the border with India. + Site visit was not permitted by Local authority due to sensitive area near the international border with India.
G-7	Gongri	Pondage	590	2,582	Low	Outside	No	33.7	-	+ Since thick unconsolidated sediment is distributed on the right bank around the original dam site and it is not suitable for a dam site, the dam site was shifted about 2km upper stream.

Project Code	Name of Project	Project Type	Installed Capacity (MW)	Annual Energy (GWh)	Geological Risk	National Park	Resettlement	Unit Cost (Nu/kWh)	Rank	Remarks
	Gongri Rev	Pondage	546	2,391	Low	Outside	No	25.7	**A**	+ 56 acres of paddy field and residential land with 4 settlements, most important cultural heritages in Bhutan (Gom Kora), and substation currently under construction for Kholongchhu HPP may be inundated.
G-9	Gamrichhu-3	ROR	123	538	Middle	Dam (Core)	No	20.4	**D**	+ Since the dam site is in the core zone of the Sakteng Wildlife Sanctuary (protected area), the development is considered to be very difficult. Therefore, the plan is changed to be integrated with the downstream project of G-10 (Gamrichhu - 2).
G-10	Gamrichhu-2	ROR	104	458	-	-	No	25.5	-	+ The plan is changed to be integrated with the upstream project of G-9 (Gamrichhu - 3).
	Gamrichhu-2 Rev2	ROR+Pond	108	473	Middle	Outside	No	22.4	**A**	+ Since G-9 site was abandoned to develop, the dam site was shifted to the upmost stream outside of the protected area (a plan to combine the G-9 and G-10 sites). + There is no particular big problem.
G-11	Gamrichhu-1	Pondage	108	474	-	-	Several HHs	47.1	-	
	Gamrichhu-1 Rev2	ROR	150	657	Middle	Outside	No	20.8	**A**	+ Since the dam site of G-10 was shifted to the upper stream, the dam site (G-11) was also shifted to the upper stream and make the water head increase. + There is no particular big problem.
G-13	Sherichhu	ROR	53	230	Middle	Outside	No	35.6	-	+ Considering that it is possible to construct open-air type de-silting pond, intake dam is relocated at the 0.3km upstream. + And due to the geological condition, outlet is relocated at the 1.4km upstream.
	Sherichhu Rev	ROR	58	254	Middle	Outside	No	33.2	**C**	+ If the development at Uzorong site is not realized, the powerhouse at Sherichhu site can be changed to open-air type, and the effective head can also be increased by about 100 m.
G-14	Uzorong	Pondage	763	3,343	Middle	Outside	35HHs	25.4	-	+ Considering the geological condition, dam is relocated at the 1.5km downstream.

Project Code	Name of Project	Project Type	Installed Capacity (MW)	Annual Energy (GWh)	Geological Risk	National Park	Resettlement	Unit Cost (Nu/kWh)	Rank	Remarks
	Uzorong Rev	Pondage	764	3,346	Low	Outside	35HHs	23.5	**A**	+ There is no particular big problem. However, there are 35 households, a cultural heritage, and agricultural lands of the Queen Support Project etc. in submerged area of the project, it is necessary to consider relocation or resettlement at implementation stage. + In case of considering the construction of a PSPP (lower pond: Uzorong reservoir, upper pond: in Jerichhu), it is recommended to shift the dam location about 2.4 km downstream.
G-16	Jerichhu	ROR	40	175	Middle	Outside	No	30.5	**B**	+ Both the dam site and powerhouse site are not accessible and cannot be assessed. + Although there is no problem in terms of geology and social environment, flowing water in the river cannot be confirmed from the sky, and there is a possibility that the river flow rate is smaller than expected.
G-19	Nagor	ROR	53	232	Middle	Outside	No	30.1	**C**	+ The flow rate at the intake is very small. + Geologic concerns remain, including the possibility of crossing the aquifer due to hydrothermal alteration in the route of the waterway.
G-22	Panbang	Pondage	1,100	4,818	High	A part of Reservoir (Multiple)	More than 45HHs	24.5	**D**	+ The geology at the dam site is easily crushable, it is not suitable for construction of a 150 m class height concrete gravity dam. Also, it is distributed around the hydrothermal alteration zone. In any case, detailed geological survey is necessary. + Due to the construction of the reservoir, at least 45 households in 4 villages will have to be resettled.
N-1	Nyera Amari Kangpara (G)	ROR	71	312	Low	Outside	No	19.7	**A**	+ Dam and powerhouse sites are not accessible even by foot path at this moment.
N-2	Lamai Gonpa	ROR	37	161	Low	Outside	No	40.1	**D**	+ The dam site is not accessible and cannot be assessed. + Approx. 0.33 km distance from powerhouse and the waterway, there is an oldest cultural heritage known as Lamai Gonpa Lhalkhang

Project Code	Name of Project	Project Type	Installed Capacity (MW)	Annual Energy (GWh)	Geological Risk	National Park	Resettlement	Unit Cost (Nu/kWh)	Rank	Remarks
N-3	Paydung-Kangpar	ROR+Pond	85	374	Low	Outside	No	33.9		+ By shifting the power plant position and water tank position to downstream, an additional head of about 70m is obtained.
	Paydung-Kangpar Rev	ROR+Pond	102	447	Low	Outside	No	30.4	**B**	+ It is necessary to investigate the distribution of hydrothermal alteration zone around the power plant in detail. + In some neighboring tributary, river flow rate is smaller than the volume calculated by the catchment area, so river flow measurement at intake point is indispensable.

(Source: JICA Survey Team)

7.4.4 Supplementary Site Survey

(1) Projects for which Salient Features were revised giving weight to economic efficiency

The layouts and salient features of the projects P-29, P-34, P-35, M-6, and N-3, for which economic efficiency only was low, were revised and supplementary site surveys were carried out to verify their validity.

The provisional evaluation results of each project plan are shown in Table 7-62. The provisional evaluation results for all revised projects except N-3 (Paydung-Kangpar) were increased in rank up to A.

The individual supplemental site survey report is described next to the pre-revised site reconnaissance report in Appendix – 1.

Table 7-62 Provisional Evaluation Results for Each Project (Revised)

Project Code	Name of Project	Project Type	Installed Capacity (MW)	Annual Energy (GWh)	Geological Risk	National Park	Resettlement	Unit Cost (Nu/kWh)	Rank	Remarks
P-29	Kago	ROR	58	256	Low	Dam	No	32.1	**C**	+ Eastern side of the intake is located on the border of Jigme Singye Wangchuck National Park. + It is possible to change the power plant and penstock to an open-air type structure.
	Kago Rev	ROR	58	254	Low	Dam	No	20.1	**A**	+ Diversion of tributary is abandoned and intake site is sifted to upmost stream, which is outside of the protected area on the left bank. + Accordingly, the water head increases by around 100m and construction costs are drastically reduced.
P-34	Darachhu	ROR	61	266	Middle	Outside	No	29.2	**C**	+ The dam site is not accessible and cannot be evaluated.
	Darachhu Rev	ROR	89	390	Middle	Outside	No	22.2	**A**	+ In line with revision of the Dagachhu II plot plan, the outlet site is shifted downstream. + Accordingly, the water head increases by around 230m.
P-35	Dagachhu-II	ROR	94	413	Middle	Outside	No	29.0	**B**	+ There are no particularly large problems.
	Dagachhu-II Rev	ROR	71	311	Middle	Outside	No	23.4	**A**	+ Diversion of Darachhu is abandoned and the two intake dams are changed to a weir which is shifted to the confluence point of a tributary. + Accordingly, the water head increases by around 100m and construction costs are reduced.
M-6	Jongthang	ROR+Pond	170	743	Middle	Outside	No	40.9	**-**	+ Dam is relocated 2km downstream from original plan due to geological conditions (Jongthang Rev). + The original powerhouse and outlet are located near the Trongsa Dzong in Trongsa Town.
	Jongthang Rev2	Pondage	164	718	Low	Outside	No	53.8	**D**	+ Because the location of the dam is shifted downstream, the head decreases and the economic efficiency deteriorates.

Project Code	Name of Project	Project Type	Installed Capacity (MW)	Annual Energy (GWh)	Geological Risk	National Park	Resettlement	Unit Cost (Nu/kWh)	Rank	Remarks
	Jongthang Rev3	ROR+Pond	227	994	Low	Outside	No	23.0	**A**	+ Since the M-5 site was hard to develop due to it being inside a protected area, the dam site was shifted to the upmost stream outside of the protected area. + The water head increased up to 1.5 times that of the Rev 2 plan and the dam height was lowered to 30 m.
N-3	Paydung-Kangpar	ROR+Pond	85	374	Low	Outside	No	33.9		+ By shifting the powerhouse and surge tank downstream, an additional head of about 70m is obtained.
	Paydung-Kangpar Rev	ROR+Pond	102	447	Low	Outside	No	30.4	**B**	+ It is necessary to investigate the distribution of the hydrothermal alteration zone around the power plant in detail. + In a neighboring tributary, river flow rate is smaller than the discharge calculated by the catchment area, so river flow measurement at the intake site is necessary.
	Paydung-Kangpar Rev 2	ROR	73	320	Low	Outside	No	25.2	**B**	+ Since the Lamai Gonpa project is hard to develop due to its low economic efficiency, intake site is shifted to the upper stream of Nyera Amari. + Accordingly, the water head increases by 75m and the intake dam is changed to a weir type.

(Source: JICA Survey Team)

7.5 Secondary Screening

Site reconnaissance was conducted for the 37 sites extracted as a result of the primary screening. In the site reconnaissance, the plan formulated via desk study was reviewed in consideration of the following points.

- Avoiding development in protected areas as much as possible
- Avoiding places with geological unstable as much as possible
- Avoiding places with social or environmental sensitive as much as possible
- Changing a plan that can be more economical

After that, secondary screening was conducted and, based on its results, 18 short listed sites were selected as sites to be developed preferentially.

The secondary screening was conducted according to the following criteria and weights for MCA.

