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MINISTRY OF EXTERNAL AFFAIRS



ROYAL GOVERNMENT OF BHUTAN
MINISTRY OF ECONOMIC AFFAIRS

WANGCHU HYDRO-ELECTRIC PROJECT (4X142.5 MW) DISTRICT CHUKHA, BHUTAN



DETAILED PROJECT REPORT

VOLUME – III

HYDROLOGY

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Consultant:

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(A Joint Venture of Govt. of India and Govt. of Himachal Pradesh)

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DETAILED PROJECT REPORT CONTENTS

This Detailed Project Report is presented in following volumes:

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	Executive Summary
Volume-I	Project Engineering
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Volume-II	Bill of quantities and Cost Estimate
Volume-III	Hydrology
Volume-IV	Site Investigations and Geology
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Abbreviations used:

CEA- Central Electricity Authority

CERC – Central Electricity Regulatory Commission

CWC – Central Water Commission

DPR – Detailed Project Report

EJG – Empowered Joint Group

GSI- Geological Survey of India

GWh- Giga Watt hour

HRT- Head Race Tunnel

Km- Kilometer

m – Meter

MDDL- Minimum Drawdown Level

MW – Mega Watt

PMF- Probable Maximum Flood

PMP- Probable Maximum Precipitation

RGoB- The Royal Govt. of Bhutan

ROR- Run-of-the river

SPS- Standard Project Flood

TOD- Top of Dam

TRC- Tail Race Channel

TRT- Tail Race Tunnel

TWL- Tail Water Level

U/s,D/s- Upstream, Downstream

WB- West Bengal

WHEP – Wangchu Hydro Electric Project

1 GENERAL

Bhutan is a land-locked country bordering China in the North and India in the West, South and East. Bhutan lies between latitudes 26.7°N and 28.4°N and longitudes 88.7°E and 92.2°E. It has an estimated hydro potential of 30,000 MW and 120 TWh mean annual energy generation indicating an average development potential of 781kW in a square kilometer of land area. India has been the leading partner in providing both technical and financial assistance towards developing the vast hydropower potential of Bhutan. The relationship developed in the Hydro power sector has been a win-win situation for both the countries as India has a power shortage while Bhutan has a large hydro power potential.

The Royal Government of Bhutan (RGoB) is proposing to harness the country's vast hydro power potential and the RGoB has assigned the task of investigation and preparation of Detailed Project Report (DPR) of various hydro power projects to India.

The work for investigation and preparation of DPR of Wangchu Hydro-Electric Project on river Wangchu has been assigned to SJVN Ltd. through MOP, Govt. of India.

Wangchu Hydroelectric Project is the lower most hydro- electric scheme proposed downstream of Tala Hydroelectric Project on the River Wangchu in Bhutan before it enters India. The project envisages construction of a 134 m high dam across the river Wangchu to provide diurnal storage between FRL 494 m and MDDL 484 m, a 12.38 km long 8.5 m dia headrace tunnel with a discharge capacity of 209 cumec, terminating in a surge shaft of 20 m dia and a surface power house with an installation of 4 units of 142.5 MW each.

The project area lies in the South Western part of Bhutan in Chukha Dzongkhag (District). The dam axis of the project is about 7.5 Km downstream of Tala TRT outfall. The co-ordinates at dam site are 26° 48' 52.63"N - 89° 37' 57.11" E and power house are 26° 46' 06"N - 89° 44' 08" E.

1.1 Objective of Hydro-meteorological Studies

Hydro-meteorological studies have been carried out keeping in view the following objectives;

- To assess the water availability of the proposed project so as to carryout simulation studies for estimation of power potential
- To determine the probable maximum floods corresponding to different probabilities so as to ensure safe passage of flood as well as GLOF
- To determine diversion flood for construction planning
- Assessment of sediment inflow into the reservoir
- Estimation of sediment load and sedimentation studies

2 RIVER SYSTEM AND BASIN CHARACTERISTICS

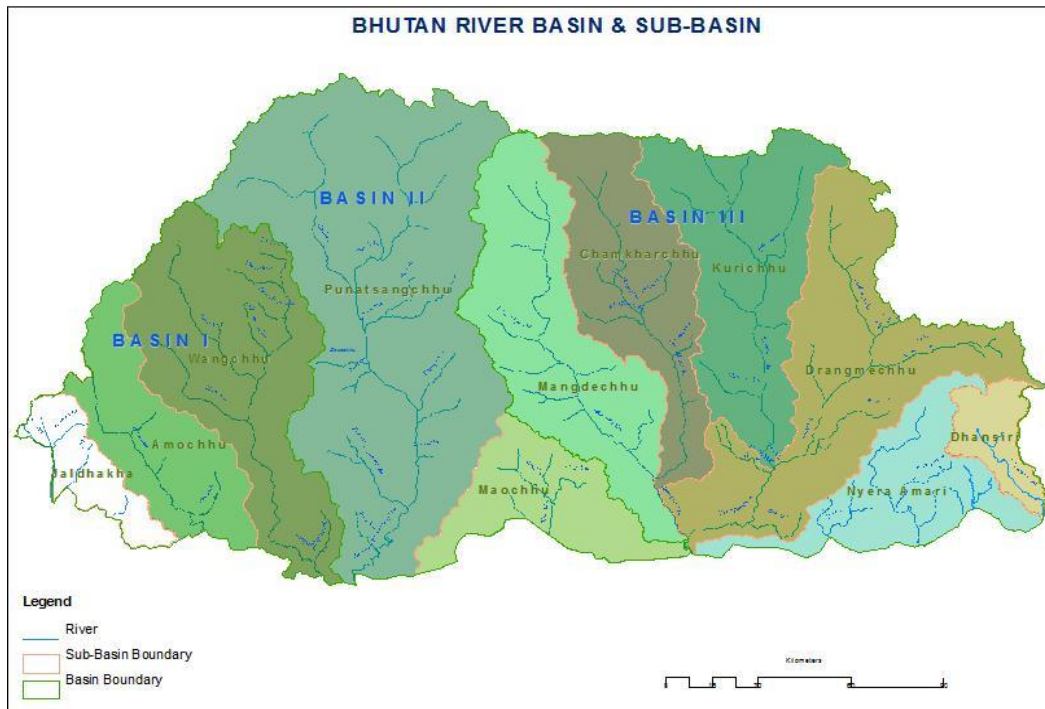
2.1 Wangchu Basin

As per the topography of Bhutan, major rivers flow north to south with their sources in perpetual snow cover. These rivers have steep longitudinal gradients and narrow steep gorges, which occasionally open up and provide broader valleys with small areas of flat land for cultivation. Bhutan's water resources are confined to four major river basins which originate from the high altitude alpine area and from the perpetual snow cover in the north and flow into the Brahmaputra River in the Indian plains.

Wangchu-Amochu basin, situated in the western part of Bhutan comprises of Amochhu and Wangchhu rivers. It is the smallest of the river systems also known as Torsachhu. It has its origin in Chumbi valley of Tibet and flows through western districts of Haa and Samtse before draining into plains of India. It consists of three major tributaries from the three valleys of Thimphu, Paro and Haa. They originate within Bhutan from the glaciers and snow-capped mountains in the north. It flows through Chukha District to the Indian plains of West Bengal.

Wangchu river is formed by the confluence of three major snow-fed streams viz Parochu, Thimpuchu and Haachu, originating in Jumolhari glaciers in the Himalayas at an elevation ranging from 6500 m to 7300 m. Parochu and Thimphu chu streams join at an elevation of 2097 m and Ha chu joins at an elevation of 1961 m. Wangchu river has perennial flow being a snow-fed. It flows in North-South direction. The overall profile of river Wangchu from its source to the diversion site is relatively steep. In its stretch from the confluence of Paro Chu with Thimphu Chu upto the piping junction, the Wangchu descends by about 1900m. There are some glaciers and glacial lakes in the upper portion of the catchment. The total length of rivers with tributaries in Bhutan is about 7200 km. The total length travelled by river Wangchu in Bhutan is lesser as compared to the rivers situated in central and eastern Bhutan such as river Sankosh and Manas.

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2.2 The Catchment

The catchment area of proposed Wangchu Hydro-Electric Project falls in the 1:50,000 toposheet no. 78E/01, E/02, E/03, E/05, E/06, E/07, E/08, E/09, E/10, E/11, E/12, E/15 and 78 F/09, F/13 & F/14 prepared by Survey of India. The project area falls in the toposheet no. F/09. Since, all the toposheets of the catchment were not available, GIS based catchment area mapping was carried out using SRTM DEM. The total catchment area of Wangchu river upto Tala and Wangchu project sites has been found as 3751 km² and 4147 km² respectively. The above catchment area for Wangchu and Tala HEPs includes the 95.5 km² of snowfed catchment common for both the projects. The permanent snowline to find out the snowfed catchment have been considered at 5000 m above msl.

Total catchment area including snowbound area upto various sites on river Wangchu is shown in **Table-2.1**.

Table-2.1

S.No.	Name of site	Snow bound area	Rainfed area	Total catchment area
1.	Bunakha dam site	95.5 km ²	3445 km ²	3540.5 km ²
2.	Tala dam site	95.5 km ²	3655.5 km ²	3751.0 km ²
3.	Wangchu site	95.5 km ²	4051.5 km ²	4147.0 Km ²

The gross catchment area of river Wangchu at proposed dam site is shown in **Plate 2.1**.

2.3 Meteorological Aspects

Bhutan being in the eastern Himalayas, is mostly mountainous, with flat land limited to broader river valleys and along the foothills bordering the Indian subcontinent. Bhutan has perhaps the greatest diversity of climate of any country of its size in the world. The country has three major landform features: the southern foothills, the inner Himalayas and the higher Himalayas. The Wangchu HEP, however, falls in the southern foothills of western Bhutan, the total catchment extends into the inner and higher Himalayas. The climate is humid and subtropical in the project area as it falls in southern foothills. Summer weather commences in mid-April with occasional showers and continues through the pre-monsoon rains of June. The monsoon starts in the month of June and lasts by late September with heavy rains from southwest. The monsoon weather, its northward progress blocked by the Himalayas brings heavy rains, high humidity, flashfloods, landslides and numerous misty overcast days. From late November until March, winter sets in with snowfall common above 3,000 meters.

2.3.1 Temperature

As the project lies in the southern foothills of Himalayas a hot humid climate helps maintain a fairly even temperature range of between 15°C and 30°C year-round, although temperature sometimes reaches 40°C in the valleys during the summer. The temperature



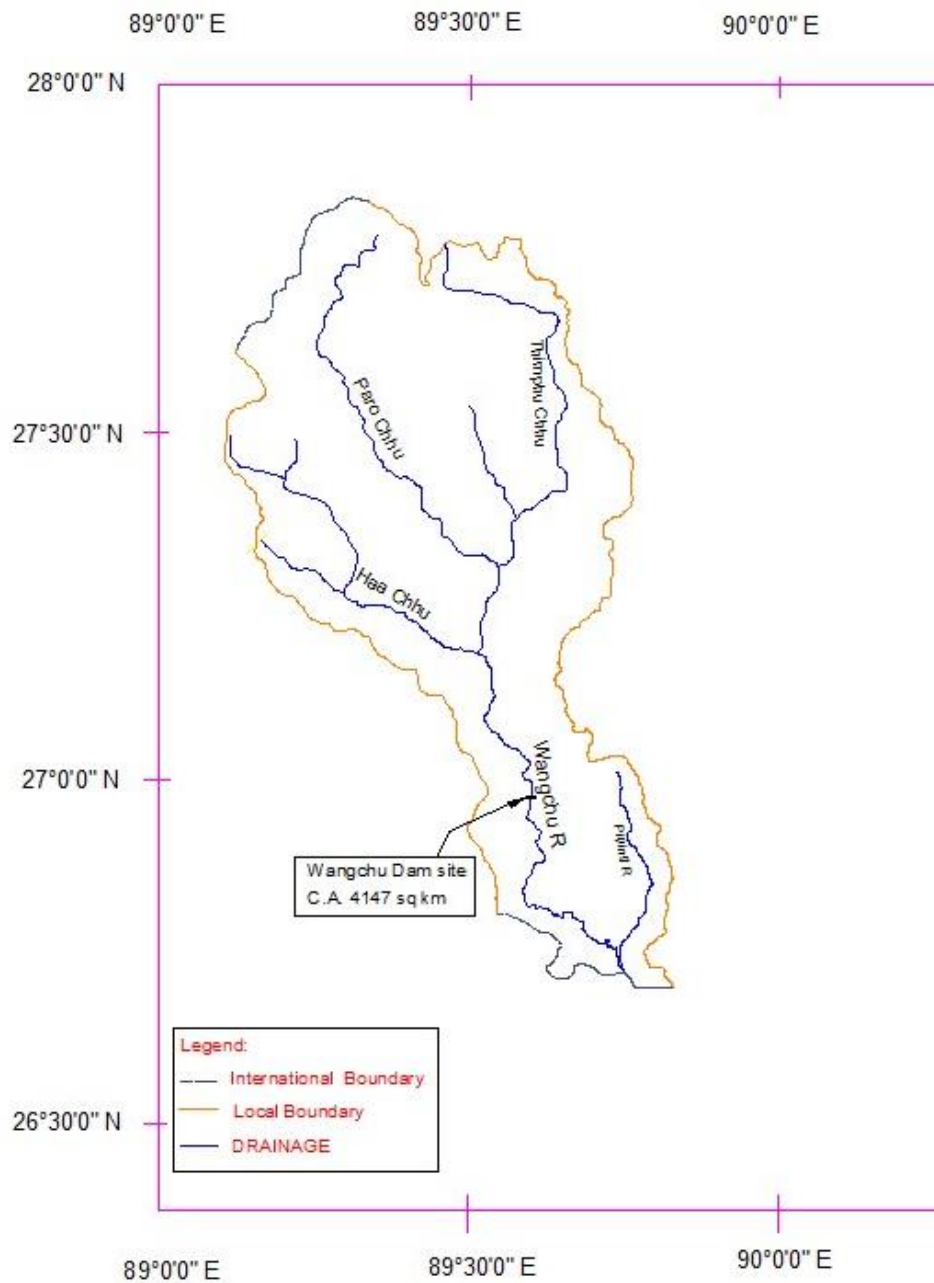
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varies with the altitude. In the Thimphu and Paro valleys, daytime temperature in winter averages 20⁰ C during clear winter days but drops well below freezing during the night with light snowfall and occasional snowstorms.