Table 7-63 Criteria and Weights for MCA for Secondary Screening

No.	Criteria	Sub-criteria		Weights	
1.1	Technical	Hydrological quality	30%	50%	40%
1.2		Geological risk	50%		
1.3		GLOF risk	5%		
1.4		Sedimentation risk	5%		
1.5		Site accessibility	5%		
1.6		Transmission line risk	5%		
2.1	Economic	Economic efficiency		50%	
3.1	Impact on Social environment	Land Acquisition	25%	50%	40%
3.2		Resettlement and Asset Loss	25%		
3.3		Lifestyle and Livelihood	20%		
3.4		Cultural Heritage	30%		
4.1	Impact on Natural Environment	Located in protected area	35%	50%	
4.2		Loss of primary forest	30%		
4.3		Loss of wetland	10%		
4.4		Loss of endangered species	10%		
4.5		Fish migration	5%		
4.6		Access road/dam site erosion	5%		
4.7		Impact on Landscape	5%		
5.1	Social Development	Improved access to socioeconomic benefits	50%	100%	20%
5.2		Employment and potential for income opportunities	50%		

(Source: JICA Survey Team)

There are no major differences from the MCA items used for primary screening, but the item "Loss of endangered species" was added in the natural environment section.

7.5.1 Changes in each Item

(1) Technical

There are no particular changes. However, based on the results of the site reconnaissance, the assessment of the geological aspect was greatly reconsidered.

(2) Economic

The following items were added for the value evaluation.

- Value of providing ancillary services (refer to 4.5.2)

■ Increase in Firm power at downstream power plants (refer to 4.4)

For the minimum flow rate of the river, the average flow rate in February was used in the primary screening, but in the secondary screening the average flow rate in the 4 months from December to March is used for evaluation as per the indication from DHPS.

In addition, for the sites where a review of the plan was carried out, the benefits and costs were also reviewed.

(3) Impact on Social environment, Social development

(a) Land acquisition

<Revision of scoring categories for evaluation>

It was confirmed in the local interview during the 1st site reconnaissance in December 2018 that (i) people prefer land-to-land compensation to cash compensation, (ii) they expect more fertile substitute land given for their original land to grow better crops, and (iii) it has become more difficult these days to find and offer the affected people alternative land with the same or better conditions in the vicinity of their original locations. Therefore, impacts on the people due to land acquisition are deemed quite significant.

It was also found in the field survey in December 2018 that the private land area for the reservoir was not particularly large in terms of the thresholds applied in the primary screening. There were, in fact, only a few cases in which private land acquisition size exceeded 200 acres, and most of these were categorized in the smaller-scale range of under 100 acres (especially under 50 acres). Accordingly, the smallest to the largest categories of land acquisition size were revised as per the table below:

Table 7-64 Revised Evaluation Scores for Land Acquisition

Land size	State	Private
100 acres and over		1
50 acres to less than 100 acres		2
25 acres to 50 acres	5	3
Under 25 acres		4
Nothing (0)		5

(Source: JICA Survey Team)

The land records based on which the scoring is conducted are: (i) the latest land use information based on the GIS data collected from NLC as of January 2019, and (ii) owners' information obtained through site reconnaissance and local interviews between November 2018 and March 2019, to the evaluation in the 2nd MCA.

(b) Resettlement and asset loss

Adverse impacts caused by resettlement were quite significant for the affected people according to the findings in the 1st site reconnaissance. The categories for the score were thus revised to be smaller and more detailed, as per the table below.

Table 7-65 Revised Evaluation Scores for Resettlement & Asset Loss

No. of Houses	Score
50 and over	1
25 to less than 50	2
Less than 25	3
Nothing (0)	5

(Source: JICA Survey Team)

The numbers of structures in the project sites mentioned in the 2nd MCA represent the structures observed on-site and confirmed through local interviews with Gewog Offices during the site reconnaissance from November 2018 to March 2019.

(c) Living and livelihood means

Taking into consideration the fact that the livelihoods of rural Bhutanese people heavily rely on agriculture, the evaluation scores for living and livelihood means were thoroughly revised as per the following table.

Table 7-66 Revised Evaluation Scores for Living and Livelihood Means

Activities affected	Score
Negative impacts on agriculture	1
Negative impacts on forest products (NTFPs) or timber products	3
Negative impacts on livestock	3
Negative impacts on local businesses*	3
None	5

Note: a local business means a shop, factory, sand quarry, etc.

(Source: JICA Survey Team)

(d) Cultural heritage

It was decided that each site should be scored according to the number of affected heritage sites, and a score of "1" shall be given, no matter how many sites are affected, if the project would cause negative impacts on a site of national importance, including those located within 500m from the intake dam or powerhouse. The following table shows the revised evaluation scores:

Table 7-67 Revised Evaluation Scores for Cultural Heritage

<table>
<tr><th>No. of Affected Heritage Sites</th><th>National importance</th><th>Score</th></tr>
<tr><td>3 and more</td><td rowspan="3">1</td><td>1</td></tr>
<tr><td>2</td><td>2</td></tr>
<tr><td>1</td><td>3</td></tr>
<tr><td>None</td><td>5</td><td>5</td></tr>
</table>

(Source: JICA Survey Team)

It is DOC who should judge and make the final decision for the evaluation, as DOC collects ideas from all stakeholders from different levels and reaches a conclusion with comprehensive analyses. Special notes should be taken that reflect the DOC's view at this MP stage, instead of dropping them from the list, if there are heritage sites of national importance found among or in the vicinity of the potential project sites.

(4) Social Development

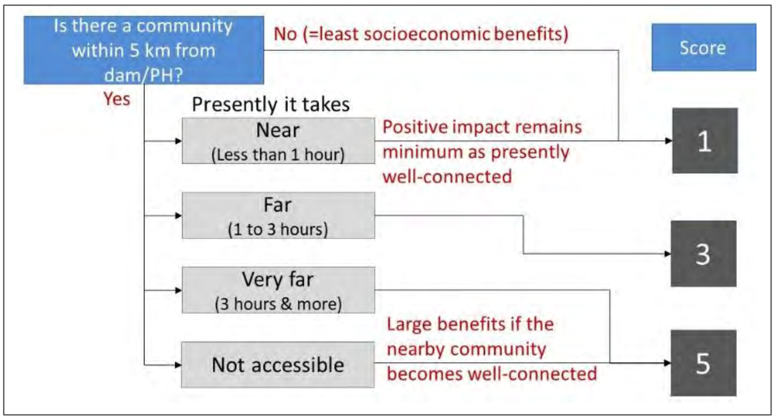
(a) Improved access to socioeconomic benefits

Given the fact that both education and health facilities are facilities essential to human development, it was agreed that the following three issues be included under the sub-criterion: i) local connectivity, ii) access to education facilities, and iii) access to health facilities, with weights of 40%, 30% and 30% respectively.

1) Local connectivity

Roads are paved (mentioned as "black-topped" in the context of Bhutan) and wide enough for vehicles to pass each other up to the Dzongkhag Administration Office and Gewog Office. Local people then use "farm roads" or "footpaths" from the Gewog Office to reach their Chiwogs and villages, which remain unpaved, narrow and rough. Traveling on such roads takes them extra time, no matter how short the physical distance is.

The roads to the dam/powerhouse will likely be improved (i.e., paved, widened, or newly developed) to enable workers to travel effectively and to facilitate the transportation of construction materials and equipment, which will benefit local people in the surrounding communities too. Road development and improvement will enable people to shorten their traveling time. For scoring purposes, the traveling time by vehicle between dam/PH and the nearest community is set as the indicator: the score shall be "1" if they are close to each other, "3" if they are far apart, and "5" if they are very far from each other, or not accessible by car. The "nearest community" is represented by one of Chiwog center, Gewog Office, local market, or town. The weights are given equally to dam site and PH site (50% and 50%). If there is no community within 5km from the dam/powerhouse sites, the score shall be "1", as there are expected to be no development effects from the project implementation.



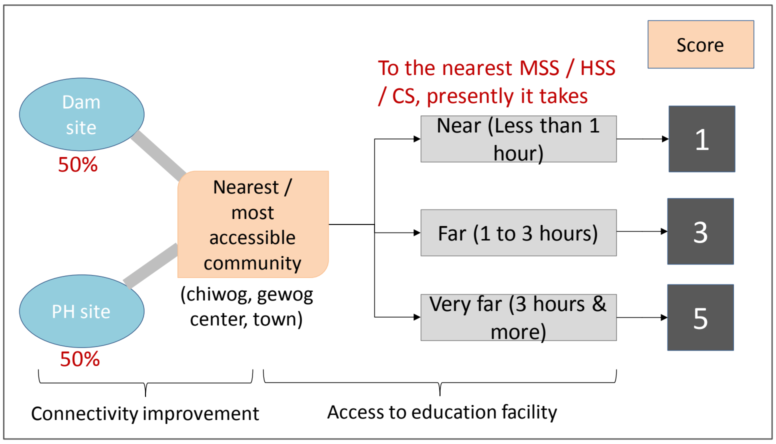
(Source: JICA Survey Team)

Figure 7-5 Evaluation Method for Local Connectivity

2) Access to education

Local people in rural Bhutan usually send their children to primary schools (PS) within walking distance, then to secondary schools with boarding facilities away from their villages as they cannot commute every day. Hydropower development shall be associated with road development, which will improve the local connectivity. Access to education will thus be enhanced by reducing local people's traveling time up to the nearest (or most accessible) community.

For the purpose of scoring, the traveling time by vehicle between their nearest community and the nearest (or most accessible) post-primary education facility is set as the indicator: the score shall be "1" if they are already close to Middle secondary schools, higher secondary schools or central schools, "3" if they are far from these schools, and "5" if they are very far. The weights are given equally to dam site and powerhouse site (50% and 50%).