2.3.2 Precipitation

Distribution of rain in Himalayan mountain region is extremely complex due to complex orography and no generalizations are possible. Western Bhutan is particularly affected by the monsoons that bring between 60 to 90 percent of region's rainfall. Mid December to early January can be beautifully clear and dry here. Annual precipitation varies widely in various parts of the country. During April and May pre-monsoon showers accompanied by hail storm, generally occur and during the month of October, post-monsoon storms occasionally occur, which only last a few days. The November to March period is generally dry and occasional small showers may occur. The northern parts of Bhutan get scanty rainfall and receive precipitation in the form of snow during winter.

CATCHMENT PLAN OF WANGCHU HEP



3 WATER AVAILABILITY STUDIES

A network of hydro-meteorological stations have been established by the Royal Government of Bhutan on various rivers of Bhutan to ensure identification of most promising sites in a systematic manner. The hydro-meteorological data is being monitored and maintained by the Department of Hydro-Met Services, MoEA, RGoB with its head office at Thimphu. Some of automatic stations have loggers to record information which is then downloaded every month, while some of automatic stations transmit data real-time to Thimphu through GSM/GPRS/satellite telemetry.

3.1 Rainfall Data

The rainfall data being monitored at various meteorological stations, in and around the project catchment area, was collected from the Department of Hydro-Met Services, Royal Government of Bhutan and is given in **Table-3.1**.

Table-3.1

S No.	Name of Met. Station	Latitude	Longitude	Elevation (m)	Period of data availability	Average Rainfall (mm)
1	Baisi	26°50' 0"N	89°35' 21"E	504 m	1990-2009	3197.6
2	Lobichu	27°28'22"N	89°38' 21"E	2310 m	1994-2009	1386.9
3	Piping	26°45' 59"N	89°43' 55"E	171 m	1994-2009	4116.3
4	MoEA Complex Thimphu	27°28'16"N	89°38' 14"E	2380 m	1996-2009	665.47
5	Begana	27°26' 30"N	91°10' 35"E	982 m	2008-2009	1053.8
6	Simtokha	27°26' 18"N	89°40' 31"E	2310 m	1996-2009	608.0
7	Gidakom	27°23' 5"N	89°44' 31"E	2210 m	1990-2009	587.87
8	Betikha	27°15' 0"N	89°24' 59"E	2660 m	1990-2008 (except 92-94)	1961.8
9	Dochula	27°28' 59"N	89°45' 0"E	3171 m	1995-2006	1470.8

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S No.	Name of Met. Station	Latitude	Longitude	Elevation (m)	Period of data availability	Average Rainfall (mm)
10	Drukgyel Dzong	27°30' 0"N	89°19' 59"E	2547 m	1995-2009	1021.82
11	Paro	27°22'59"N	89°25' 12"E	2406 m	1996-2009	674.45
12	Chukha	27°03' 59"N	89°33' 59"E	1600.0m	1985-2008	1480.70
13	Gedu	26°54' 29"N	89°31' 33"E	1980.0m	1990-2008	3496.17
14	Namjeyling (Haa)	27°23' 17"N	89°16' 55"E	2720.0m	1990-2009	888.16

The monthly and annual rainfall values for the above said stations are given in **Tables 3.1(a) to 3.1 (k)** and monthly maximum, minimum and mean rainfall variation for each station have been plotted and are given in **Figure 3.1 (a) to 3.1 (j)**. Rainfall data available at above stations in and around the catchment has been utilized to carry out the water availability studies.

3.2 Gauge and Discharge Data

The gauge and discharge data at the proposed dam site was established only in March 2011. The data available on river Wangchu and its tributaries is given in **Table-3.2**.

Table-3.2

S. No.	Name of G&D Site	River	Latitude	Longitude	Elevation (m)	Catch. Area (Sq.km)	Period of Availability of Daily Discharge
1.	Tala Dam site	Wang chu	27°02' 9.5"N	89°35' 43.6"E	1366 m	3751 km ²	June, 1962 to May 2009
2.	Chukha Dam site	Wang chu	27°06' 34"N	89°32' 2"E	1820 m	3540.5 km ²	Jan 1976 to March 1986 Dec 1986 to July 2008

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S. No.	Name of G&D Site	River	Latitude	Longitude	Elevation (m)	Catch. Area (Sq.km)	Period of Availability of Daily Discharge
3.	Piping	Wangchu	26°45' 59"N	89°43' 55"E	171 m	4243 km ²	11th July 1991 to Dec 1992 Jan 1994 to Oct 1994 Feb 1995 to Aug 1995 Jan 1996 to July 2001 21 st Sept 2001 to Oct 2009
4.	Baisi	Wangchu	26°50' 0"N	89°35' 21"E	501 m	3839 km ²	Jan 1995 to Dec 1995 July 1996 to July 1999 Nov 1998 to Feb,99 July 1999 Sept 1999 to July 2000 May 2001 –20 Aug 2003 Sept 2003- 20 Aug 2004 Sept 2004 to March 2009
5.	Tamchhu	Wangchu	27°14' 36"N	89°31' 38"E	1990 m	2520 km ²	May 1995 to March 1999 July 2002 to Dec 2007
6.	Lungtenphu	Thimphu	27°26' 48"N	89°39' 40"E	2260 m	663 km ²	May 1991 to May 2008
7.	Paro	Parochhu	27°26' 00"N	89°25' 30"E	2255 m	1049 km ²	Jan 1988 to June 2008
8.	Haa	Haachhu	27°22' 16"N	89°17' 08"E	2700 m	320 km ²	Jan 2000 to June 2008

The rainfall stations and Gauge and discharge sites located in the catchment area of Wangchu HEP are shown in the **Plate 3.1**.

3.3 Analysis of Data

From the available daily discharge data at the G& D sites situated in the Wangchu catchment, a long inflow data series at Tala dam site is available from 1962-1963 to 2008-2009. Also, the Tala HE project lies upstream of the proposed Wangchu HE project. The flow series of Tala HEP has been utilized to find out the water availability for Wangchu HEP. However, the inflow data at Chukha and other G&D sites on Wangchu river and its tributaries have been utilized while carrying out the hydro-meteorological studies for the project. The inflow series at Tala dam site (1962-1963 to 2008-09) is given at **Annexure 3.1**.

3.3.1 Consistency Checks

Before using the data to find out the water availability series, it needs to be checked for consistency. Following consistency checks were carried out to check the accuracy and consistency of the observed discharge data at various sites.

3.3.1.1 Single Mass Curves

Ten daily average discharge data for Tala dam site, situated just upstream of the proposed Wangchu HEP, is available for 47 years from 1962-63 to 2008-2009. The ten daily average data was used to find out the annual inflows in Million Cubic meters (MCM) and cumulative annual inflows at Tala dam site are listed in the **Table 3.3**. Single mass curve for cumulative annual yield at Tala dam site has been plotted and is given at **Figure 3.2**.

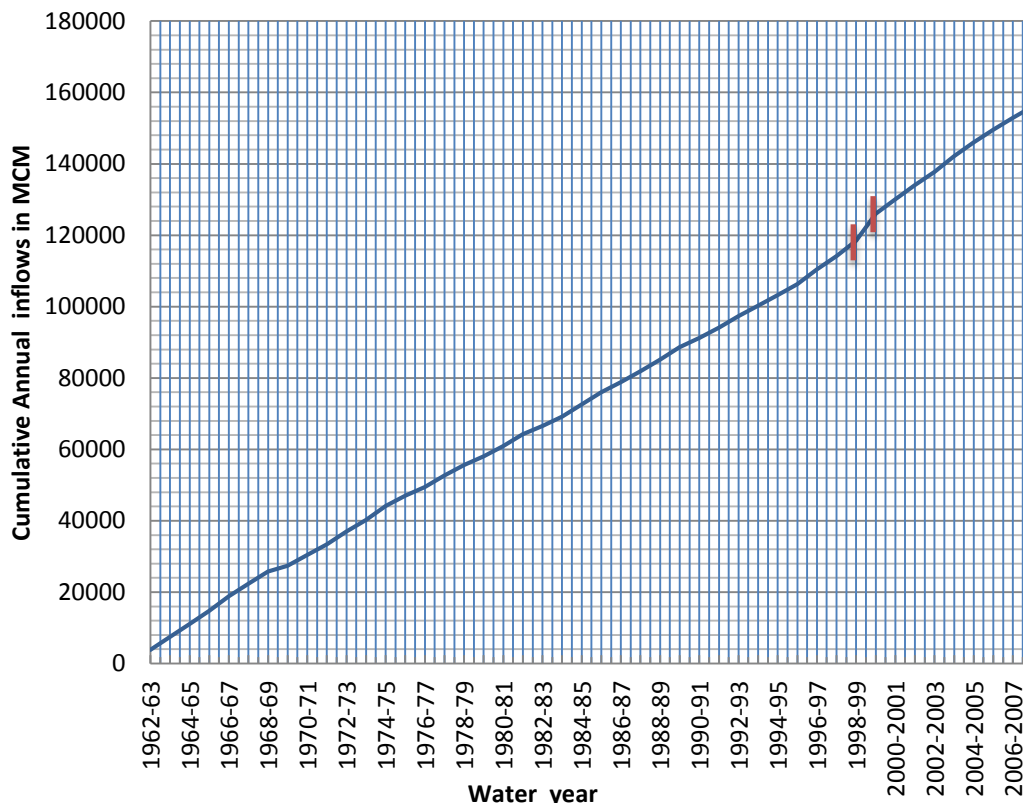
Table 3.3: Annual and cumulative yields at Tala dam site

Year	Annual Inflows In MCM	Cumulative Annual Inflows In MCM	Year	Annual Inflows In MCM	Cumulative Annual Inflows In MCM
1962-63	3770.27	3770.27	1985-86	3383.88	75990.91
1963-64	3752.34	7522.60	1986-87	2904.49	78895.40
1964-65	3551.30	11073.91	1987-88	3021.43	81916.83
1965-66	3714.08	14787.99	1988-89	3172.89	85089.72
1966-67	4113.36	18901.35	1989-90	3525.11	88614.83
1967-68	3486.20	22387.55	1990-91	2577.90	91192.73

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Year	Annual Inflows In MCM	Cumulative Annual Inflows In MCM	Year	Annual Inflows In MCM	Cumulative Annual Inflows In MCM
1968-69	3374.75	25762.31	1991-92	2946.30	94139.03
1969-70	1594.32	27356.62	1992-93	3210.03	97349.06
1970-71	3064.29	30420.91	1993-94	2936.87	100285.94
1971-72	2981.83	33402.74	1994-95	2941.46	103227.40
1972-73	3543.80	36946.54	1995-96	3052.45	106279.85
1973-74	3278.08	40224.62	1996-97	4159.98	110439.83
1974-75	3962.43	44187.04	1997-98	3757.48	114197.30
1975-76	2820.44	47007.48	1998-99	4265.39	118462.69
1976-77	2476.99	49484.47	1999-2000	7547.60	126010.29
1977-78	3158.34	52642.81	2000-2001	4065.99	130076.27
1978-79	2968.58	55611.39	2001-2002	4052.68	134128.95
1979-80	2447.59	58058.98	2002-2003	3629.94	137758.89
1980-81	2891.61	60950.59	2003-2004	4370.47	142129.36
1981-82	3307.92	64258.52	2004-2005	3923.86	146053.22
1982-83	2273.87	66532.39	2005-2006	3507.52	149560.74
1983-84	2630.22	69162.61	2006-2007	3379.31	152940.05
1984-85	3444.42	72607.03	2007-2008	3087.94	156027.99

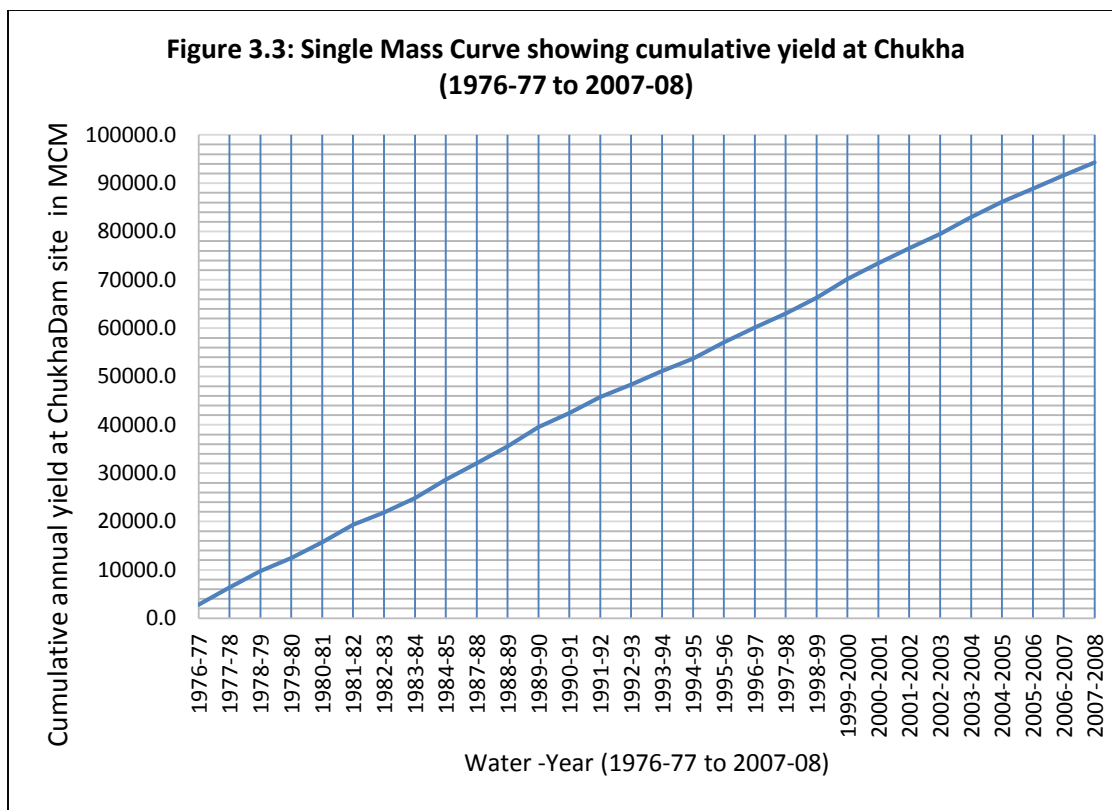
Figure 3.2: Single Mass Curve showing cumulative yield at Tala (1962-63 to 2007-08)



From the single mass curve of Tala dam site flow data it is observed that there is a significant deviation in slope beyond 1998-1999 year. This anomalous trend in the data at Tala beyond 1998-1999 year was needed to be checked for other stations in the Wangchu catchment. The ten daily average discharge data for Chukha dam site was available from the year 1976-77 to 2008-09 (**Annexure 3.2**). Annual inflows in MCM for Chukha dam site were computed, cumulative values of annual inflows for Chukha dam site are given in **Table 3.4**. Single mass curve for yield at Chukha dam site was plotted and is given in **Figure 3.3**.

Table 3.4: Annual and cumulative yields at Chukha Dam site

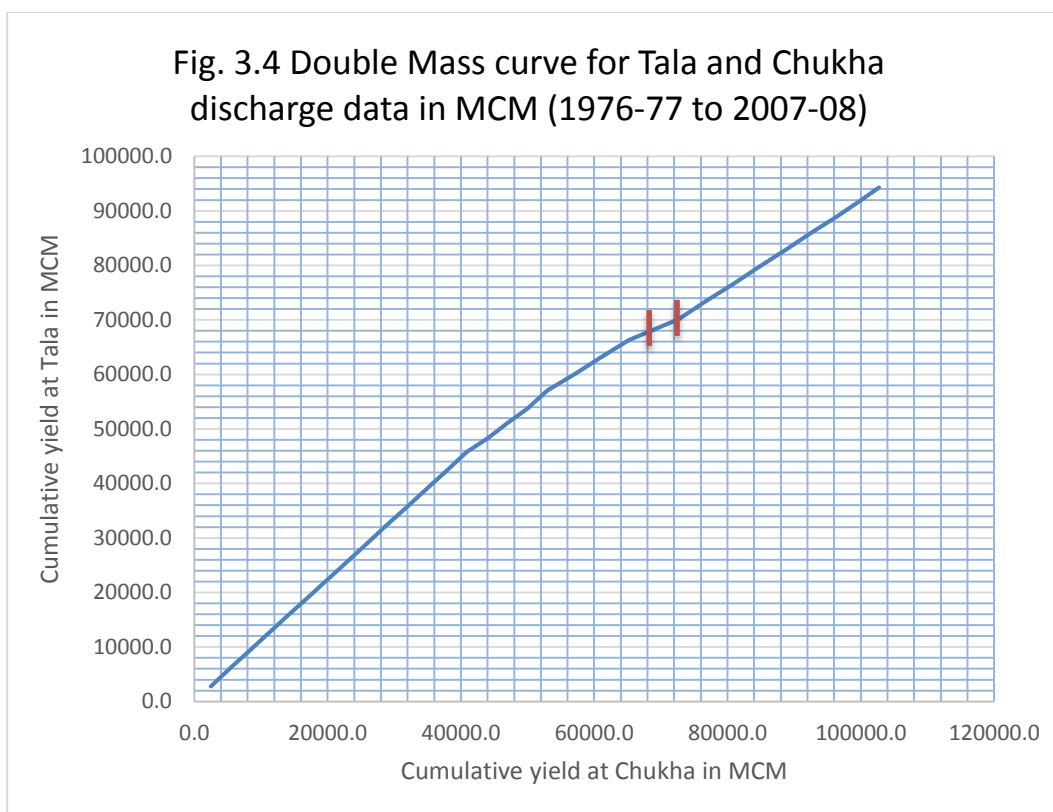
Hydrological Year	Accumulated Chukha MCM	Hydrological Year	Accumulated Chukha MCM
1976-77	2751.0	1993-94	51108.3
1977-78	6389.8	1994-95	53695.9
1978-79	9719.8	1995-96	57087.7
1979-80	12445.4	1996-97	60111.7
1980-81	15673.9	1997-98	63060.2
1981-82	19343.0	1998-99	66310.8
1982-83	21852.5	1999-2000	70163.6
1983-84	24799.1	2000-2001	73452.1
1984-85	28683.2	2001-2002	76548.0
1987-88	32059.8	2002-2003	79516.6
1988-89	35575.8	2003-2004	82987.7
1989-90	39543.9	2004-2005	86131.5
1990-91	42415.3	2005-2006	88836.3
1991-92	45758.1	2006-2007	91633.8
1992-93	48307.3	2007-2008	94261.9



As may be seen from the single mass curve at Chukha, there is not any change in slope beyond 1998-99 year, as is observed in the Tala data. Thus the Discharge data of Tala beyond 1998-99 needed another checks.

3.3.1.2 Double Mass Curve

In order to check the consistency of inflow data at Tala, double mass curve of the annual inflows at Tala was prepared w.r.t. Chukha inflows for the concurrent years of data availability i.e. from 1976-1977 to 2008-09. The double mass curve between Tala dam site annual inflows and Chukha annual inflows has been plotted and is given in **Fig. 3.4**.



The above mass curve also shows a change of slope beyond 1998-1999 year, cumulative yield at Tala beyond which crosses 70,000 MCM. Thus, the discharge data at Tala beyond 1998-99 has been excluded from water availability computations for this project. The reliable discharge series for 37 years is much more than the required minimum years (i.e. 10 years) data series for the studies of diversion projects with pondage, as per the “Guidelines for preparation of DPR of Irrigation and Multipurpose projects”- page 91 of Annexure-4.

3.4 Comparison of Rainfall and Runoff

The distribution of rainfall in Himalayan mountain region is extremely complex due to complex orography and no generalizations are possible. This complexity of rainfall is also evident from the average annual rainfall data for the meteorological stations in the catchment of Wangchu. Although, in general the annual average rainfall decreases as we move from Himalayan foothills through mid- Himalayas to higher Himalayas, yet average annual rainfall at certain raingauge stations such as Betikha and Dochula (Thimphu) is much higher than the other stations like MTI Complex, Paro, Simtokha and Namjeyling situated at about same or comparable altitude.

Keeping in view the high variation in the rainfall pattern of Wangchu catchment, the foothill area below Tala HEP was considered separately from the upper catchment to find out the average annual rainfall. **The GIS based catchment area mapping for Wangchu and Tala HE projects have been carried out using SRTM DEM.** The catchment area upto Tala dam site works out to be 3751 km² and 4147 km² at proposed Wangchu dam site which includes the 95.5 km² of snowfed area common to both.

The average annual rainfall of Tala catchment corresponding to Paro, Thimphu, Lobichu, Drukgyel Dzong, Dochula, Haa and Chukha town raingauge stations have been estimated as 1084 mm. The yield at Tala corresponding to consistent observed data of period 1962-1963 to 1998-1999 has been estimated as 855 mm. The corresponding runoff factor of Tala is about 0.79 which is justified for its steep hilly catchment. The intermediate catchment between Wangchu and Tala is about 396 km². The representative annual rainfall for this area has been taken as 3198 mm corresponding to Baisi raingauge station located near Tala TRT outfall. Based on the areal weightage the average annual rainfall corresponding to the Wangchu catchment has been estimated as 1291 mm. For the above average annual rainfall scenario rainfall variability correction factor between Wangchu and Tala Project site for a runoff factor of 0.79 has been computed as 1.191 as per details given in **Table 3.5 and 3.6** below;

Table 3.5: Rainfall / Snowmelt details of Wangchu Catchment

Catchment		C.A. (sq. km)	Rainfall/ Snowmelt (mm)	Rainfall/ Snowmelt (MCM)	Runoff (MCM)
Upto Tala	Snow fed	95.5	912.5	87.14375	87.14
	Rain fed	3655.5	1084	3962.56	3130.42
Between Tala & Wangchu	Rain fed	396	3197.6	1266.25	1000.34
Total		4147		5315.96	4217.90

Table 3.6: Rainfall / Snowmelt details of Tala Catchment

Catchment		C.A. (sq. km)	Rainfall/ Snowmelt (mm)	Rainfall/ Snowmelt (MCM)	Runoff (MCM)
Upto Tala	Snow fed	95.5	912.5	87.14375	87.14
	Rain fed	3655.5	1084	3962.56	3130.42
Total		3751		4049.71	3217.57

$$\begin{aligned} \text{Specific yield at} \\ \text{Tala corres. to} &= \frac{1000 \times 3130.42}{(3751 - 95.5)} = 856.36 \text{ mm} \\ \text{rainfed catchment} \end{aligned}$$

$$\begin{aligned} \text{Specific yield at} \\ \text{Wangchu corres. to} &= \frac{1000 \times (3130.42 + 1000.34)}{(4147 - 95.5)} = 1019.56 \text{ mm} \\ \text{= rainfed catchment} \end{aligned}$$

Therefore,

$$\begin{aligned} \text{Rainfall variability} &= \frac{1019.56}{856.36} = 1.191 \\ \text{Correction factor} & \end{aligned}$$

3.5 Development of Flow Series at Dam site

Long time ten daily flow series is desirable for the planning purpose of the run-of-river projects. Since the proposed Wangchu HEP is situated just downstream of the Tala HEP and a long flow series is available for Tala HEP, hence this series was utilized for the project planning purpose. As discussed in the earlier section, there is appreciable variation in the average annual rainfall for the catchment area at Tala and catchment area at Wangchu dam site. Thus, the flow series at Tala was needed to be transferred to Wangchu dam site, not only on the basis of catchment area proportions, but also considering the rainfed specific yield variability. Following procedure has been adopted for estimating the 10-daily discharge series at dam site;

- The snowmelt contribution of 5.33 cumec (5 mm/day) was deducted from the 10-daily discharge series (from 1962-1963 to 1998-1999) at Tala HEP dam site.

- ii) The snowmelt deducted series of Tala was then transferred to Wangchu dam site on the basis of rainfed specific yield variability correction factor i.e. 1.191 and rainfed catchment area proportioning i.e. 1.108.
- iii) The snowmelt contribution was then added in the above series to get the water availability series at Wangchu dam site.

The discharge series at the proposed Wangchu dam site thus obtained is given in **Annexure 3.3**.

3.6 Dependable Discharges

Annual flows for Wangchu project site for the period 1962-1963 to 1998-1999 have been computed from the final ten daily flow series for Wangchu HEP at **Annex-3.3**. The annual flows thus derived have been arranged in descending order. The following equation developed by Weibull has been used for estimating the percentage dependable flows:

$$D = (m / (N+1)) \times 100$$

Where,

D = % age dependability

m = Rank of annual flow in descending order

N = Number of years of data

Dependable flows have been estimated in **Table 3.7**

Table 3.7 Estimation of dependable flows for Wangchu Dam site

S. No.	Hydro-year	Annual Runoff MCM	Hydro year	Annual runoff (MCM) in descending order	Dependability (%)
1	1962-63	4949	1998-99	5602	2.63
2	1963-64	4925	1996-97	5463	5.26
3	1964-65	4670	1966-67	5402	7.89
4	1965-66	4875	1974-75	5202	10.53
5	1966-67	5402	1962-63	4949	13.16
6	1967-68	4574	1997-98	4932	15.79
7	1968-69	4427	1963-64	4925	18.42

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S. No.	Hydro-year	Annual Runoff MCM	Hydro year	Annual runoff (MCM) in descending order	Dependability (%)
8	1969-70	2076	1965-66	4875	21.05
9	1970-71	4017	1964-65	4670	23.68
10	1971-72	3908	1972-73	4646	26.32
11	1972-73	4646	1989-90	4625	28.95
12	1973-74	4299	1967-68	4574	31.58
13	1974-75	5202	1984-85	4519	34.21
14	1975-76	3695	1985-86	4439	36.84
15	1976-77	3242	1968-69	4427	39.47
16	1977-78	4308	1981-82	4338	42.11
17	1978-79	3891	1977-78	4308	44.74
18	1979-80	3203	1973-74	4299	47.37
19	1980-81	3789	1992-93	4209	50.00
20	1981-82	4338	1988-89	4160	52.63
21	1982-83	2973	1970-71	4017	55.26
22	1983-84	3444	1995-96	4001	57.89
23	1984-85	4519	1987-88	3960	60.53
24	1985-86	4439	1971-72	3908	63.16
25	1986-87	3806	1978-79	3891	65.79
26	1987-88	3960	1991-92	3861	68.42
27	1988-89	4160	1994-95	3855	71.05
28	1989-90	4625	1993-94	3849	73.68
29	1990-91	3375	1986-87	3806	76.32
30	1991-92	3861	1980-81	3789	78.95
31	1992-93	4209	1975-76	3695	81.58
32	1993-94	3849	1983-84	3444	84.21
33	1994-95	3855	1990-91	3375	86.84
34	1995-96	4001	1976-77	3242	89.47
35	1996-97	5463	1979-80	3203	92.11
36	1997-98	4932	1982-83	2973	94.74
37	1998-99	5602	1969-70	2076	97.37

The 90% and 50% dependable annual flows at the Wangchu HEP dam site have been worked out corresponding to the **1979-80** and **1992-93** hydro years respectively. The 10-

daily discharges during the 90% dependable year of 1979-80 for Wangchu dam site are given in **Table 3.8**.