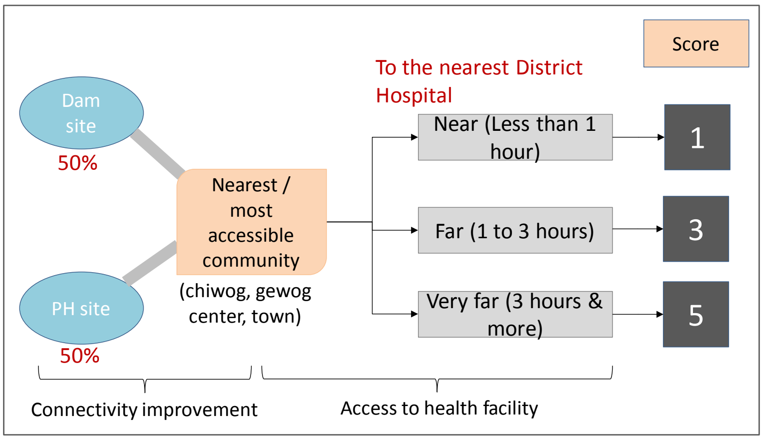


(Source: JICA Survey Team)

Figure 7-6 Evaluation Method for Access to Education

3) Access to health facilities

A referral system has been established in Bhutan to provide health services throughout the country. Every village has an outreach clinic (ORC), and every Gewog has a basic health unit (BHU) that provides primary health care services: awareness raising, preventive care, maternal and child health care and primary medical services. Day-to-day consultation and simple treatments are done at these facilities, and patients with complicated diseases and illness that require operations are transferred to the District Hospital or Regional Referral Hospital. Hydropower development shall be associated with road improvement, which will improve the local connectivity. Access to health facilities will thus be improved by reducing local people's traveling time up to the nearest (or most accessible) community. For the purpose of scoring, the traveling time by vehicle between their nearest community and the nearest (or most accessible) District Hospital is set as the indicator: the score shall be "1" if they are already close to a DH, "3" if they are far from a DH, and "5" if they are very far. The weights are given equally to dam site and PH site (50% and 50%).



(Source: JICA Survey Team)

Figure 7-7 Evaluation Method for Access to Health Facilities

(b) Employment and potential for income opportunities (Income improvement in low-income area)

Creation or enhancement of employment opportunities and local business opportunities are expected due to the project, which will enable local people, particularly low-income households, to generate/increase their income. The household poverty ratio at the Dzongkhag level was applied in the primary screening process to compare potential sites. However, it turned out in the 1st site reconnaissance survey that local people in certain gewogs are rather wealthier than the Dzongkhag average, and those in other gewogs in the same Dzongkhag are poorer than the average. The degree of disparity also varies from one Dzongkhag to another. Replacing the thresholds of each category to implement the scoring with the actual amount of per capita income was discussed, as shown in the table below. The weights are 30% for the dam site and 70% for the PH site, since the locations of the dam and powerhouse are different, meaning that each case should be evaluated separately. If the project site covers several Gewogs, data from the gewog with the lowest per capita income among them is used for scoring.

Table 7-68 Evaluation Method for Income Improvement in Low-income Areas

Sub-criteria (per capita income at gewog level)	Score
Nu 80000 and more	1
Nu 60,000 to Nu 80,000	2
Nu 40,000 to Nu 60,000	3
Nu 20,000 to Nu 40,000	4
Less than Nu 20,000	5

The data source of per capita income at gewog level is the Bhutan Living Standards Survey Report 2012.

(Source: JICA Survey Team)

(5) Impact on Natural Environment

The item "Loss of endangered species" was newly added per the request from the SEA Task Team members, and the weight was evaluated as 10%. Therefore, the weight of "Located in protected area" was changed from 40% to 35%, and that of "Loss of primary forest" was changed from 35% to 30%.

(a) Evaluation method for Loss of endangered species

If endangered species specified in IUCN are identified around each site, this was evaluated as follows.

Table 7-69 Evaluation Method for Loss of Endangered Species

Category of Endangered Species (Threatened Species listed in Red Data by IUCN)	Score
Critically Endangered (CR)	1
Endangered (EN)	2
Vulnerable (VU)	3
Nothing	5

(Source: JICA Survey Team)

(b) Change of evaluation method for Impact on landscape

As for Impact on landscape, in the primary screening it was evaluated via the distance of the transmission line, but in response to the indication from DHPS that the height is also a problem, the evaluation method was changed as follows.

Table 7-70 Evaluation Method for Impact on Landscape

Distance from Nearest Pooling station/Substation	Voltage		
	400kV	220kV	132kV
More than 100 km	1	1	2
From 50 km to 100 km	1	2	3
From 20 km to 50 km	2	3	4
From 10 km to 20 km	3	4	5
Less than 10 km	4	5	5

(Source: JICA Survey Team)

7.5.2 Comprehensive Evaluation

The comprehensive evaluation results are shown below.

Table 7-71 Comprehensive Evaluation (Base Case)

Project Code	Name of Project	Installed Capacity (MW)	Annual Energy (GWh)	Technical	Economic	Impact on Social environ-ment	Impact on Natural environ-ment	Social develop-ment	Total	Rank
A-4	Kunzangling	860	3,766	15.3	20.0	20.0	7.0	12.4	74.7	10
A-5	Tingma	783	3,428	15.4	20.0	20.0	14.6	14.0	84.0	2
A-8	Dorokha	550	2,407	15.9	20.0	20.0	14.6	12.4	82.9	3
W-6	Chuzom	152	664	15.5	4.0	4.0	16.4	6.0	45.9	37
W-8	Zangkhepa	54	236	14.3	4.0	15.2	13.8	4.8	52.1	36
W-19	Pipingchhu	100	436	12.1	7.6	16.8	15.4	13.6	65.5	24
P-15	Tamigdamchu	188	824	15.1	6.4	20.0	8.6	11.2	61.3	31
P-17	Tseykha	215	943	16.2	20.0	12.0	11.2	9.6	69.0	20
P-26	Thasa	706	3,094	15.6	14.8	17.0	15.2	11.6	74.2	11
P-28	Kago-1	102	448	15.2	20.0	20.0	8.4	15.6	79.2	5
P-29	Kago	58	255	14.6	14.4	20.0	12.2	14.8	76.0	7
P-30	Pinsa	153	672	15.9	20.0	20.0	11.4	12.0	79.3	4
P-34	Darachhu	89	389	14.1	12.0	16.8	15.2	12.8	70.9	17
P-35	Dagachhu-II	71	311	14.6	10.4	20.0	15.4	11.2	71.6	14
P-38	Tashiding	81	356	10.8	10.8	20.0	15.2	11.8	68.6	21
M-5	Bemji	333	1,458	15.6	17.6	20.0	9.2	10.6	73.0	13
M-6	Jongthang	227	995	15.9	19.2	14.8	15.4	10.8	76.1	6
M-11	Wangdigang	502	2,200	15.3	17.2	9.0	10.4	4.8	56.7	35
M-17	Buli	69	302	15.0	14.8	20.0	12.4	13.6	75.8	8
M-18	Nyekhar	43	188	15.2	4.0	20.0	12.2	14.0	65.4	26
C-7	Chamkharchhu-IV	451	1,974	13.6	20.0	10.0	16.0	9.6	69.2	19
C-10	Chamkharchhu-II	414	1,814	15.0	20.0	20.0	15.0	18.0	88.0	1
K-13	Minjey	673	2,948	13.4	19.6	8.0	10.2	11.2	62.4	30
K-15	Phawan	499	2,185	14.5	6.8	13.4	12.2	12.4	59.3	33
G-6	Khamdang	512	2,242	16.1	14.8	15.8	15.6	10.8	73.1	12
G-7	Gongri	546	2,392	15.6	12.8	7.0	15.2	10.0	60.6	32
G-9	Gamrichhu-3	123	538	12.7	14.0	20.0	8.4	12.2	67.3	23
G-10	Gamrichhu-2	108	471	14.3	14.8	20.0	15.6	10.8	75.5	9
G-11	Gamrichhu-1	150	656	13.7	14.8	17.6	15.4	10.0	71.5	15
G-13	Sherichhu	58	254	12.6	4.0	20.0	16.0	12.2	64.8	27
G-14	Uzorong	840	3,678	14.2	20.0	8.4	15.0	13.0	70.6	18
G-16	Jerichhu	39	169	13.0	5.2	20.0	16.2	11.0	65.4	25
G-19	Nagor	59	258	10.4	5.6	17.6	15.0	15.4	64.0	29
G-22	Panbang	993	4,349	10.7	14.8	6.2	14.6	11.6	57.9	34
N-1	N.A. Kangpara (G)	71	312	13.5	12.8	20.0	15.2	10.0	71.5	16
N-2	Lamai Gonpa	37	161	11.0	4.0	20.0	15.6	13.6	64.2	28
N-3	Paydung-Kangpar	73	319	13.9	10.0	17.6	15.4	11.4	68.3	22

(Source: JICA Survey Team)

Of the 37 sites listed above, it would be very difficult to develop the following 13 sites, which have issues such as major geological risks, major components of the project being in protected areas, so many resettlements being required, and being very close to the international border. Therefore, they are excluded from the priority development candidate sites.

Table 7-72 Sites that are considered difficult to develop

Project Code	Name of Project	Installed Capacity (MW)	Annual Energy (GWh)	Total	Rank	Reasons why development is difficult
A-4	Kunzangling	860	3,766	74.7	10	Main component is in protected area
W-6	Chuzom	152	664	45.9	37	Many residents need to be resettled
W-19	Pipingchhu	100	436	65.5	24	Geologically difficult
P-15	Tamigdamchu	188	824	61.3	31	Main component is in protected area

Project Code	Name of Project	Installed Capacity (MW)	Annual Energy (GWh)	Total	Rank	Reasons why development is difficult
P-28	Kago-1	102	448	79.2	5	Main component is in protected area
P-38	Tashiding	81	356	68.6	21	Geologically difficult
M-5	Bemji	333	1,458	73.0	13	Main component is in protected area
G-6	Khamdang	512	2,242	73.1	12	Very close to international border
G-9	Gamrichhu-3	123	538	67.3	23	Main component is in protected area
G-13	Sherichhu	58	254	64.8	27	Geologically difficult
G-19	Nagor	59	258	64.0	29	Geologically difficult
G-22	Panbang	993	4,349	57.9	34	Geologically difficult
N-2	Lamai Gonpa	37	161	64.2	28	Geologically difficult

(Source: JICA Survey Team)

Excluding the 13 sites that would be difficult to develop, the resulting 24 sites are sorted in descending order of evaluation score, as shown below.

Table 7-73 Overall Rank (Base Case)

Rank	Project Code	Name of Project	Installed Capacity (MW)	Annual Energy (GWh)	Technical	Economic	Impact on Social environ-ment	Impact on Natural environ-ment	Social develop-ment	Total
1	C-10	Chamkharchhu-II	414	1,814	15.0	20.0	20.0	15.0	18.0	88.0
2	A-5	Tingma	783	3,428	15.4	20.0	20.0	14.6	14.0	84.0
3	A-8	Dorokha	550	2,407	15.9	20.0	20.0	14.6	12.4	82.9
4	P-30	Pinsa	153	672	15.9	20.0	20.0	11.4	12.0	79.3
5	M-6	Jongthang	227	995	15.9	19.2	14.8	15.4	10.8	76.1
6	P-29	Kago	58	255	14.6	14.4	20.0	12.2	14.8	76.0
7	M-17	Buli	69	302	15.0	14.8	20.0	12.4	13.6	75.8
8	G-10	Gamrichhu-2	108	471	14.3	14.8	20.0	15.6	10.8	75.5
9	P-26	Thasa	706	3,094	15.6	14.8	17.0	15.2	11.6	74.2
10	P-35	Dagachhu-II	71	311	14.6	10.4	20.0	15.4	11.2	71.6
11	G-11	Gamrichhu-1	150	656	13.7	14.8	17.6	15.4	10.0	71.5
12	N-1	N.A. Kangpara (G)	71	312	13.5	12.8	20.0	15.2	10.0	71.5
13	P-34	Darachhu	89	389	14.1	12.0	16.8	15.2	12.8	70.9
14	G-14	Uzorong	840	3,678	14.2	20.0	8.4	15.0	13.0	70.6
15	C-7	Chamkharchhu-IV	451	1,974	13.6	20.0	10.0	16.0	9.6	69.2
16	P-17	Tseykha	215	943	16.2	20.0	12.0	11.2	9.6	69.0
17	N-3	Paydung-Kangpar	73	319	13.9	10.0	17.6	15.4	11.4	68.3
18	G-16	Jerichhu	39	169	13.0	5.2	20.0	16.2	11.0	65.4
19	M-18	Nyekhar	43	188	15.2	4.0	20.0	12.2	14.0	65.4
20	K-13	Minjey	673	2,948	13.4	19.6	8.0	10.2	11.2	62.4
21	G-7	Gongri	546	2,392	15.6	12.8	7.0	15.2	10.0	60.6
22	K-15	Phawan	499	2,185	14.5	6.8	13.4	12.2	12.4	59.3
23	M-11	Wangdigang	502	2,200	15.3	17.2	9.0	10.4	4.8	56.7
24	W-8	Zangkhepa	54	236	14.3	4.0	15.2	13.8	4.8	52.1

(Source: JICA Survey Team)

Because the top 14 sites have a high overall score of 70 points or more, these sites should be developed with priority.

For the above 24 sites, the results of the "Economy Emphasizing Case" were reevaluated, whereby the weight of Technical is increased. The results of sorting the sites in descending order of B/C are shown below.

Table 7-74 Evaluation for "Economy Emphasizing Case"

Economy Emphasizing Case (Tech. 60%, Env. 20%, Dev 20%)				Descending order of B/C			
Rank	Project Code	Name of Project	Score	Rank	Project Code	Name of Project	B/C
1	C-10	Chamkharchhu-II	88.0	1	A-5	Tingma	2.81
2	A-5	Tingma	84.4	2	P-30	Pinsa	2.32
3	A-8	Dorokha	83.5	3	C-10	Chamkharchhu-II	2.21
4	P-30	Pinsa	81.6	4	G-14	Uzorong	2.09
5	M-6	Jongthang	78.5	5	C-7	Chamkharchhu-IV	1.90
6	G-14	Uzorong	75.9	6	A-8	Dorokha	1.84
7	P-17	Tseykha	75.5	7	P-17	Tseykha	1.82
8	M-17	Buli	74.4	8	K-13	Minjey	1.77
9	P-29	Kago	74.4	9	M-6	Jongthang	1.75
10	P-26	Thasa	73.3	10	M-11	Wangdigang	1.66
11	C-7	Chamkharchhu-IV	73.0	11	G-11	Gamrichhu-1	1.55
12	G-10	Gamrichhu-2	72.3	12	M-17	Buli	1.55
13	K-13	Minjey	69.8	13	G-10	Gamrichhu-2	1.54
14	G-11	Gamrichhu-1	69.3	14	P-26	Thasa	1.53
15	P-34	Darachhu	68.0	15	P-29	Kago	1.51
16	N-1	N.A. Kangpara (G)	67.0	16	G-7	Gongri	1.44
17	P-35	Dagachhu-II	66.5	17	N-1	N.A. Kangpara (G)	1.44
18	N-3	Paydung-Kangpar	63.8	18	P-34	Darachhu	1.41
19	G-7	Gongri	63.8	19	P-35	Dagachhu-II	1.33
20	M-11	Wangdigang	63.3	20	N-3	Paydung-Kangpar	1.29
21	M-18	Nyekhar	58.8	21	K-15	Phawan	1.13
22	K-15	Phawan	57.1	22	G-16	Jerichhu	1.06
23	G-16	Jerichhu	56.3	23	M-18	Nyekhar	0.98
24	W-8	Zangkhepa	46.7	24	W-8	Zangkhepa	0.76

(Source: JICA Survey Team)

For the above 24 sites, the results of the "Environment Emphasizing Case" were reevaluated, whereby the weight of Environment is increased, and the results of "Development Emphasizing Case", whereby the weight of Social development is increased. These are shown below.

Table 7-75 Evaluation for "Environment Emphasizing Case" and "Development Emphasizing Case"

Environment Emphasizing Case (Tech. 20%, Env. 60%, Dev. 20%)				Development Emphasizing Case (Tech. 30%, Env. 30%, Dev 40%)			
Rank	Project Code	Name of Project	Score	Rank	Project Code	Name of Project	Score
1	C-10	Chamkharchhu-II	88.0	1	C-10	Chamkharchhu-II	88.5
2	A-5	Tingma	83.6	2	A-5	Tingma	80.5
3	A-8	Dorokha	82.2	3	A-8	Dorokha	77.6
4	G-10	Gamrichhu-2	78.8	4	P-29	Kago	75.5
5	P-29	Kago	77.6	5	P-30	Pinsa	74.5
6	M-17	Buli	77.1	6	M-17	Buli	73.8
7	P-30	Pinsa	77.1	7	M-6	Jongthang	70.6
8	P-35	Dagachhu-II	76.8	8	P-26	Thasa	70.2
9	N-1	N.A. Kangpara (G)	75.9	9	G-10	Gamrichhu-2	70.2
10	P-26	Thasa	75.1	10	P-34	Darachhu	69.2
11	G-16	Jerichhu	74.4	11	G-14	Uzorong	69.2
12	P-34	Darachhu	73.9	12	P-35	Dagachhu-II	67.7
13	G-11	Gamrichhu-1	73.8	13	M-18	Nyekhar	66.5
14	M-6	Jongthang	73.6	14	G-11	Gamrichhu-1	66.1
15	N-3	Paydung-Kangpar	72.9	15	N-1	N.A. Kangpara (G)	66.1
16	M-18	Nyekhar	71.9	16	N-3	Paydung-Kangpar	65.5
17	C-7	Chamkharchhu-IV	65.4	17	C-7	Chamkharchhu-IV	63.9
18	G-14	Uzorong	65.2	18	P-17	Tseykha	63.7
19	P-17	Tseykha	62.5	19	G-16	Jerichhu	62.8
20	K-15	Phawan	61.4	20	K-13	Minjey	60.8

Environment Emphasizing Case (Tech. 20%, Env. 60%, Dev. 20%)				Development Emphasizing Case (Tech. 30%, Env. 30%, Dev 40%)			
Rank	Project Code	Name of Project	Score	Rank	Project Code	Name of Project	Score
21	G-7	Gongri	57.5	21	K-15	Phawan	59.9
22	W-8	Zangkhepa	57.4	22	G-7	Gongri	58.0
23	K-13	Minjey	55.0	23	M-11	Wangdigang	48.5
24	M-11	Wangdigang	50.2	24	W-8	Zangkhepa	45.0

(Source: JICA Survey Team)

7.5.3 Selection of Short listed Sites

Fourteen (14) sites with an overall evaluation score of 70 points or more (with an overall evaluation rank of 14 or less) are sites to be developed with priority. In addition, it is not included the sites that have major issues in development in the 24 sites that were finally evaluated. Therefore, even if the overall evaluation rank is 15 or less, the sites where the evaluation score is 75 or more when the weight of each item is changed, and the sites whose B/C is 1.5 or more, are selected as promising sites. It is thought that these sites should be developed.

Based on the evaluation results in the secondary screening, the following 18 sites are selected as Short listed sites.

Table 7-76 Short listed Sites

Project Code	Name of Project	Project Type	Installed Capacity (MW)	Annual Energy (GWh)	Max discharge (m^3/s)	Effective head (m)	B/C
A-5	Tingma	ROR	783	3,428	148.3	611.9	2.81
A-8	Dorokha	ROR+Pond	550	2,407	174.8	364.6	1.84
P-17	Tseykha	ROR	215	943	162.8	153.5	1.82
P-26	Thasa	Pondage	706	3,094	489.3	167.4	1.53
P-29	Kago	ROR	58	255	17.9	376.7	1.51
P-30	Pinsa	ROR	153	672	29.4	604.5	2.32
P-34	Darachhu	ROR	89	389	15.3	674.3	1.41
P-35	Dagachhu-II	ROR	71	311	21.3	386.0	1.33
M-6	Jongthang	ROR+Pond	227	995	83.3	316.2	1.75
M-11	Wangdigang	ROR+Pond	502	2,200	176.4	330.2	1.66
M-17	Buli	ROR	69	302	14.0	572.0	1.55
C-7	Chamkharchhu-IV	Pondage	451	1,974	130.7	399.9	1.90
C-10	Chamkharchhu-II	ROR+Pond	414	1,814	130.4	368.3	2.21
K-13	Minjey	Pondage	673	2,948	381.5	204.6	1.77
G-10	Gamrichhu-2	ROR+Pond	108	471	23.7	525.5	1.54
G-11	Gamrichhu-1	ROR	150	656	38.1	455.7	1.55
G-14	Uzorong	Pondage	840	3,678	615.9	158.1	2.09
N-1	N.A. Kangpara (G)	ROR	71	312	10.8	762.6	1.44
	Total		6,130	26,849			

Note) ROR: Run-of-River Type (no regulating capability)
ROR+Pond: Run-of-River Type with Pond (daily regulating capability)
Pondage: Pondage Type (Regulating capability: 5% or less)

(Source: JICA Survey Team)

It is desirable that these sites be developed with priority, as they are considered to be sites that have little adverse impact on the natural environment and the social environment, and are also expected to be profitable from an economic aspect.