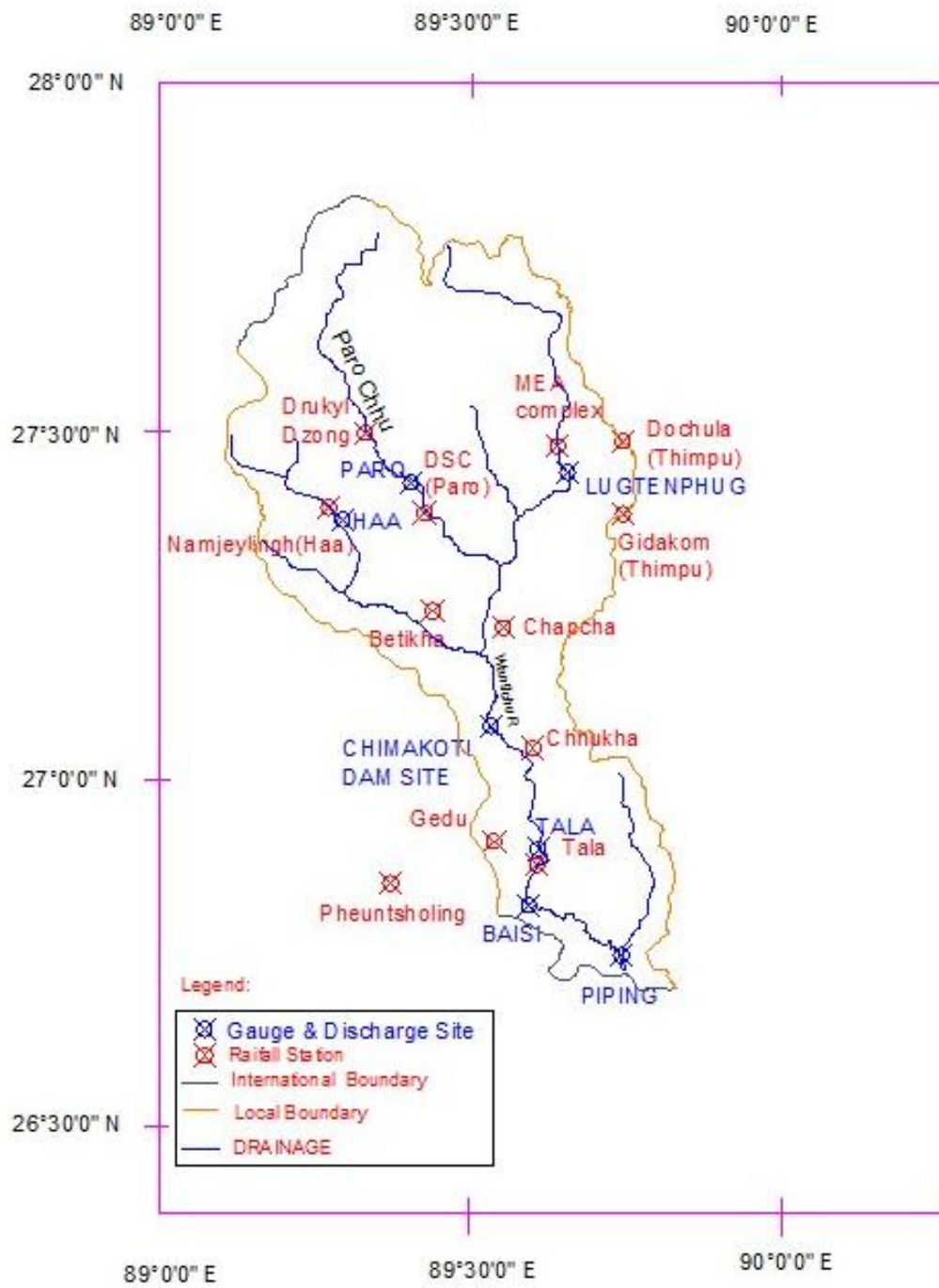
Table 3.8 90% dependable year flows

Sr. No.	Month		No. of days	90% Hydro year Discharge in cumecs
1	JUN	I	10	34.68
2		II	10	69.64
3		III	10	128.73
4	JULY	I	10	121.48
5		II	10	223.61
6		III	11	391.94
7	AUG	I	10	402.92
8		II	10	278.17
9		III	11	244.64
10	SEP	I	10	248.32
11		II	10	165.60
12		III	10	74.26
13	OCT	I	10	118.96
14		II	10	95.25
15		III	11	58.98
16	NOV	I	10	56.42
17		II	10	48.33
18		III	10	46.21
19	DEC	I	10	55.96
20		II	10	48.09
21		III	11	52.93
22	JAN	I	10	43.28
23		II	10	34.65
24		III	11	28.72
25	FEB	I	10	28.71
26		II	10	27.68
27		III	9	27.54
28	MAR	I	10	26.69
29		II	10	25.77
30		III	11	35.47
31	APR	I	10	40.58
32		II	10	59.56
33		III	10	61.86

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Sr. No.	Month		No. of days	90% Hydro year Discharge in cumecs
34	MAY	I	10	67.37
35		II	10	71.98
36		III	11	78.32

Rainfall Stations and G&D sites in Wangchu Catchment



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Table 3.1 (a) Monthly Rainfall at Betikha (mm)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1990	19.4	24.8	73	57	49.8	222	326	124	45.5	30.5	25.3	18	1015.3
1991	9.6	32	60	71	92	205	203.5	108.3	86.7	27	12.6	0	907.7
1995	0	25.1	32	56	85.1	128.5	185.8	163.8	85	26	13	11	811.3
1996	5	7.6	8.7	6	68.8	87	213.7	255	149.9	48	45.1	17.6	912.4
1997	23	39.2	50	65.4	120.4	103.6	194.2	264.5	67	12.2	27.4	24	990.9
1998	0	8	64.2	558	103.6	107.4	876	287	32	0	0	0	2036.2
1999	16.8	14.2	24.6	119.8	65.6	187	94.2	159	40.2	38.7	0	0	760.1
2000	32	8.8	66	83.4	141.8	493	1154	214.8	95.6	60	0	0	2349.4
2001	7	63.5	364	215.8	376	644	108.6	194.6	454.4	117.2	14	8.2	2567.3
2002	10	5.2	-	283	431	322	852	403.9	540	16.5	7	5	2875.6
2003	16.8	32.7	11.8	52.8	24.6	344.1	548	301	200.2	218.2	0	11	1761.2
2004	30.6	58	112.3	646	428	466	686	360	77	430	0	0	3293.9
2005	28	45.8	29.3	253	424	254	818	494	395.5	107.2	37	0	2885.8
2006	0	7	67	-	407	311	520	0	0	165	14	4.5	1495.5
2007	0	202.5	162	142.1	201	546	794	466	986	182	0	0	3681.6
2008	22.8	0	100	647	168	-	565	995	225	168	0	0	2890.8
Avg	13.81	35.90	81.66	217.09	199.17	294.71	508.69	299.43	217.50	102.91	12.21	6.21	1961.8
Max	32.00	202.50	364.00	647.00	431.00	644.00	1154.00	995.00	986.00	430.00	45.10	24.00	3681.60
Min	0.00	0.00	8.70	6.00	24.60	87.00	94.20	0.00	0.00	0.00	0.00	0.00	760.10

Table 3.1 (b) Monthly Rainfall at Drukyl Dzong (mm)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1995	0	0	0	25	36	157.7	186.4	113.2	98	52	16.5	0	684.8
1996	0	0	-	21	75.6	128.2	235.3	183	138.7	167	0	0	948.8
1997	5	0	0	41.5	37.7	118.8	237.1	172.7	93	3	0	0	708.8
1998	0	3	3.8	21.5	4.5	26	313	392.8	199.1	35.5	0	0	999.2
1999	0	0	0	38.3	216.5	374	469	464	332	305.5	0	0	2199.3
2000	0	0	50	87.6	227	196.5	482	1158.5	319.5	0	0	0	2521.1
2001	0	60	150	80.1	84.4	122.2	227.4	215	130.9	51.5	0	0	1121.5
2002	0	0	0	0	47.1	123	229	206.2	114	16	0	0	735.3
2003	0	15	4.8	30	35.3	178.7	209.5	94	196	141	0	0	904.3
2004	0	0	0	33	42	153.8	146.5	215	104.5	77	0	0	771.8
2005	0	0	13	11	6	49	129	160	60	144.5	0	0	572.5
2006	0	0	30.5	71	53	99	203	196.5	111	30	21	5	820.0
2007	0	10	8	9.5	67.5	84	129	148	142	18	3	0	619.0
2008	0	0	19	20	28	217.5	222.5	243	56	40	4	0	850.0
2009	0	0	13	24	179	73	135	265	42	140	0	0	871.0
Avg	0.33	5.87	20.86	34.23	75.97	140.09	236.91	281.79	142.45	81.40	2.97	0.33	1021.8
Max	5.00	60.00	150.00	87.60	227.00	374.00	482.00	1158.50	332.00	305.50	21.00	5.00	2521.10
Min	0.00	0.00	0.00	0.00	4.50	26.00	129.00	94.00	42.00	0.00	0.00	0.00	572.50

Table 3.1 (c) Monthly Rainfall at Paro (mm)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1996	3.4	4.7	7.4	19.4	38.6	54.7	105.2	99.8	123.8	44.2	0	0	501.2
1997	18	9.4	37.1	36.6	37	114.4	185.4	230.9	52.9	9.5	0	42.5	773.7
1998	0	0	82.4	29.8	30	99.9	111.3	89.8	77.9	11.9	0	0	533
1999	0	0	28.6	34.2	88.8	139.5	215.2	231.4	218.9	161.7	0	0	1118.3
2000	0	0	11	23.4	98.4	109.1	108.5	84.3	74.8	0	0	0	509.5
2001	0	0	0	79.6	68.2	131.5	117	85.7	90.8	57.8	0	0	630.6
2002	0	0	0	38.8	29.2	79.1	127.8	87	36	17.6	0	0	415.5
2003	12	52.1	2	20.2	58	111.8	147.1	76	104.4	80.5	0	0	664.1
2004	0	42	14.9	23.3	48.4	59.4	126.2	103.7	67.1	58.7	0	0	543.7
2005	40	5.9	24.8	33.1	25.5	55	98	124.4	99.2	156.4	0	0	662.3
2006	0	7.6	29.7	55.5	28.5	33.6	915.4	115.6	97.6	29.5	27.3	2.1	1342.4
2007	0	48.7	16.5	14.7	32.2	50	118.8	60	109.6	5.6	0	0	456.1
2008	31.2	0	30.2	29.4	69	121.3	160.8	147.2	55.2	38.5	0	0	682.8
2009	0	23.2	17.2	22.4	146.4	29.1	48	131.6	52	138.2	1	0	609.1
Avg	7.47	13.83	21.56	32.89	57.01	84.89	184.62	119.10	90.01	57.86	2.02	3.19	674.45
Max	40.00	52.10	82.40	79.60	146.40	139.50	915.40	231.40	218.90	161.70	27.30	42.50	1342.40
Min	0.00	0.00	0.00	14.70	25.50	29.10	48.00	60.00	36.00	0.00	0.00	0.00	415.50

Table 3.1 (d) Monthly Rainfall at Dochula (mm)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1995	40.00	32.30	27.60	13.70	58.80	299.60	372.40	419.10	356.80	42.10	92.80	20.00	1775.20
1996	3.20	10.60	20.60	17.00	44.60	263.00	375.20	410.80	262.30	154.90	6.80	0.00	1569.00
1997	16.70	40.00	20.60	17.00	127.60	244.00	369.80	397.40	166.80	34.80	2.80	24.20	1461.70
1998	0.00	23.60	79.20	37.00	91.20	0.00	424.90	301.20	193.70	38.70	0.00	0.00	1189.50
1999	0.00	0.00	33.00	14.00	178.80	214.70	488.10	177.80	137.20	115.40	4.00	10.40	1373.40
2000	7.40	32.10	51.10	32.70	115.20	245.20	266.50	288.40	211.60	23.20	10.40	0.00	1283.80
2001	18.50	0.00	0.00	51.20	122.20	345.80	339.10	373.60	243.20	96.00	13.60	11.00	1614.20
2002	12.60	21.00	8.20	50.70	148.60	247.80	409.80	489.30	195.00	66.20	5.00	9.40	1663.60
2003	28.80	33.40	22.30	77.20	34.00	360.00	447.20	440.60	331.40	134.40	22.20	22.10	1953.60
2004	35.00	10.50	34.40	37.80	146.00	353.80	392.20	256.90	137.80	102.50	3.70	0.00	1510.60
2005	16.80	31.20	27.30	15.00	55.80	126.70	271.60	340.20	179.00	132.70	11.00	0.00	1207.30
2006	2.60	11.60	11.80	85.80	124.80	240.80	289.10	281.20	0.00	0.00	0.00	0.00	1047.70
Avg	15.13	20.53	28.01	37.43	103.97	245.12	370.49	348.04	201.23	78.41	14.36	8.09	1470.80
Max	40.00	40.00	79.20	85.80	178.80	360.00	488.10	489.30	356.80	154.90	92.80	24.20	1775.20
Min	0.00	0.00	0.00	13.40	34.00	0.00	266.50	177.80	0.00	0.00	0.00	0.00	1047.70

Table 3.1 (e) Monthly Rainfall at Gidacom (mm)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1990	0	11.4	35	63.6	35.9	58.1	131.3	104.5	63.6	52.4	13.6	8	577.4
1991	0	1.5	31.7	19.2	37.5	126.3	208.6	172.8	162.2	54.6	16.2	4.5	835.1
1992	1	6.4	0	0	35.6	42.8	200.6	142	69.8	9	0	3.5	510.7
1993	23.2	13.8	26.4	33.7	59.5	75.9	78.6	140.2	90.4	0	0	0	541.7
1994	42.6	28.4	19.4	34	15	85.8	107.8	153.9	60.6	1.8	1.2	0	550.5
1995	35.2	28.6	37.2	13.7	31	57.6	190.8	111	138.7	5.4	122.6	8.5	780.3
1996	26	7.5	19.7	3.1	45.9	89.8	94.4	108	48.8	29.6	0	0	472.8
1997	5.2	6.6	37.1	35.6	11.4	95.6	131.4	211.5	33.8	10.6	0	61	639.8
1998	0	2	75	6	20.2	70.6	166	105.2	76.2	10.8	0.6	0	532.6
1999	0	3.6	29.7	54.6	28.2	148.4	215	140.3	115.6	109.8	0	0	845.2
2000	0.5	16.2	18.9	33.6	60.1	258.8	131.5	100.2	50.6	2.4	0	0	672.8
2001	0.6	10.2	12.5	87.4	80.7	104.2	94	128.2	56.5	64.6	0	0	638.9
2002	15.5	0	14.2	25.5	84.8	80.3	125.1	127.2	87.5	12.4	0	0	572.5
2003	15.6	24	0	17.6	23	105.5	117.2	79.8	82.6	90.2	0	6.4	561.9
2004	23.8	0	10.9	40.7	20.8	67.4	99.5	98.6	35.8	35.8	0	0	433.3
2005	5.6	37.8	16	29	26.9	35.6	106.4	102.4	89.6	139.3	0	0	588.6
2006	0	1.6	18	27.5	29.5	18.8	160.6	126.6	58.9	25.9	7.9	2.3	477.6
2007	0	42.3	19.2	20.6	57.1	52.8	81	112.1	57.2	9.5	0	0	451.8
2008	8.5	0	27.4	31.6	3.8	131.9	96.8	132.7	29.5	34.2	0	0	496.4
2009	0	4	20.4	15.7	128.2	40.1	54.9	158.6	39.5	113.2	0	3	577.6
Avg	10.17	12.30	23.44	29.64	41.76	87.32	129.58	127.79	72.37	40.58	8.11	4.86	587.875
Max	42.60	42.30	75.00	87.40	128.20	258.80	215.00	211.50	162.20	139.30	122.60	61.00	845.20
Min	0.00	0.00	0.00	0.00	3.80	18.80	54.90	79.80	29.50	0.00	0.00	0.00	433.30

Table 3.1 (f) Monthly Rainfall at MoEA Complex, Thimphu (mm)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1996	6	4	2.6	10.6	20.8	123	128.3	190.7	154.6	33.3	0	0	673.9
1997	8.6	0	39	65.4	0.6	86.3	115.2	173.2	42.1	8.7	0	7.7	546.8
1998	0	0	54.7	25.1	62.1	79.8	202.9	112.8	114.4	11.2	0.4	0	663.4
1999	2.4	0	23.9	24	55.3	130.1	173.7	168.9	122.3	99.1	2.2	0	801.9
2000	1.8	1.2	6.6	33.8	93.6	92.7	202.4	121.5	83.6	6.6	0.2	0.4	644.4
2001	0.8	6.4	5.7	67.2	75.3	145.2	143.6	155.6	85.1	1.2	1.2	0.3	687.6
2002	19.2	0.3	9.8	48.9	72.7	103.6	156.5	197.7	89.2	27.3	0	0	725.2
2003	13.1	22.5	7.8	37.6	31.4	175.6	181	154.7	111.2	96.7	0	14.6	846.2
2004	20.2	5	11.3	35.5	38.2	120.9	177.7	180.3	60.7	54.1	0	0	703.9
2005	13.2	14.2	13.7	29.2	20.6	78.7	63.1	78.8	80	135.4	0.2	0	527.1
2006	0	0	15.1	70.7	56.4	38	229.7	177.6	64.8	27	18	2.2	699.5
2007	0	30.6	13.6	24.8	47.5	81.3	153.5	90.7	117.9	11.8	2.4	0	574.1
2008	11.4	0	15.9	16.6	44.3	133.3	177.5	145.5	-	39.2	0	-	583.7
2009	0	14.8	9.5	21.4	151.1	38.3	67.8	186.1	40.4	109.6	0	0	639.0
Avg	6.91	7.07	16.37	36.49	54.99	101.91	155.21	152.44	89.72	47.23	1.76	1.94	665.48
Max	20.20	30.60	54.70	70.70	151.10	175.60	229.70	197.70	154.60	135.40	18.00	14.60	846.20
Min	0.00	0.00	2.60	10.60	0.60	38.00	63.10	78.80	40.40	1.20	0.00	0.00	527.10

Table 3.1 (g) Monthly Rainfall at Simtokha (mm)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1996	0.00	0.00	0.00	12.50	25.00	112.70	129.60	115.60	79.10	26.80	0.00	0.00	501.30
1997	0.00	19.50	57.00	39.70	3.80	161.40	153.00	214.40	45.40	12.90	0.00	52.40	759.50
1998	0.00	8.20	48.10	13.70	37.60	54.40	209.50	152.20	54.60	8.00	1.00	0.00	587.30
1999	0.00	0.00	21.80	28.60	56.50	139.20	151.30	130.60	85.90	106.60	1.80	0.00	722.30
2000	2.40	3.80	14.40	22.80	63.00	85.20	197.30	53.00	8.50	11.80	0.00	0.00	462.20
2001	0.00	0.00	0.00	91.30	100.60	132.30	129.10	150.60	111.30	55.90	5.60	1.80	778.50
2002	31.30	4.50	32.80	20.40	32.30	129.60	253.70	189.20	121.40	17.30	1.90	5.00	839.40
2003	27.10	31.30	9.10	27.50	22.10	159.40	168.10	162.30	74.90	92.90	0.00	6.50	781.20
2004	21.50	6.50	6.40	30.00	38.00	116.20	114.60	142.50	18.80	48.30	0.00	0.00	542.80
2005	0.80	18.80	11.90	28.60	17.90	37.80	67.40	124.90	36.90	115.90	0.00	0.00	460.90
2006	0.00	0.00	15.80	41.10	56.00	24.60	147.40	122.70	70.80	19.10	10.00	2.10	509.60
2007	0.00	35.90	14.10	14.60	29.20	46.10	82.90	79.90	90.20	18.60	0.80	0.00	412.30
2008	15.80	0.00	17.70	15.10	27.50	132.90	152.30	115.10	68.60	46.70	0.00	1.60	593.30
2009	1.00	0.00	0.00	27.00	146.60	18.80	80.90	127.30	46.10	108.50	1.20	4.20	561.60
Avg	7.14	9.18	17.79	29.49	46.86	96.47	145.51	134.31	65.18	49.24	1.59	5.26	608.01
Max.	31.30	35.90	57.00	91.30	100.60	161.40	253.70	214.40	121.40	115.90	10.00	52.40	839.40
Min.	0.00	0.00	0.00	12.50	3.80	24.60	67.40	53.00	8.50	8.00	0.00	0.00	412.30

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Table 3.1 (h) Monthly Rainfall at Gedu (mm)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1990	11	111.7	274.8	345.4	475.2	666.2	598.4	438.5	359.1	172.4	0.8	0	3453.5
1991	85.2	58	189.8	284	556.2	573.9	624.5	475.7	382.5	69.6	42.1	48	3389.5
1992	56.9	137.4	37.2	204.6	384.7	444.4	884.5	319.6	423.4	276.2	0.2	31.4	3200.5
1993	95.8	100.4	118.6	264.6	574.9	553.6	910.5	788.6	236	238.7	42.3	16.2	3940.2
1994	159	134.3	177.2	365.8	407.4	429	648.5	437.4	293.8	205.6	15.8	8	3281.8
1995	81.5	90	107.2	116	680	833	658.4	586.1	385.8	73.2	29.1	16.2	3656.5
1996	80.7	123.3	70.1	69.4	698.4	421.3	530	270.9	321.1	111.6	21.4	0	2718.2
1997	39.5	123.7	34.1	110.5	320.2	1405.6	358.2	366.2	336.8	79.5	6.4	0	3180.7
1998	18.4	0	123.8	174.6	267.8	1585.5	1884.6	1056.7	78	-	10.2	3	5202.6
1999	38.2	0	42	118.5	425.2	791.7	767.4	874.2	223.2	239.6	5.2	9.4	3534.6
2000	24.4	38.2	124.4	345.2	360	885.9	575.2	1812.5	462.1	37.2	12	0	4677.1
2001	34	167.2	13.3	139.7	319.2	377.2	427.8	513.6	340.4	320	12.2	32	2696.6
2002	48.2	32	148.2	45.4	26.9	36.2	1199.4	336.2	374.2	132.6	13	20.2	2412.5
2003	30.4	136.2	168	561.6	303.8	531.4	1162.2	332.7	288.4	321.8	2	35.5	3874
2004	57.5	84.4	129.4	348.8	1093.2	407.6	1304.6	298.8	223.4	237.3	0	8	4193
2005	48.9	12.2	194.7	210.8	237	205	1632.4	442.2	355.6	339	23	0	3700.8
2006	0	16.3	77.1	237.2	504.2	745.8	447.3	125.8	432.2	68	-	22.6	2676.5
2007	0	175.7	59.6	271.4	266	446	1303.5	262	583	190.2	20	1	3578.4
2008	33	-	243.6	304.5	313.2	523.6	576	776	192.2	80.2	7	11	3060.3
Avg	49.61	85.61	122.79	237.79	432.29	624.36	868.07	553.35	331.12	177.37	14.59	13.82	3496.17
Max	159.00	175.70	274.80	561.60	1093.20	1585.50	1884.60	1812.50	583.00	339.00	42.30	48.00	5202.60
Min	0.00	0.00	13.30	45.40	26.90	36.20	358.20	125.80	78.00	37.20	0.00	0.00	2412.50

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Table 3.1 (i) Monthly Rainfall at Namjeyling (Haa) in mm

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1990	0	0	23	65.1	50.2	121.2	242.6	149.2	93.2	68.2	0	0	812.7
1991	0	19.6	32	57.8	48.2	186.6	168	248.8	100.1	27.4	0	0	888.5
1994	1.3	13.5	39.2	192.5	51.5	241.1	78.7	171.3	89.5	1	8	0	887.6
1995	16	45.8	35.4	32	37.9	118.5	239.6	173.9	198	18	13.1	38	966.2
1996	30.8	10.9	18.2	40.4	72.2	100.2	156	211	152.9	57.8	0	0	850.4
1997	23	15.7	32.4	65.4	44.1	175.2	257.1	240.1	95.9	10.7	0	57.6	1017.2
1998	23	6.3	67.4	71.5	48.9	126.9	208.9	132.5	88	28	3.2	0	804.6
1999	6.4	3.8	0	50.5	98.6	205.3	257	251.1	194.1	177.5	0	0	1244.3
2000	0	16.2	36.6	70.6	122.8	164.5	143	144	144.1	0	0	0	841.8
2001	3.8	9.4	23.8	126.2	97	158.5	240.2	180.9	161.3	82.6	0	0	1083.7
2002	27.4	5	31.9	57.7	71.7	113.4	215.7	197.6	146.9	28.4	0	0	895.7
2003	23.8	51.7	5.5	41.2	53.2	164.8	187.1	114.7	185.4	115.7	0	16.5	959.6
2004	31.4	2.8	27.4	45.9	35.6	131.8	142.3	143.9	79	88.4	0	0	728.5
2005	23	91.8	39.2	41.1	42.8	50.4	139.4	152.8	91.5	160.2	0	0	832.2
2006	0	8	56.5	62.9	46.5	70	249.9	166.9	121.9	25.3	32.6	0	840.5
2007	0	55.2	24.4	25.8	25.8	83.5	159.4	101.8	178.4	17.8	2.4	0	674.5
2008	11.8	0	44.4	45	27.4	183.5	199.1	233.1	62.2	39.1	0	0	845.6
2009	0	0	31.3	42	195.5	65.1	85	159	67.4	164.7	3.1	0	813.1
Avg	12.32	19.76	31.59	62.98	64.99	136.69	187.17	176.26	124.99	61.71	3.47	6.23	888.15
Max	31.40	91.80	67.40	192.50	195.50	241.10	257.10	251.10	198.00	177.50	32.60	57.60	1244.30
Min	0.00	0.00	0.00	25.80	25.80	50.40	78.70	101.80	62.20	0.00	0.00	0.00	674.50

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Table 3.1 (j) Monthly Rainfall at Begana (mm)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
2008	16	0	28	5	30	135	265.2	295.7	84	32	3	0	893.9
2009	0	13.5	15.5	20	172.4	100.1	349.4	396.4	104.4	42	0	0	1213.7
Avg	8	6.75	21.75	12.5	101.2	117.55	307.3	346.05	94.2	37	1.5	0	1053.8
Max	16	13.5	28	20	172.4	135	349.4	396.4	104.4	42	3	0	1213.7
Min	0	0	15.5	5	30	100.1	265.2	295.7	84	32	0	0	893.9

Table 3.1 (k) Monthly Rainfall at Chukha (mm)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1985	0	0	0	0	147.3	362.8	340.5	0	210.9	0	16.7	36.6	1114.8
1986	1.5	26.6	72	133.4	186.2	209.9	301.6	136.4	195.8	112.4	4.4	21.3	1401.5
1987	2.6	53.4	69.4	89	72.2	158	232.8	383.4	190.4	147	0.4	0	1398.6
1988	4.4	-	99.6	87.1	168.5	118.2	414.8	409	202.4	12.4	18.4	8.4	1543.2
1989	22.8	91.4	74.4	121.4	251.6	369.4	295.4	199.3	269.3	18.6	14.4	6.8	1734.8
1990	1.4	84.8	97.1	217.1	141.3	282.4	244.7	135.6	122.7	54.6	0.6	0	1382.3
1991	66.3	39.8	74	108.9	166	391	205.5	352.7	251.9	11.8	2	8.7	1678.6
1992	14.1	42.5	41.8	99.5	139.7	274.9	208.4	253.2	180.2	62.9	21	11.6	1349.8
1993	53	37.5	61.7	119.2	180.2	250.5	264.7	256.1	147.4	36.1	10.4	2.2	1419
1994	83.5	65.3	55.4	154.5	227.1	273.1	308.6	286	127	16.8	7.3	2.7	1607.3
1995	31.8	118.6	36.6	67.6	139.8	298.5	272.6	207.5	208.7	19.7	184.2	8.8	1594.4
1996	51.6	23	184.3	252.8	245.5	139.6	439.2	186	184.4	43.8	0	0	1750.2
1997	13.4	31.5	52.8	71.2	105.9	335.4	146.2	219.8	197.4	11.6	3.8	55.6	1244.6
1998	0	11.2	169.9	80.5	162.2	433.4	469.3	336.8	141	70.9	0.6	0	1875.8
1999	11	0	35.2	168.2	162.6	281.4	287.6	330	207	239	0	1.6	1723.6
2000	12	30.8	63	133.7	150.2	397.8	187.2	600.8	206.1	14.4	12	3	1811
2001	12.4	30.8	30	98.8	150.1	188.7	273.9	316.9	138	256.2	2.2	9.8	1507.8
2002	29.8	2	77.1	167.4	118.3	121.9	368.7	169	125.7	50.4	6.4	0.4	1237.1
2003	30.9	73.8	63.8	148.6	81.3	189.8	419.6	198.4	146.2	242.7	1	27.8	1623.9
2004	64.8	32.9	38.6	143.8	195.6	192.8	369.1	144.2	112.8	87.9	2.5	0	1385
2005	31.8	51.6	87	76	115	111.6	355.3	226.3	142	165	0	0	1361.6
2006	0	0	0	0	196	245.4	183.4	99	159.4	43.8	15.2	16.8	959
2007	0	99.1	46	92.4	109.4	207.2	336.3	232.2	352.7	41.3	1.7	0	1518.3
2008	24.2	30.2	110.4	127.8	116.9	283.1	259	412.2	82	62	0	9.2	1517
2009	2.4	51.7	84.1	109.8	248.1	131.7	225.3	265	42	118.2	0	0	1278.3
Avg	22.63	42.85	68.97	114.75	159.08	249.94	296.39	253.78	179.23	75.89	13.55	9.64	1480.7
Max	83.50	118.60	184.30	252.80	251.60	433.40	469.30	600.80	352.70	256.20	184.20	55.60	1875.80
Min	0.00	0.00	0.00	0.00	72.20	111.60	146.20	0.00	82.00	0.00	0.00	0.00	959.00