Chapter 8. Power Development Plan

The future power development plan based on the results of previous studies is as discussed in this chapter.

8.1 Power Development Scenario

(1) Existing sites and planned sites

An outline of the existing sites and planned sites is shown below.

Table 8-1 Outline of Existing Sites and Planned Sites

	Name	Installed capacity (MW)	Annual energy (GWh)	Status
Existing	Chhukha	336	1,840	Under Operation
	Tala	1,020	4,865	Under Operation
	Basochhu	64	300	Under Operation
	Dagachhu	126	552	Under Operation
	Kurichhu	60	400	Under Operation
	Mangdechhu	720	2,924	Under Operation
	Sub total	2,326	10,881	
2020-2025	Punatsangchhu-II	1,020	4,667	Under Construction
	Nikachhu	118	505	Under Construction
	Punatsangchhu-I	1,200	5,585	Under Construction
	Kholongchhu	600	2,599	Under Construction
	Sub total	2,938	13,356	
2026-2030	Dorjilung	1,125	4,558	DPR completed
	Sankosh	2,585	6,365	DPR completed
	Nyera-Amari I & II	404	1,700	DPR under process
	Sub total	4,114	12,623	
2031-2035	Wangchhu	570	2,011	DPR completed
	Bunakha reservoir	180	719	DPR completed
	Chamkharchhu-I	770	3,344	DPR completed
	Kuri-Gongri	2,640	10,056	DPR under process
	Sub total	4,160	16,130	
Beyond 2040	Amochhu reservoir	540	1,835	DPR completed
	Total	14,078	54,825	

Note: as of August 2019

(Source: created by the JICA Survey Team based on NTGMP 2018)

These sites shown above are already under construction or under investigation and development is decided, so they are out of scope for this MP.

(2) Target sites for this MP

Based on the evaluation results in the secondary screening, the 18 sites shown in Table 7-76 are selected as short listed sites.

8.2 Proposal on Power Development Plan

In Bhutan, there are already sufficient power generation facilities that enable the country to exceed domestic power demand. Therefore, the main objectives for developing hydropower plants in Bhutan are as follows.

- To develop hydropower, which is a domestic resource, and sell it to neighboring countries to secure foreign currency income and stabilize the national finances.
- To attract overseas industries (especially power-intensive industries) to create domestic demand and secure employment with the development of hydropower, which can supply cheap electricity.
- Regional development will facilitate access to social infrastructure, such as education and healthcare, through the construction of roads that will be developed along with hydropower development in areas where sufficient education and healthcare have not been provided so far.
- In addition to the fact that employment can be secured for construction and operation, trading of various goods in the development area increases, and improvement of the poverty rate in the development area can be expected.

The following economic effects can be expected when developing a hydropower plant in Bhutan.

Table 8-2 Economic Effects that can be expected when developing a Hydropower Plant

<**During construction**>

	Impacts on national level	**Impacts on the surrounding area**
Securing employment	Employment of skilled workers	Employment of non-skilled workers
Purchase of major equipment	No impact at all (Because these are not produced in Bhutan, and have to be imported.)	No impact at all
Civil work	Main contractors: Indian companies Subcontractors: Bhutanese companies (partly)	No particular impact Secondary subcontractors: Local companies
Purchase of materials	Iron: Imported from India Manufacturing of rebar: Bhutanese companies (partly) Cement, gravel: Bhutanese companies (partly)	No particular impact
Construction of worker's dormitories	Increase orders to domestic house builders and furniture suppliers	Increase orders to local house builders and furniture suppliers
Purchase of daily necessities	No significant impact	Purchase volumes increase in the surrounding area while construction workers are staying there
Expansion of road construction	Avoiding expenditure from the state financial resources (however, the expansion priority may not be high)	Shorter access time to social infrastructure (hospitals/schools) Same as during operation
Transportation of materials	Impact on domestic transport industry	Some impact
Movement of personnel	No significant impact	Increase in use of taxis etc.

<**During operation**>

	Impacts on national level	**Impacts on the surrounding area**
Power sales	Very big income resource	Improvement of system reliability
Providing ancillary services	Depends on Indian market	No impact at all
Carbon credit sales	Depends on Indian market	No impact at all

Securing employment	Employment of skilled workers	Employment of non-skilled workers (not as much as during construction)
Purchase of materials	Maintenance goods: Bhutanese companies (partly)	No particular impact
Purchase of daily necessities	No significant impact	Volume increases in the surrounding area (not as much as during construction)
Attract new electricity customers	Employment of workers (in industrial zone)	No particular impact
Conversion from other energies	Decrease in firewood usage Suppression of petroleum-based fuel imports (introduction of EVs, FCVs, etc.)	No particular impact
Tourism	Increase in tourists	Derivation of new tourism resources is possible depending on maintenance method and advertisement method
Buildings during construction	No significant impact	Possibility of new industries by using the site and buildings

(Source: JICA Survey Team)

In this way, when developing a hydropower plant, many economic effects can be expected on the national level and the surrounding areas. Therefore, a project that greatly contributes to regional development and has very few negative impacts on the natural environment and social environment, and gains certain benefits from the economic aspect, should be actively promoted. However, in promoting each project, in addition to securing construction funds, it is necessary to allocate excellent human resources in order to ensure conditions of advanced quality control.

There are already plans to carry out the development of 11,212MW at 11 sites by 2035, including sites under construction. Many of these sites will be developed in collaboration with India, with full support from India in terms of financial and human resources. It is assumed that many skilled Bhutanese persons will be required to realize these developments. However, in addition to the development of these sites, it is desirable to develop the promising sites (short listed sites) extracted by this MP at the same time because they will also be highly profitable and can be expected to contribute to regional development.

The speed of development will differ depending on the type of development formula for each project. If all projects are implemented by Bhutanese alone, the amount of skilled human resources in Bhutan will be limited, and there is a limit to the number of projects that can be developed simultaneously. With regard to project quality control, it is possible to increase the number of projects developed simultaneously by hiring experienced foreign consultants.

The development plan for the promising sites extracted by this MP is shown below.

Table 8-3 Development Plan for the promising Sites extracted by this MP

	Project Code	Name of Project	Installed Capacity (MW)	Annual Energy (GWh)	Construction cost (million Nu)			Unit cost (Nu/kW)	Unit cost (Nu/kWh)
					Power plant	T/L	Total		
2031-35	A-8	Dorokha	550	2,407	46,103	4,341	50,444	91,717	21.0
	C-10	Chamkharchhu-II	414	1,814	34,377	4,251	38,628	93,303	21.3
	P-30	Pinsa	153	672	8,947	1,596	10,543	68,911	15.7
		Total	1,117	4,893	89,427	10,188	99,615		
2036-40	A-5	Tingma	783	3,428	37,491	5,307	42,798	54,659	12.5
	M-6	Jongthang	227	995	22,878	2,913	25,791	113,617	25.9
	G-14	Uzorong	840	3,678	78,776	5,298	84,074	100,088	22.9
		Total	1,850	8,101	139,145	13,518	152,663		
2041-50	P-17	Tseykha	215	943	21,463	2,340	23,803	110,712	25.2
	P-26	Thasa	706	3,094	79,615	2,852	82,467	116,809	26.7
	P-29	Kago	58	255	5,116	988	6,104	105,239	23.9
	P-34	Darachhu	89	389	8,650	1,427	10,077	113,225	25.9
	P-35	Dagachhu-II	71	311	7,276	1,250	8,526	120,087	27.4
	M-11	Wangdigang	502	2,200	49,895	2,877	52,772	105,124	24.0
	M-17	Buli	69	302	6,070	1,010	7,080	102,609	23.4
	C-7	Chamkharchhu-IV	451	1,974	37,916	4,416	42,332	93,863	21.4
	K-13	Minjey	673	2,948	81,444	5,941	87,385	129,844	29.6
	G-10	Gamrichhu-2	108	471	10,552	1,778	12,330	114,168	26.2
	G-11	Gamrichhu-1	150	656	13,642	1,739	15,381	102,541	23.4
	N-1	N.A. Kangpara (G)	71	312	6,134	1,814	7,948	111,939	25.5
		Total	3,163	13,855	327,773	28,432	356,205		
		All Total	6,130	26,849	556,345	52,139	608,484		

Note: The construction cost is an estimated value calculated using the construction cost calculation kit created in this MP.

(Source: JICA Survey Team)

The priority of the development plan basically follows the overall evaluation order (Base Case) shown in Table 7-73. However, some corrections have been made for the following sites.

- Comparing the overall evaluation score at Tingma and Dorokha, Tingma is slightly higher, but there is no significant difference. Both sites are in the same Amochhu basin, and the Tingma site is located upstream of the Dorokha site. At present, there is an access road around the dam and power plant site at Dorokha, but there is no access to the Tingma site, so construction at the Dorokha site is easier. For this reason, it is desirable to prioritize the development of the Dorokha site and continue to develop the Tingma site after the environmental conditions for development, such as access roads and worker accommodation (colonies), have been established.
- There are 35 buildings and farmland in the planned inundation area at the Uzorong site, and the overall evaluation score is low because the evaluation score for the social environment is very low. However, it has a high score in economic and social development. There is information that only 4 out of 35 buildings in the inundation area are permanent residences, and it is desirable that development priority be given to the Uzorong site if the impact on the buildings and farmland existing in the inundation area can be avoided by securing alternative land.