Figure 3.1(a) Maximum, Minimum and Mean Rainfall at Betikha

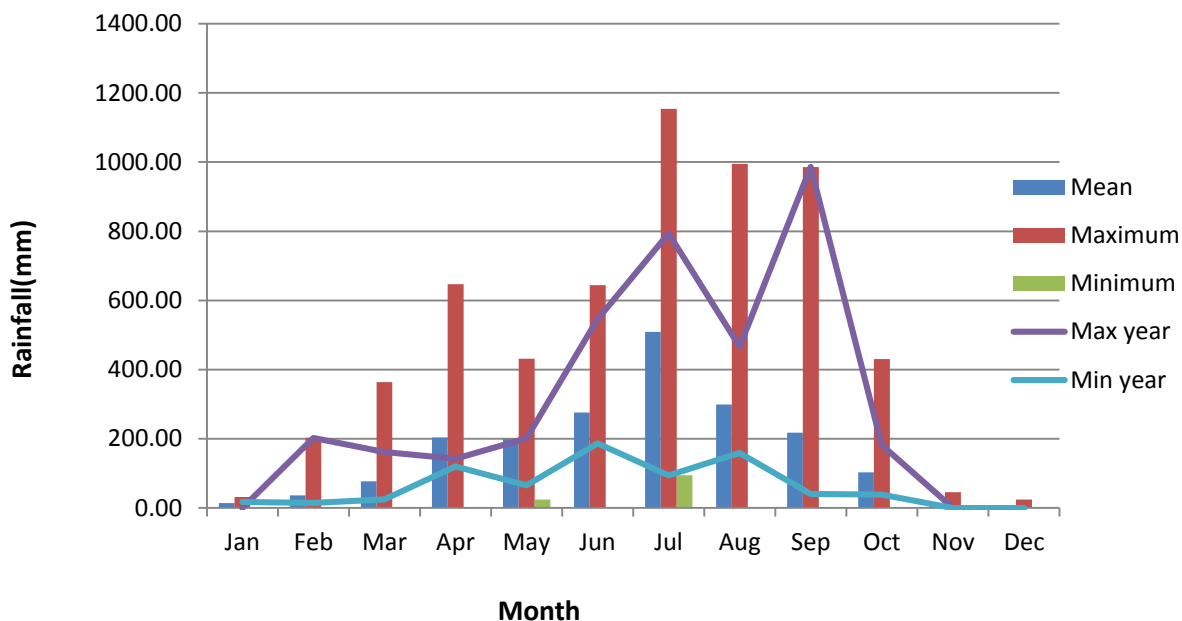
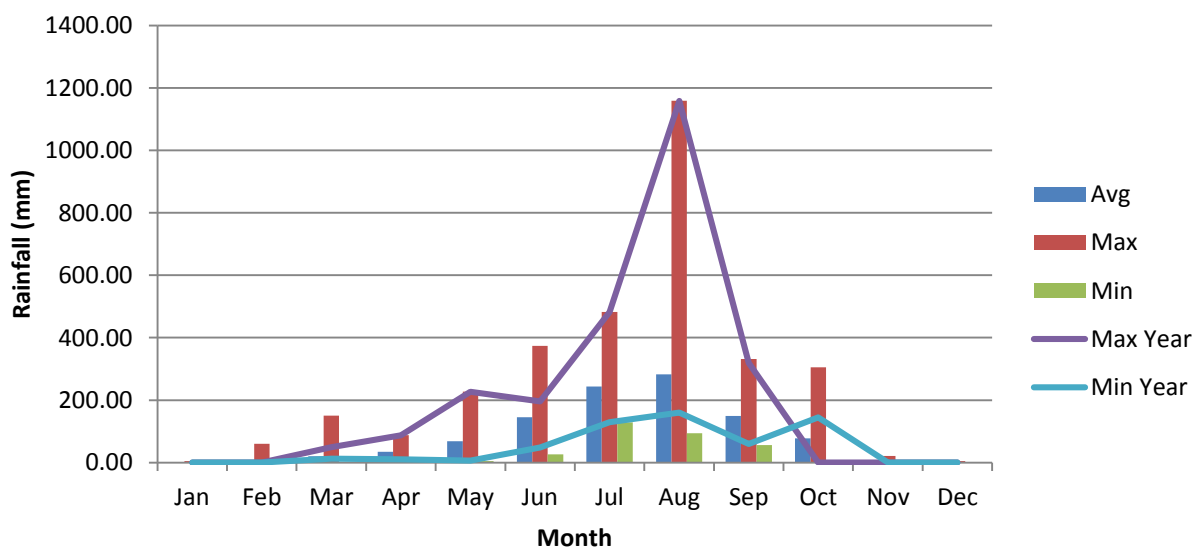


Figure 3.1(b) Maximum, Minimum and Mean Rainfall at Drukyl Dzung



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Figure 3.1(c) Maximum, Minimum and Mean Rainfall at Paro

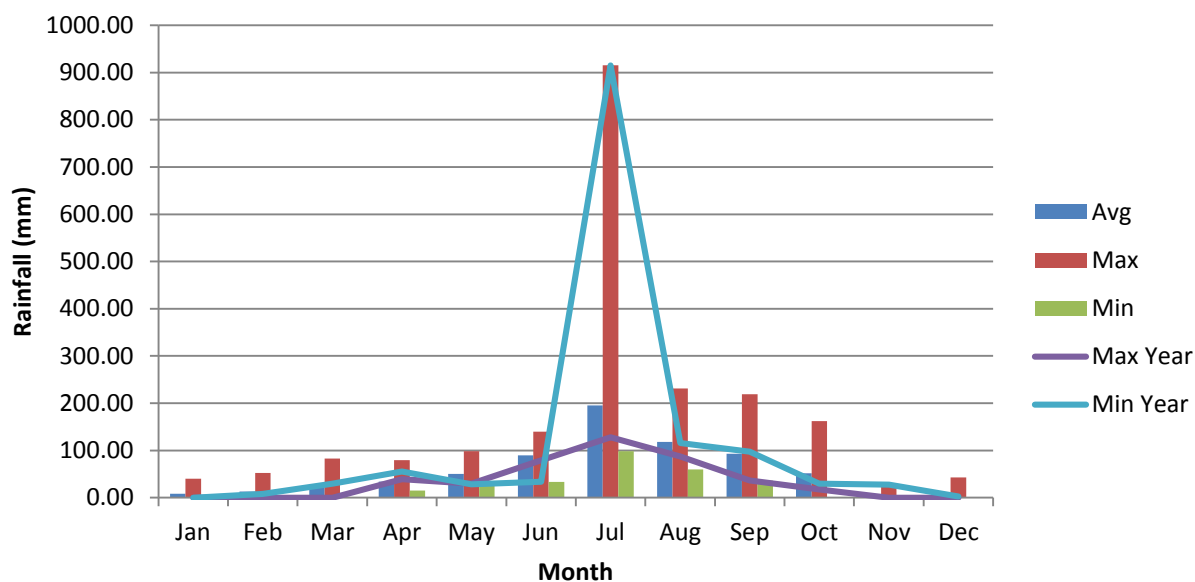


Figure 3.1(d) Maximum, Minimum and Mean Rainfall at Dochula

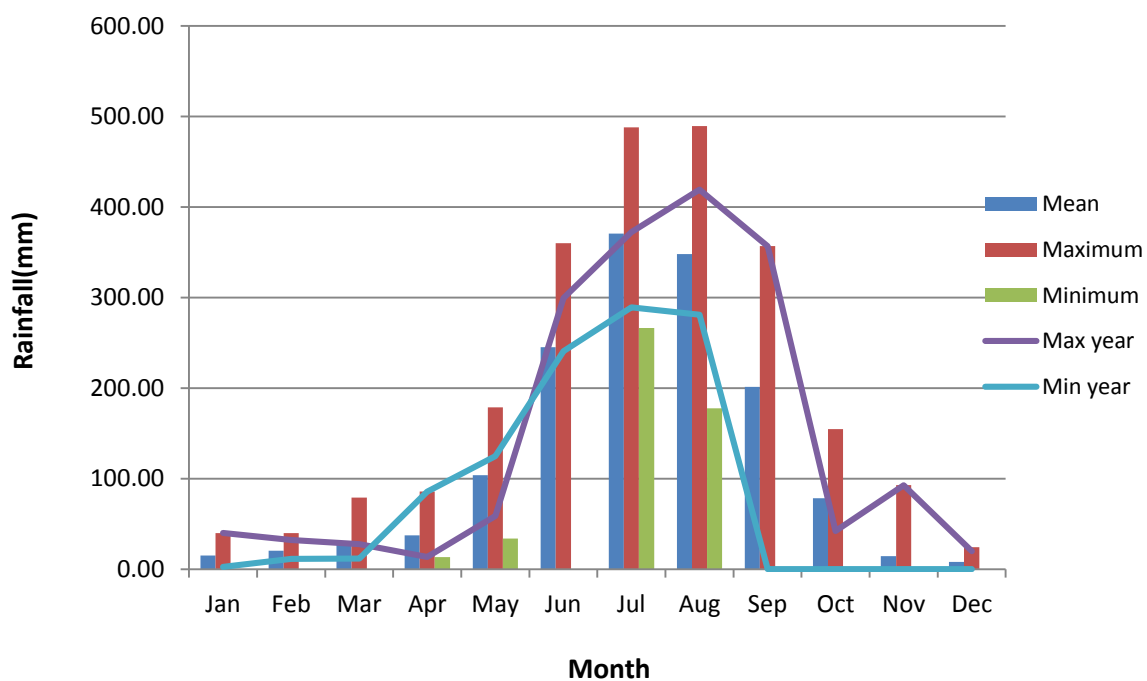


Figure 3.1(e) Maximum, Minimum and Mean Rainfall at Gidakom

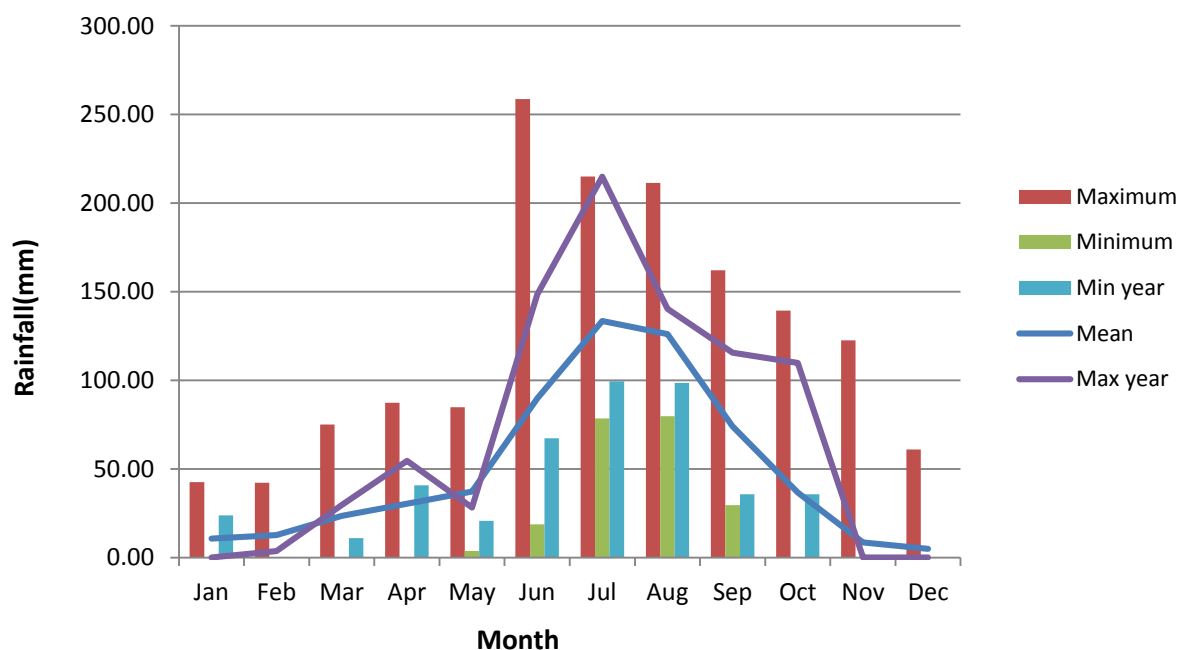
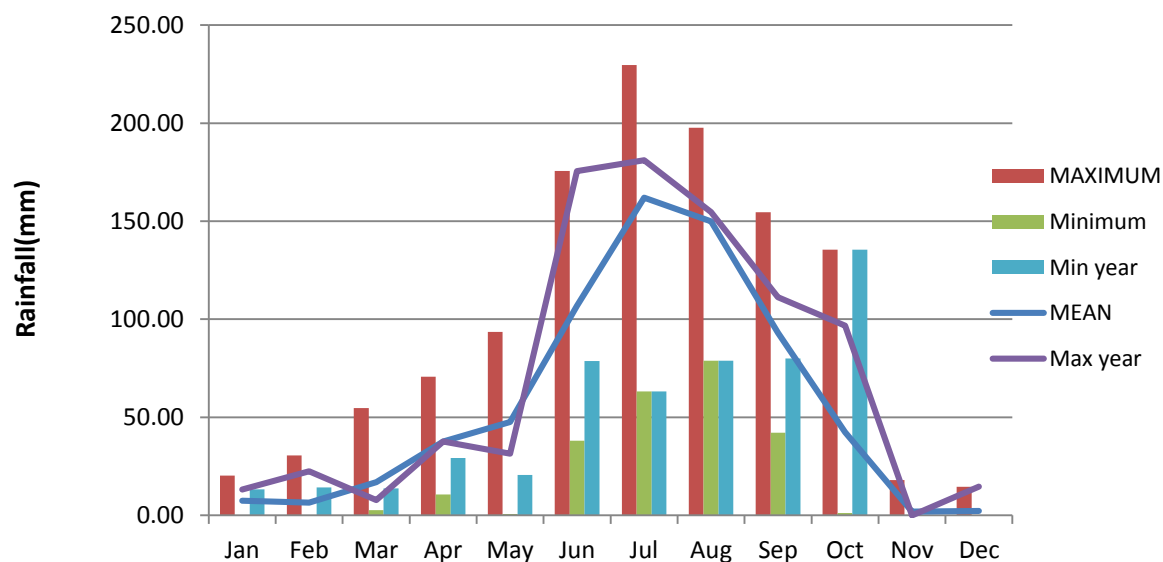