The development of 18 sites (6,130MW) in 20 years from 2031 to 2050 is proposed. Although this is the same as the development time for the already decided sites at the planning stage, which are out of scope of this MP, three sites with high development priority, identified as a result of the MCA evaluation, shall be developed from 2031 to 2035.

The total construction cost for the 18 sites shown above is Nu. 608.5 billion, and on average over the 20 years, approximately Nu. 30.4 billion will be needed each year.

8.3 Contribution to reducing Greenhouse Gas (CO_2) Emissions

If the power generated in Bhutan is exported to India, it will be possible to reduce the amount of thermal power generation in India and reduce CO_2 emissions by about 0.7 tons per MWh (refer to 4.6). If all the Short listed sites extracted in this MP are developed, annual power generation of 29,171 GWh can be obtained. This will contribute to reducing CO_2 emissions by about 20 million tons annually.

8.4 Promising Hydropower Projects

Conceptual designs for 5 promising hydropower projects (A-8: Dorokha, P-30: Pinsa, C-10: Chamkharchhu II, G-14: Uzorong, M-6: Jongthang) described in Section 8.2 were examined.
The primary features were determined according to Section 6.1.3 (3), but it is necessary to repeatedly review them in order to make them optimal, since the primary features may change in line with the design of the structures.
These conceptual designs were conducted based on GIS maps with a scale equivalent to 1/25,000.

8.4.1 Dorokha (A-8) HPP

(1) Hydrology

Reliability of hydrological data is high, since Dorokha gauging station (Monitoring period: 19 years) is in the vicinity of the dam site and the ratio catchment area at the gauging station and dam site is 0.85.
Designed discharge was estimated based on the designed unit discharge of the Amochhu upstream basin, which is described in Table 5-22.
Since the specific sediment yield at Dorokha gauging station is 516 ton/km^2, the annual sediment volume is estimated to be 1.34 million tons/year.

(2) Topographical and Geological Conditions

The topographical and geological conditions are described in Appendix-1 (3).

(3) Conceptual Designs of Primary Features

Primary features were examined as shown in Table 8-4.

Table 8-4 Primary Features of Dorokha HPP

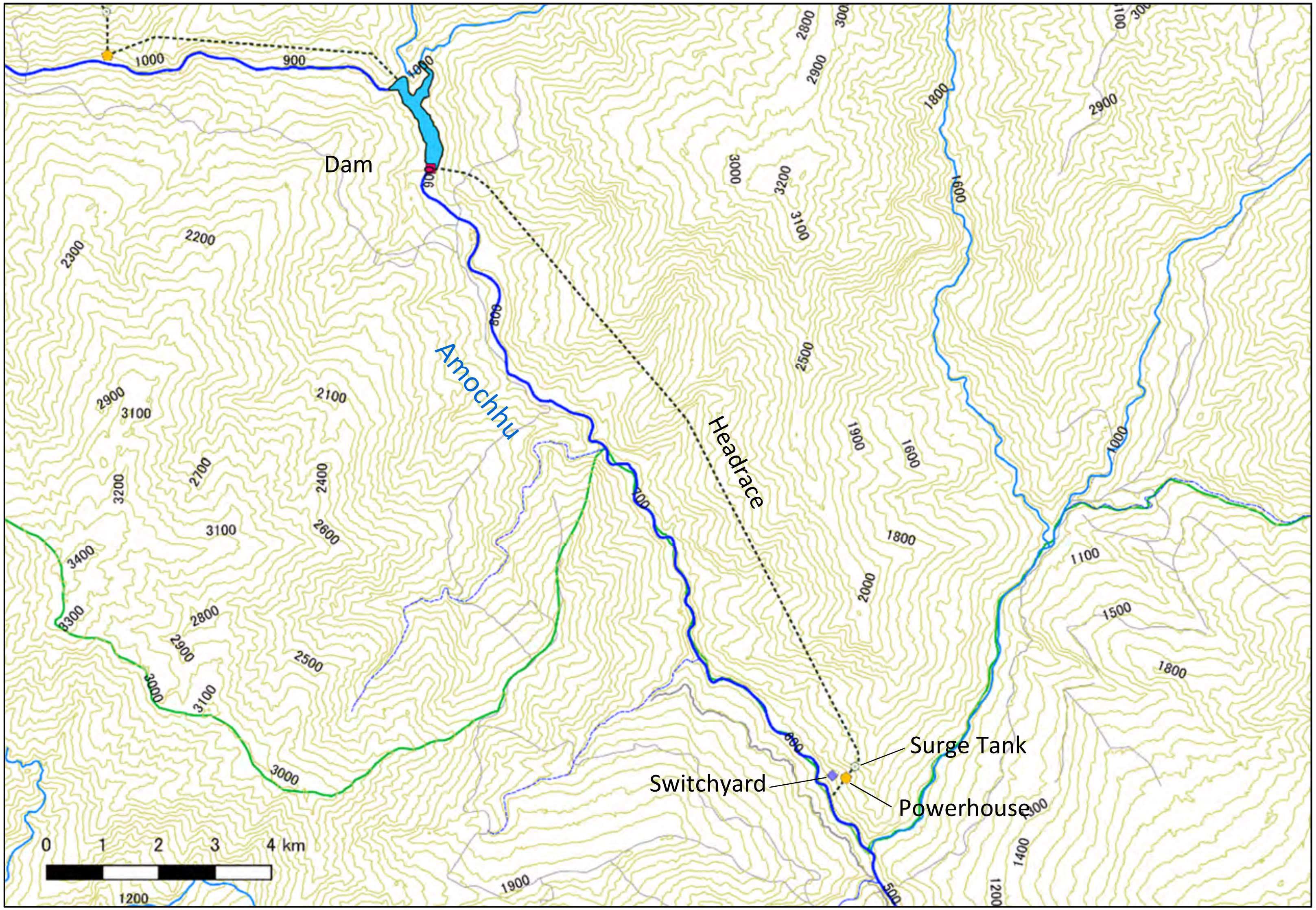
Items			Unit	Description
General	Type			ROR with Pond (II-2)
	Installed Capacity	P	MW	550
	Designed Discharge	Qd	m^3/s	174.8
	Effective Head	Hd	m	364.6
Dam and Reservoir	Type			Concrete Gravity Dam
	Height	H	m	84
	Sediment Depth		m	27
	River Bed Level	RBL	m	840
	Crest Length	L	m	250
	Dam Volume	V	m^3	445,000
	Excavation Volume	Ve	m^3	1,093,000
	Reservoir Area	Ra	ha	52.7
	Catchment Area	Ca	km^2	2,602
	F.R.L. (Full Reservoir Level)		m	892
	L.W.L. (Low Water Level)		m	872
	Usable Water Depth		m	20
	Effective Reservoir Capacity		mil.m^3	7.9
Waterway	Intake and Desilting Basin	Ve	m^3	250,000
	Headrace	L(m) x n	m	D=7.2m, 13,000 x 1
	Surge Tank	D(m) x L	m	15 x 100

	Penstock (Vertical shaft)	L(m) x n	m	D=5.3m, 620 x 1, 50 x 2
	Tailrace	L(m) x n	m	D=6.6m, 357 x 2
	Total Length	Lt	m	14,000
Power house	Type			Underground
	Overburden		m	280
	Cavern Volume		m^3	156,000
	T.W.L (Tail Water Level)		m	500
Turbine	Type			Pelton
	Number		unit	2
	Unit generating capacity		MW	275.0

(Source: JICA Survey Team)

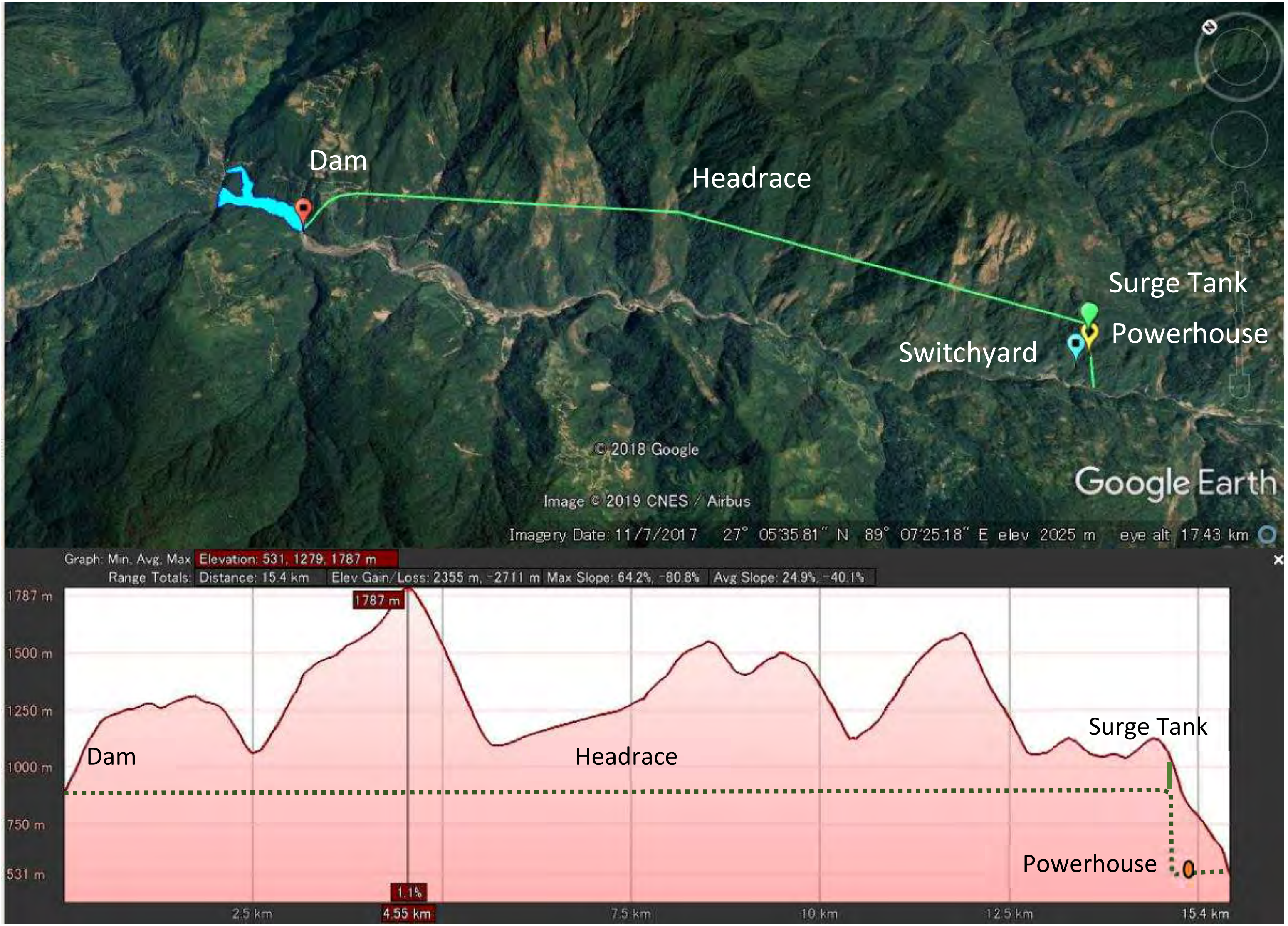
Plot plan and longitudinal profile are illustrated in Figure 8-1 and Figure 8-2, respectively. The following CAD drawings for the general plan and each main civil structure are attached in Appendix – 5 (1).

- General Plan
- Dam and Intake
- Profile of Intake Dam
- Powerhouse and Switchyard



(Source: JICA Survey Team)

Figure 8-1 Dorokha HPP: Plot Plan



(Source: JICA Survey Team)

Figure 8-2 Dorokha HPP: Longitudinal Profile

(4) Design of Main Structures and Facilities

(a) Civil structures

1) Intake dam and pond

Since the geological conditions are fair and a large flood flow of more than 5000m^3/s is anticipated, a concrete gravity dam, for which a spill way can be installed in the dam body, is adopted.
Diversion tunnel and coffer dams are to be constructed during dam construction so that flood flow, for which the probability is once in 10 years, can be diverted. In addition, coffer dams are planned to be built not only upstream but also downstream of the dam in order to excavate and remove the riverbed sediment, the depth of which is assumed to be 27m.

2) Intake and Desilting basin

The intake is planned for the right upstream of the dam in parallel with the dam axis on the left bank, where the geological conditions are fair, and in order to avoid inflow of earth and sand as much as possible. Although it has a pond, it is necessary to construct a desilting basin, because a sediment volume of 1.34 million tons/year is assumed. In addition, since it is topographically difficult to adopt a ground surface type, a pressure tunnel type is adopted.

3) Waterway and Powerhouse

The waterway route runs through the left bank of Amochhu, according to the geological and topographical conditions, and it should be the shortest route connecting the intake and the outlet.

a) Headrace

The headrace is a pressure tunnel and the inner diameter is determined to be 7.2m (one line) according to the “Guideline & Manual for Hydropower, JICA”. The excavation shape is a horseshoe, of 8.2m in height.

- Lining of the tunnel with reinforced concrete is to be conducted after excavation
- If it is necessary to improve the permeability and deformability of any loosened zone around the tunnel caused by blasting, implementation of consolidation grouting is to be examined

b) Headrace Surge Tank

The headrace surge tank location is determined so that the top end of the surge tank appears on the ground surface along the ridge, where geological conditions are fair.

c) Penstock

The penstock is planned to have a slope of 10% from the headrace surge tank to the upper bend, where the overburden does not fall below 50m, and thereafter, the penstock is a vertical shaft up to the lower bend (the central elevation of the turbine). The penstock is bifurcated from 1 line to 2 lines at the lower horizontal part and connects the inlet valve. In the construction, after excavation is completed, spaces between steel pipes and the bedrock are filled with concrete.
The details are as follows:

- The inner diameter of the penstock at the upper horizontal part is determined to be 5.3m (one line) according to the “Guideline & Manual for Hydropower, JICA”. The excavation shape is a horseshoe, of 7.0m in height
- The inner diameter of the penstock at the vertical shaft part is determined to be 5.3m (one line) according to the “Guideline & Manual for Hydropower, JICA”. The excavation diameter is 6.5m

d) Powerhouse

Since it is difficult to construct a ground surface type powerhouse in terms of the topography, the powerhouse is to be constructed underground.
In principle, although the location and direction of the underground powerhouse cavern are determined after detailed investigation of the geological conditions via an investigation adit, the location is selected so that the waterway length can be the shortest and the overburden depth does not exceed 500m of the maximum recorded.

The shape and size of the cavern refers to that of Mangdechhu HPP and the “Guideline & Manual for Hydropower, JICA”.
In addition, as permanent tunnels necessary for the underground powerhouse, an equipment transportation tunnel, cable tunnel and drainage tunnel were planned based on a 1/25,000 topographical map.

e) Tailrace

The tailrace is a non-pressure tunnel and one line, since the length is as long as about 350m. The inner diameter is determined to be 8.6m according to the “Guideline & Manual for Hydropower, JICA” and the excavation shape is a horseshoe, of 9.7m in height.

4) Outlet

The commonly used lateral type is adopted for the outlet.

(b) Turbine (Electric facility)

Because the effective head is as large as 380m and water discharge varies greatly between the rainy season and dry season, a Pelton type turbine is adopted, which enables a small discharge to generate electric power.

(c) Switchyard

Area and alignment of the switchyard refer to those of Mangdechhu HPP. The swamp topography on the upstream side of the underground powerhouse is suitable for the switchyard. However, since the plain land elevation is around EL. 550m, which is 50m higher than the powerhouse floor level, the cable tunnel is to be a partially vertical shaft 50m high.
Since the height of the cut slope is currently more than 100m, in future, cut and fill balance and/or adoption of GIS are to be examined based on topographical and geological investigations.

(d) Layout of access tunnels

The critical path for the overall process at this site is the headrace tunnel, which is 13km long. In order to make the construction length 2.5 km per face or less, one access tunnel downstream of the desilting basin, which is diverted to the earth and sand discharge tunnel, one access tunnel at the downstream end of the headrace (at the bottom of the surge tank shaft), and two access tunnels divide three equally between them, totally four access tunnels are aligned, so that the headrace can be constructed with six faces at the maximum.

(5) Rough Construction Cost Estimate

Construction costs were estimated roughly by applying the construction cost estimation kits as described in Section 5.5. The rough construction costs estimated are shown in Table 8-5.

Table 8-5 Rough Construction Costs for Dorokha HPP

(10^6Nu)

Cost Items	Cost	Remarks
I. Preparation Work	1,716	
(1) Access Road	647	
(2) Camp & Facilities	305	(III. Civil Work) x 2%
(3) Compensation & Resettlement	763	(III. Civil Work) x 5%
II. Environmental Mitigation Costs	458	(III. Civil Work) x 2%
III. Civil Work	15,269	
III.1 Intake Dam	5,676	
III.2 Intake Facilities		
(1) Intake	130	
(2) Desilting Basin	1,386	
III.3 Headrace Tunnel	4,914	
III.4 Head Tank/Surge Tank	752	
III.5 Penstock & Side Spillway		
(1) Penstock	155	
(2) Side Spillway	-	
III.7 Powerhouse	1,261	
III.8 Tailrace		
(1) Tailrace Waterway	229	
(2) Tailrace Outlet	38	
III.9 River Diversions from Neighborhood Basin	-	
III.10 Miscellaneous Work	727	(sum of III.1 to III.9) x 5%
IV. Hydromechanical Work	1,610	
(1) Gate and Screen	817	Spillway Gate, Intake Gate, Silt Flush Gate, Tailrace Gate
(2) Penstock	647	
(3) Miscellaneous Work (10% of above total)	146	
V. Electrical Work	9,336	
(1) Electro-Mechanical Equipment	8,891	
(2) Miscellaneous work (5% of above total)	445	
VI. Transmission Line		
(1) Transformer, Switchyard, Transmission Line	4,341	
VII. Administration Costs and Engineering Costs	4,258	(sum of I to V) x 0.15
VIII. Contingency	8,517	(sum of I to V) x 0.3
IX. Interest During Construction	96.7	(sum of I to VIII) x 0.4 x I x T (Assumed I = 0.05, T = 6 years)
Grand Total	50,444	

(Source: JICA Survey Team)

(6) Construction Schedule

Construction speeds of each component for the construction amount for every main civil structure are set as shown in Table 8-6 based on experiences of construction in Japan.

The critical path of the construction schedule is the process of the underground powerhouse and the headrace tunnel. Therefore, the overall construction period is estimated to be 54 months (4 and a half years).