Figure 3.1(f) Maximum, Minimum and Mean Rainfall at MoEA Complex (Thimphu)



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Figure 3.1(g) Maximum, Minimum and Mean Rainfall at Simtokha

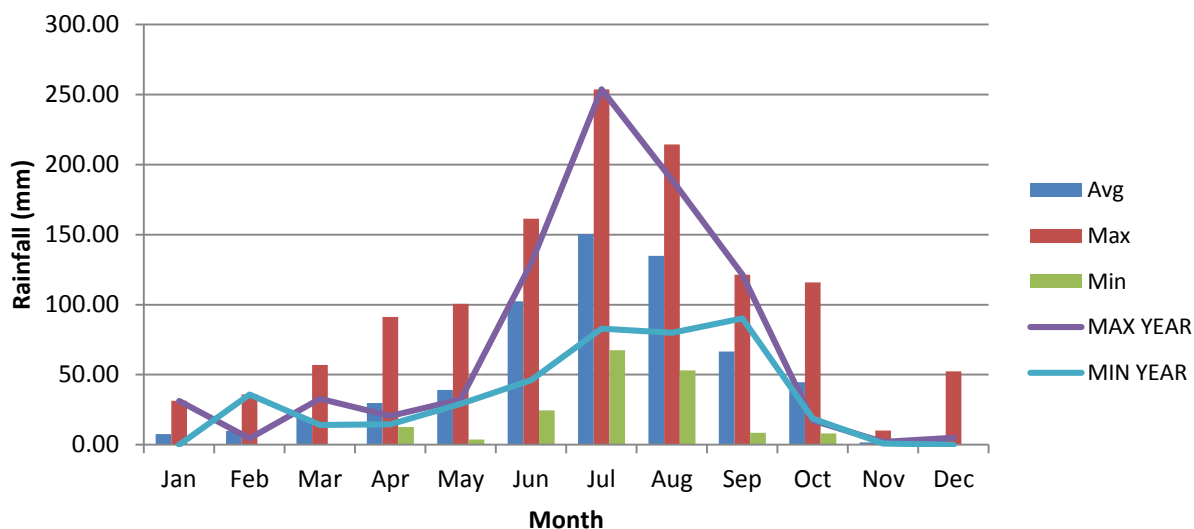
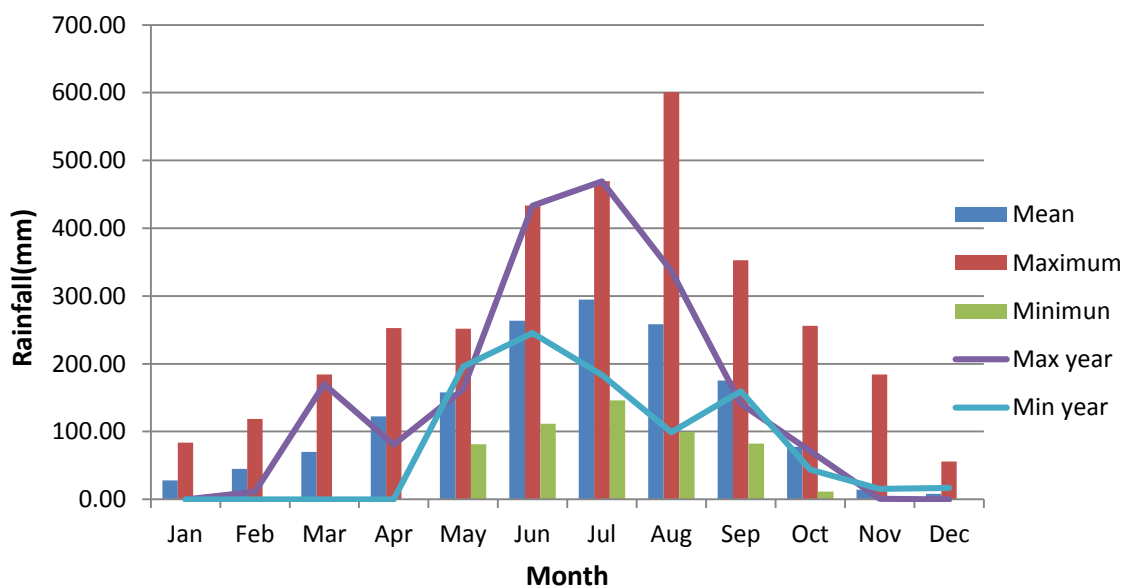


Figure 3.1(h) Maximum, Minimum and Mean Rainfall at Chhukha



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Figure 3.1(i) Maximum, Minimum and Mean Rainfall at Gedu

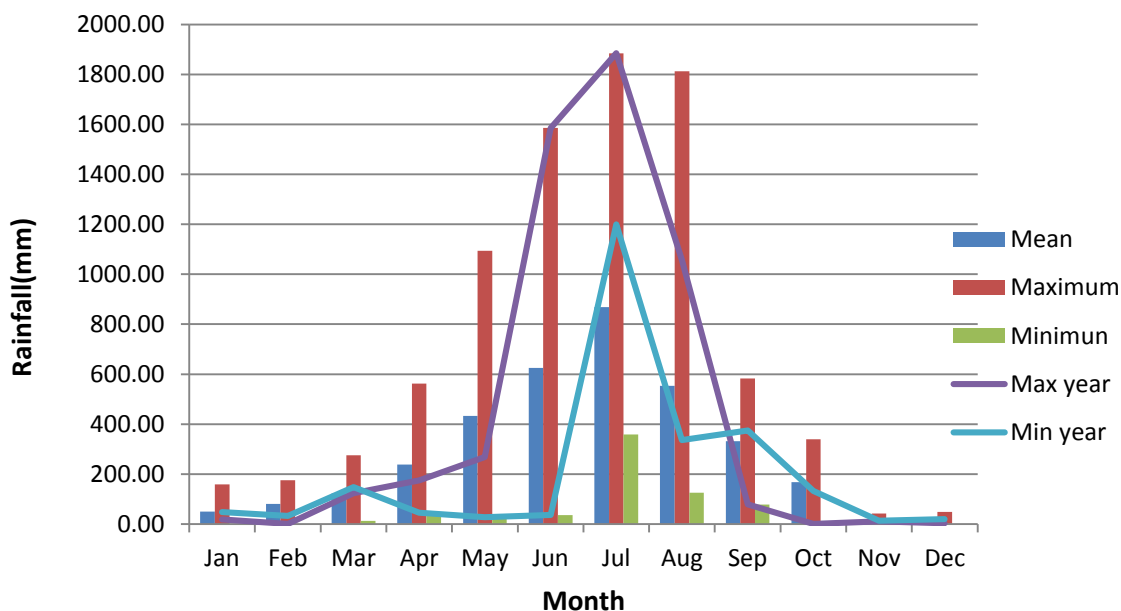
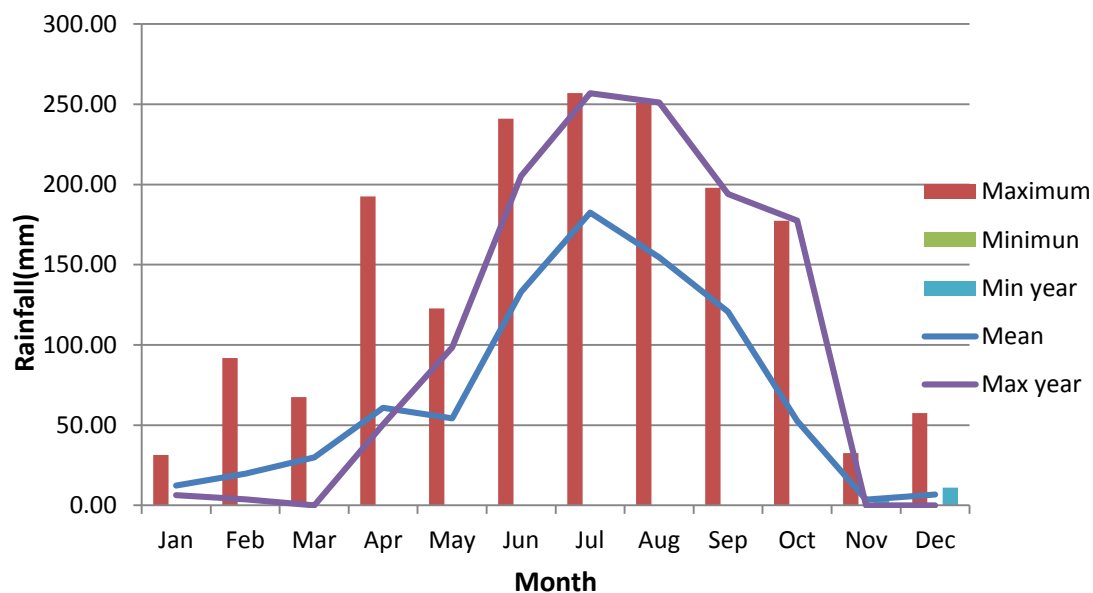


Figure 3.1(j) Maximum, Minimum and Mean Rainfall at Namjeyling



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Sheet 1 of 3

Annex-3.1 INFLOW SERIES AT TALA DAM SITE (Cumec)															
0-Daily / Year	1962-63	1963-64	1964-65	1965-66	1966-67	1967-68	1968-69	1969-70	1970-71	1971-72	1972-73	1973-74	1974-75	1975-76	1976-77
JUN 1	135.61	117.69	71.05	73.09	79.17	98.22	95.02	59.52	109.19	64.73	108.58	73.92	93.96	46.22	73.58
JUN 2	210.36	201.00	95.37	78.65	114.94	142.26	206.44	52.33	170.09	100.83	169.14	115.14	146.37	72.01	108.25
JUN 3	235.78	168.74	150.40	162.53	118.86	118.86	173.25	52.56	201.97	119.73	200.84	136.72	173.81	85.50	86.51
JUL 1	231.69	176.00	200.06	177.20	263.80	271.14	218.60	75.58	222.02	168.26	217.76	180.48	195.50	117.97	153.40
JUL 2	195.10	238.07	301.01	160.75	243.25	286.88	300.11	97.71	261.09	197.87	256.07	212.24	229.90	138.72	206.28
JUL 3	217.66	381.50	342.10	313.55	239.09	198.20	366.43	77.08	280.63	212.68	275.24	228.13	247.11	149.11	124.07
AUG 1	357.90	302.66	319.70	400.94	375.53	211.26	281.31	88.31	222.44	209.11	315.82	245.05	316.01	314.79	160.27
AUG 2	381.44	306.02	286.28	397.37	359.98	290.97	252.91	67.33	230.19	216.39	326.81	253.58	327.01	325.75	236.84
AUG 3	333.91	269.61	224.82	366.22	366.22	196.85	317.16	68.18	230.19	216.39	326.81	253.58	327.01	325.75	194.72
SEP 1	270.24	241.67	213.83	170.46	398.58	153.25	181.51	72.37	221.64	264.07	261.20	227.75	296.77	160.62	197.63
SEP 2	276.65	155.50	216.00	129.75	335.22	167.92	186.22	64.24	195.87	233.37	230.83	201.27	262.27	141.95	148.65
SEP 3	195.89	223.83	196.93	121.52	154.33	152.03	183.78	67.46	155.69	185.50	183.48	159.98	208.47	112.83	98.60
OCT 1	112.70	177.11	138.95	104.71	112.88	179.97	79.53	58.81	94.68	124.38	95.00	124.42	177.24	92.11	92.04
OCT 2	84.95	130.03	98.83	93.59	104.05	107.83	62.69	48.93	75.23	98.83	75.49	98.87	140.84	73.20	74.52
OCT 3	67.16	113.54	75.26	88.84	91.55	94.14	57.00	43.37	64.80	85.13	65.02	85.16	121.31	63.05	57.41
NOV 1	61.30	122.60	100.96	106.13	96.61	97.97	51.53	48.05	71.26	61.51	55.98	58.05	103.69	52.04	58.38
NOV 2	52.25	99.56	96.64	87.94	88.56	91.07	46.31	44.68	61.54	53.11	48.34	50.13	89.55	44.94	52.67
NOV 3	46.96	86.64	71.54	75.90	75.89	83.81	45.97	42.40	53.41	46.10	41.96	43.51	77.72	39.01	48.84
DEC 1	42.36	39.56	56.59	65.86	65.16	78.45	45.05	40.37	49.65	44.12	43.80	43.76	54.44	42.47	42.86
DEC 2	36.98	33.88	49.56	55.07	59.12	65.83	43.26	38.63	44.98	39.97	39.69	39.65	49.33	38.48	39.91
DEC 3	32.79	32.60	43.01	48.51	50.44	58.47	40.86	36.47	40.40	35.90	35.65	35.61	44.30	34.56	30.13
JAN 1	31.53	39.55	38.79	59.13	45.76	50.23	42.52	35.56	39.12	27.26	27.58	40.63	36.68	33.77	24.79
JAN 2	31.28	33.94	34.23	45.55	42.36	44.77	40.76	32.77	35.93	25.04	25.33	37.32	33.69	31.02	23.57
JAN 3	30.51	29.54	31.79	42.66	40.68	37.43	38.34	31.46	34.22	23.85	24.13	35.54	32.09	29.54	24.61
FEB 1	30.37	29.31	30.71	39.12	39.51	32.02	35.08	30.82	30.93	23.60	22.60	30.19	29.88	25.27	24.00
FEB 2	27.90	31.05	29.95	45.15	34.53	28.73	34.95	33.00	29.86	22.79	21.82	29.15	28.85	24.40	22.43
FEB 3	24.94	30.54	28.90	39.81	35.45	27.79	33.81	32.58	28.52	21.76	20.84	27.83	27.55	23.30	21.63
MAR 1	31.23	29.89	28.62	39.84	32.83	28.29	32.05	34.69	19.57	22.31	19.22	29.52	27.48	28.91	21.28
MAR 2	35.17	29.79	28.69	39.61	33.24	46.38	32.74	35.16	20.28	23.12	19.92	30.59	28.48	29.96	24.34
MAR 3	32.17	30.41	29.79	72.58	45.23	40.91	35.73	43.19	23.70	27.02	23.28	35.76	33.28	35.02	22.43
APR 1	52.67	46.10	31.66	61.45	65.10	37.90	35.71	34.93	15.17	43.53	38.35	54.80	51.82	40.46	31.49
APR 2	58.69	52.56	79.00	66.11	51.42	67.62	37.65	49.05	17.58	50.44	44.44	63.49	60.04	46.88	36.32
APR 3	67.12	52.57	66.77	72.57	62.09	69.00	41.69	49.79	20.01	57.40	50.57	72.25	68.33	53.35	40.28
MAY 1	67.08	80.28	74.36	110.87	110.60	110.24	41.54	40.01	30.80	67.90	86.93	102.99	100.85	90.51	44.57
MAY 2	82.73	62.37	83.47	91.25	122.23	76.99	50.51	48.41	34.03	75.00	96.02	113.76	111.39	99.97	69.59
MAY 3	103.88	61.52	68.91	99.24	118.50	122.02	53.77	41.83	43.89	96.75	123.87	146.75	143.70	128.97	99.07
Total	3770.27	3752.34	3551.30	3714.08	4113.36	3486.20	3374.75	1594.32	3064.29	2981.83	3543.80	3278.08	3962.43	2820.44	2476.99
(Mcum)															