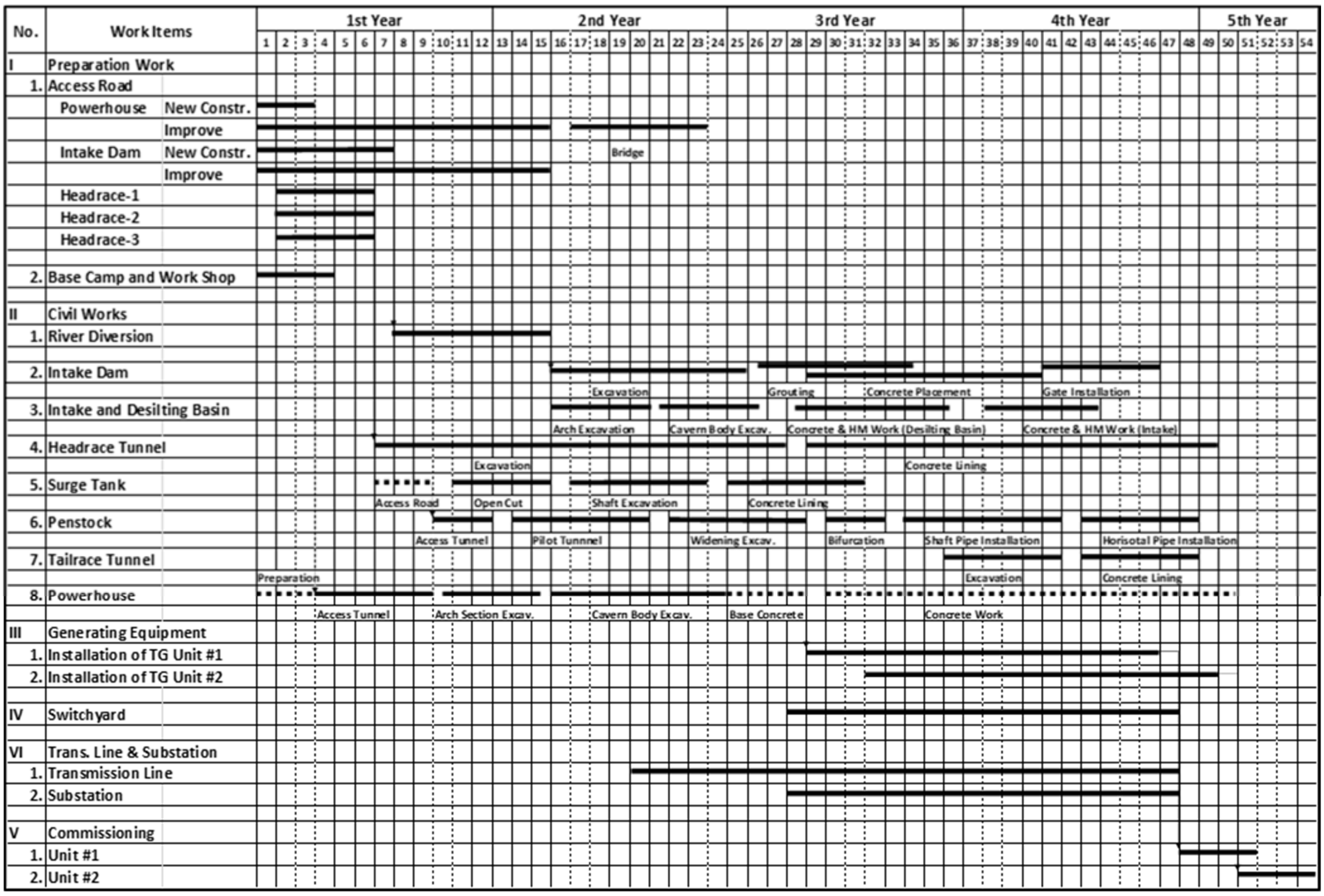
The construction schedule from commencement to commissioning (incl. preparation work) is shown in Table 8-7.

Table 8-6 Construction Speed

No.	Component	Work Item	Construction Speed
1	Access Road	Improvement	1,000 m/month
		New construction	300 m/month
2	Intake Dam	Excavation of Foundation	100,000 m^3/month
		Concrete Placement	40,000 m^3/month
3	Intake and Desilting Basin (tunnel type)	Excavation	Upper: 50 m/mon., Lower: 50 m/mon.
		Concrete Lining	50 m/month
4	Headrace/Tailrace Tunnel	Excavation	125 m/month
		Concrete Lining	100 m/month
5	Surge Tank	Excavation (Shaft)	7 months
		Concrete Lining (Shaft)	7 months
6	Vertical Shaft (Penstock)	Excavation	Pilot: 70 m/mon., Enlargement: 50 m/mon.
		Steel Pipe Installation	50 m/month
7	Excavation of Underground Powerhouse	Arch Part Excavation	5 months
		Enlargement Excavation	9 months

(Source: JICA Survey Team)

Table 8-7 Construction Schedule (Dorokha HPP)



Note) TG: Turbine generator, HM: Hydro-mechanical

(Source: JICA Survey Team)

8.4.2 Pinsa (P-30) HPP

(1) Hydrology

Reliability of hydrological data is low, since the nearest gauging station is Wangdue/Wangdirapids gauging station (Monitoring period: 25 years) and the ratio catchment area at the gauging station and dam site is 0.07. Designed discharge was estimated based on the designed unit discharge of the Punatsangchhu downstream basin, which is described in Table 5-22.
Since the specific sediment yield at Wangdue/Wangdirapids gauging station is 516 tons/km^2, the annual sediment volume is estimated to be 0.22 million tons/year.

(2) Topographical and Geological Conditions

The topographical and geological conditions are described in Appendix-1 (13).

(3) Conceptual Designs of Primary Features

Primary features were examined as shown in Table 8-8.

Table 8-8 Primary Features of Pinsa HPP

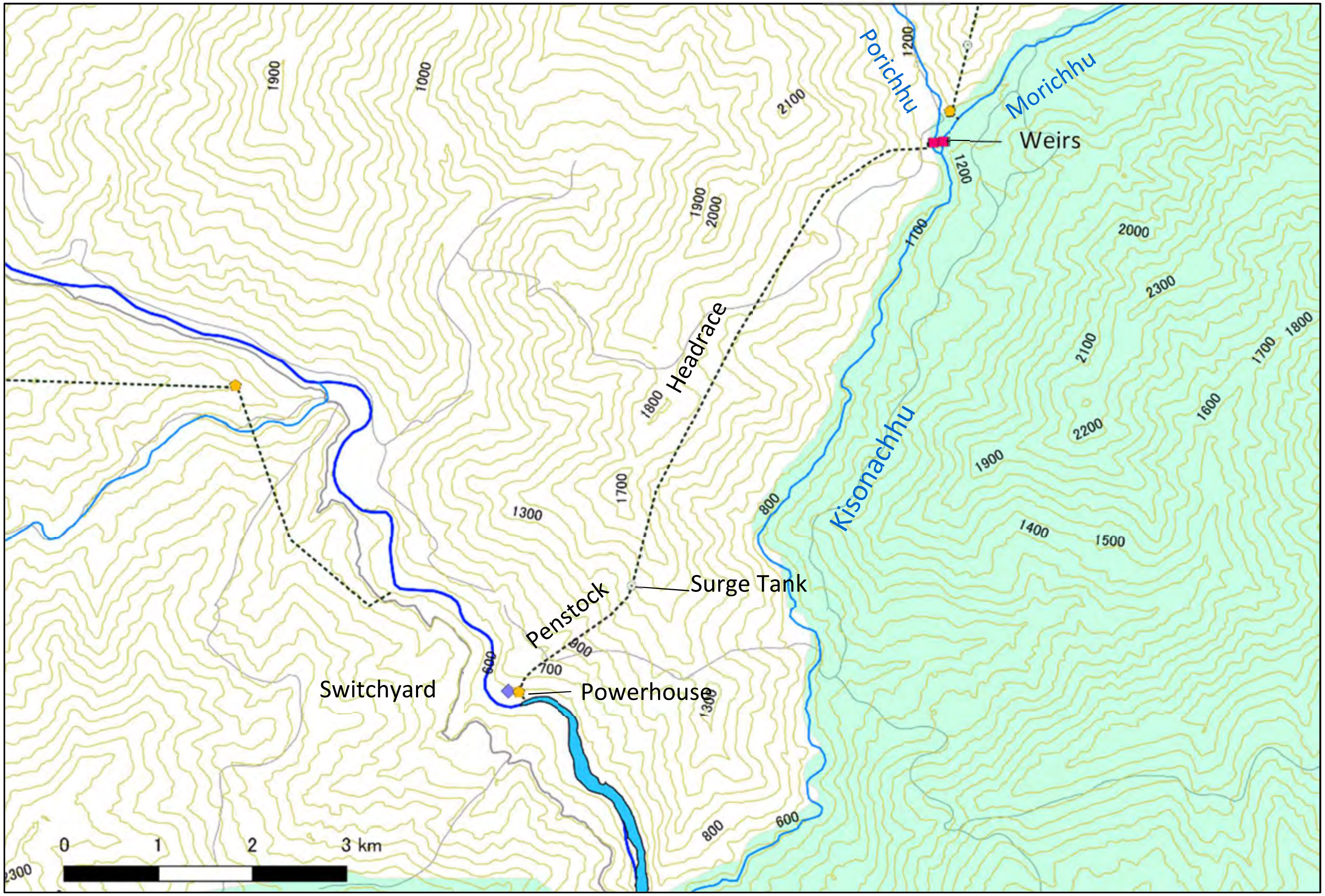
Items			Unit	Description
General	Type			ROR (I-2)
	Installed Capacity	P	MW	153
	Designed Discharge	Qd	m^3/s	20.7, 8.7
	Effective Head	Hd	m	604.8
Dam and Reservoir	Type			Trench Weir
	Height	H	m	5
	Sediment Depth		m	-
	River Bed Level	RBL	m	1,170
	Crest Length	L	m	40 (No. 1), 30 (No. 2)
	Dam Volume	V	m^3	960
	Excavation Volume	Ve	m^3	1,930
	Reservoir Area	Ra	ha	-
	Catchment Area	Ca	km^2	301 (No. 1), 126 (No. 2)
	F.R.L. (Full Reservoir Level)		m	1,170
	L.W.L. (Low Water Level)		m	-
	Usable Water Depth		m	-
	Effective Reservoir Capacity		mil.m^3	-
Waterway	Intake and Desilting Basin	Ve	m^3	-
	Headrace	L(m) x n	m	D=3.7m, 6,130 x 1
	Surge Tank	D(m) x L	m	8 x 100
	Penstock (Inclined shaft)	L(m) x n	m	D=2.8m, 1,563 x 1, 10 x 2
	Tailrace		m	H x W=3.5m x 4.4m, L=79m x 2
	Total Length	Lt	m	7,800
Power house	Type			Ground Surface
	Overburden		m	-
	Excavation Volume		m^3	32,757
	T.W.L. (Tail Water Level)		m	540

Turbine	Type			Pelton
	Number		unit	2
	Unit generating capacity		MW	76.5

(Source: JICA Survey Team)

Plot plan and longitudinal profile are illustrated in Figure 8-3 and Figure 8-4, respectively. The following CAD drawings for the general plan and each main civil structure are attached in Appendix – 5 (2).

- General Plan
- Dam and Intake
- Profile of Intake Dam
- Powerhouse and Switchyard



(Source: JICA Survey Team)

Figure 8-3 Pinsa HPP: Plot Plan