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Annex-3.1 INFLOW SERIES AT TALA DAM SITE (Cumec)															
1977-78	1978-79	1979-80	1980-81	1981-82	1982-83	1983-84	1984-85	1985-86	1986-87	1987-88	1988-89	1989-90	1990-91	1991-92	1992-93
86.33	97.95	27.61	76.28	71.21	77.88	96.11	151.15	63.87	82.44	56.20	42.88	184.29	83.69	51.33	79.34
126.98	135.45	54.10	152.04	92.11	150.59	64.12	193.88	76.32	122.64	67.83	151.46	349.90	65.28	199.17	123.60
116.56	142.88	98.86	172.11	131.86	127.10	142.71	235.97	123.16	132.30	162.15	89.50	183.56	125.29	106.67	146.76
1.48	128.35	93.37	175.27	256.94	119.60	223.86	210.02	195.02	171.27	190.27	150.45	259.44	162.73	183.63	184.49
198.17	186.24	170.74	239.20	223.56	131.28	108.94	304.82	229.14	202.60	186.38	247.76	276.58	237.23	186.73	216.96
220.30	238.58	298.26	305.01	243.07	160.49	172.22	317.56	222.81	228.38	260.45	247.36	223.99	191.44	130.65	233.19
256.29	348.17	306.58	255.62	261.30	116.24	117.81	242.74	199.64	238.40	308.78	251.13	233.22	214.95	205.32	217.58
246.83	278.10	212.07	198.55	253.82	123.38	169.12	230.99	180.28	235.69	308.12	347.18	203.81	233.83	289.54	225.15
307.43	190.51	186.67	183.23	260.35	135.32	146.66	223.82	212.74	211.96	218.19	288.50	194.79	132.68	285.58	225.15
222.48	160.56	189.46	207.28	294.02	130.61	163.95	297.06	219.07	190.74	211.67	205.46	195.79	122.23	404.66	169.58
210.36	211.64	126.79	152.16	211.64	135.79	191.73	269.19	233.65	174.73	187.67	152.46	233.87	136.36	302.39	149.87
127.96	158.26	57.60	98.88	141.13	111.92	177.92	188.22	193.24	140.53	164.73	109.46	260.79	136.59	133.76	119.12
202.63	133.12	91.46	88.44	121.49	77.80	144.41	128.02	124.76	139.78	95.33	83.78	168.45	123.18	90.78	161.39
114.94	93.35	73.50	70.81	86.98	54.71	133.16	131.86	182.44	111.84	106.94	62.80	91.33	98.17	69.47	128.25
79.68	71.71	46.02	63.59	77.95	93.23	83.80	98.08	161.28	87.40	92.47	50.27	71.64	68.22	54.96	110.46
80.45	73.40	42.74	55.79	80.14	58.81	82.68	76.89	124.80	83.90	77.98	50.94	66.71	63.05	53.86	99.97
64.09	65.57	36.61	51.07	69.53	53.56	69.42	60.96	102.53	56.39	62.48	41.84	56.79	53.85	46.50	86.33
50.45	59.72	35.01	51.81	57.82	43.54	60.96	47.52	86.85	55.24	52.68	36.65	49.80	44.93	41.22	74.93
44.26	52.81	42.39	50.15	52.95	39.43	52.29	38.00	73.67	39.76	46.95	34.14	41.96	40.32	36.91	58.36
39.11	49.82	36.43	48.94	51.05	38.17	38.19	28.84	66.68	37.43	41.31	31.04	37.65	34.27	32.91	52.88
36.02	43.16	40.10	47.94	47.42	28.93	32.98	27.37	64.42	33.44	36.08	29.20	34.26	31.36	31.17	47.49
34.16	33.34	32.79	46.22	42.55	24.77	25.56	25.77	61.05	30.13	33.31	28.44	30.75	33.55	27.98	38.74
34.16	30.56	26.25	43.75	39.94	23.39	23.67	25.32	59.99	27.99	30.52	26.65	29.65	29.16	26.00	35.59
31.02	27.51	21.76	43.16	37.02	22.99	21.98	24.44	60.40	25.97	28.03	25.54	28.53	27.84	24.61	33.89
28.62	26.59	21.75	35.27	27.77	20.57	20.53	24.39	57.54	25.33	26.25	25.39	25.97	25.08	23.77	30.23
28.76	25.08	20.97	34.77	25.36	20.06	19.91	23.24	43.00	23.58	25.51	23.47	27.27	25.26	21.85	29.19
29.17	22.74	20.86	32.73	24.38	20.49	19.62	23.22	30.93	23.72	24.69	28.09	24.58	27.65	21.02	27.88
27.68	21.66	20.22	17.62	24.39	20.27	20.28	24.59	29.97	23.18	23.37	29.52	23.58	26.73	23.54	30.81
30.59	22.66	19.52	19.71	23.95	24.19	21.28	23.46	30.02	25.45	25.63	31.76	24.57	30.89	23.46	31.93
30.98	22.60	26.87	16.71	30.89	22.89	20.51	22.52	28.30	43.23	25.08	44.34	27.28	36.94	25.88	37.32
42.13	28.14	30.74	18.66	71.50	26.33	23.40	26.31	28.89	41.89	29.79	50.05	31.89	39.05	25.46	35.61
61.16	29.40	45.12	28.46	53.58	26.01	26.87	29.72	29.14	34.12	30.89	60.99	51.93	36.46	25.14	41.26
77.61	35.41	46.86	39.45	58.36	39.76	37.77	27.58	29.14	37.75	37.29	59.87	54.90	40.55	26.62	46.95
75.95	45.44	52.38	45.06	73.31	82.95	62.69	29.30	63.73	47.88	50.90	68.87	65.39	59.32	41.15	87.67
107.83	50.82	55.87	51.30	70.62	106.13	93.91	35.31	68.02	55.94	54.57	54.03	87.66	45.25	41.05	96.83
107.40	36.12	60.67	63.91	67.17	91.21	81.22	47.02	82.93	54.86	50.41	316.50	67.55	51.81	40.19	124.92
3158.34	2968.58	2447.59	2891.61	3307.92	2273.87	2630.22	3444.42	3383.88	2904.49	3021.43	3172.89	3525.11	2577.90	2946.30	3210.03

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Annex-3.1 INFLOW SERIES AT TALA DAM SITE (Cumec)

1993-94	1994-95	1995-96	1996-97	1997-98	1998-99	1999-2000	2000-2001	2001-2002	2002-2003	2003-2004	2004-2005	2005-2006	2006-2007	2007-2008
88.40	109.98	93.64	95.05	102.60	121.33	211.85	143.18	132.78	86.40	70.00	88.90	50.36	108.45	56.87
137.70	171.32	145.86	272.55	134.38	139.25	247.21	220.80	189.62	142.37	93.57	203.38	56.52	168.93	88.58
163.50	203.43	173.20	203.96	176.70	226.43	560.21	273.48	278.67	163.47	346.97	241.11	95.85	200.60	105.19
213.44	173.08	236.33	259.51	299.27	403.49	571.69	203.50	154.86	319.64	412.91	240.28	197.22	209.23	190.07
250.99	203.53	277.92	350.90	277.04	297.31	609.92	297.03	242.71	271.64	340.44	355.98	420.12	246.04	223.51
269.78	218.77	298.72	347.74	224.61	253.19	662.26	323.88	271.68	376.28	305.65	409.90	335.40	264.46	240.24
165.53	155.63	249.27	274.97	227.00	303.63	562.19	517.42	260.87	277.60	305.05	390.69	227.40	232.91	244.04
171.29	161.05	257.95	300.82	420.01	498.65	510.84	339.60	338.15	340.20	271.32	316.81	337.05	241.02	252.53
171.29	161.05	257.95	259.39	230.18	290.54	690.38	330.02	363.00	401.17	286.99	228.13	310.49	241.02	252.53
148.64	244.17	162.33	262.62	245.97	245.16	518.11	408.92	274.37	222.61	314.60	207.47	208.59	257.53	301.60
131.36	215.79	143.46	257.35	231.43	164.08	457.18	281.22	304.92	149.18	331.74	158.34	125.70	227.59	266.54
104.41	171.52	114.03	225.59	184.49	141.44	429.20	179.77	193.67	171.52	211.87	145.52	156.85	180.91	211.86
151.15	104.62	80.36	189.97	117.48	100.07	289.05	109.63	284.02	114.89	175.54	219.84	210.76	135.22	119.13
120.11	83.14	63.86	155.47	102.79	69.24	324.80	84.26	173.84	99.69	154.13	142.02	124.65	107.45	94.67
103.45	71.61	55.00	147.41	80.67	75.92	365.49	68.85	111.51	78.49	151.17	98.00	153.54	92.55	81.54
77.48	59.86	60.80	80.70	67.56	70.40	121.74	50.03	85.16	65.50	103.63	79.01	87.60	69.39	61.23
66.91	51.70	52.50	66.86	70.78	80.82	104.08	50.23	73.86	55.34	82.62	67.30	69.38	59.92	52.88
58.07	44.87	45.57	64.71	48.29	75.12	83.82	45.96	63.33	49.93	72.56	58.37	56.66	52.01	45.89
56.32	48.02	38.82	54.62	57.04	62.09	78.87	39.60	57.73	45.39	59.48	50.20	50.51	46.46	40.86
51.03	43.51	35.17	57.56	68.64	61.08	75.32	38.81	51.62	42.42	38.81	43.96	48.00	42.10	37.03
45.83	39.08	31.59	49.14	57.69	52.01	65.61	34.56	41.06	37.19	50.68	38.40	36.20	37.81	33.25
47.59	38.73	21.37	47.75	55.02	43.30	101.86	32.99	37.06	37.35	49.52	39.71	31.52	35.05	30.25
43.72	35.57	19.63	34.52	51.19	47.48	98.41	29.10	34.73	30.69	48.55	32.96	30.23	32.19	27.79
41.64	33.88	18.69	37.21	39.34	51.27	93.25	29.55	37.11	27.93	46.95	36.02	30.45	30.66	26.47
34.71	31.28	19.58	43.87	42.71	53.01	32.22	29.25	35.87	27.12	35.97	36.09	29.00	31.14	26.01
33.52	30.20	18.90	42.79	54.56	44.53	31.07	26.64	32.52	28.35	33.59	35.74	29.56	30.07	25.12
32.01	28.84	18.05	47.85	47.92	30.19	30.34	25.04	34.33	26.53	32.23	35.94	27.96	28.71	23.98
22.06	25.53	26.43	48.50	42.14	28.35	29.54	23.42	31.11	25.88	31.24	40.22	25.38	34.24	25.15
22.86	26.46	27.39	46.31	34.71	25.40	28.91	23.73	31.04	25.99	28.59	36.97	27.14	35.48	26.06
26.72	30.93	32.01	44.10	53.18	44.43	34.75	24.72	37.01	28.13	44.35	44.50	29.77	41.47	30.46
24.98	22.37	40.27	50.08	59.07	73.05	72.87	25.48	36.09	54.30	35.66	38.59	34.27	43.55	36.24
28.94	25.91	46.66	48.91	56.52	75.21	55.79	48.89	45.13	51.48	77.38	42.28	40.02	50.46	41.99
32.94	29.49	53.10	53.03	65.76	114.34	88.28	55.72	56.17	66.22	64.25	55.05	50.34	57.42	47.79
54.83	70.75	68.28	67.58	77.52	80.69	66.40	57.73	61.38	51.69	46.15	62.17	47.48	47.42	39.49
60.56	78.15	75.42	67.68	63.90	115.29	71.02	68.24	68.67	50.92	98.13	63.78	63.40	52.38	43.61
78.13	100.81	97.30	71.63	110.73	280.28	160.03	80.55	77.89	62.01	112.72	72.34	109.34	67.58	56.26
2936.87	2941.46	3052.45	4159.98	3757.48	4265.39	7547.60	4065.99	4052.68	3629.94	4370.47	3923.86	3507.52	3379.31	3087.94

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Annex-3.2 INFLOW SERIES AT CHUKHA DAM SITE (Cumec)													
Year / Month	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	MCM
1976-77	103.99	186.10	229.57	172.39	86.15	52.17	36.61	23.82	22.26	22.19	35.27	70.47	2750.96
1977-78	130.50	213.33	316.98	217.31	151.96	63.63	38.84	32.15	28.27	29.16	59.04	95.35	3638.85
1978-79	145.81	218.98	313.45	205.56	114.50	64.84	47.41	29.74	24.46	21.85	30.33	43.12	3329.99
1979-80	69.99	221.76	271.35	144.87	80.85	37.31	38.82	26.16	20.75	21.89	40.05	55.27	2725.58
1980-81	155.18	281.25	245.92	177.60	85.95	51.77	47.98	43.41	34.78	17.37	28.25	52.64	3228.54
1981-82	114.32	280.17	303.19	243.97	110.33	67.66	49.37	38.91	25.39	26.00	59.87	68.81	3669.07
1982-83	137.79	160.21	145.68	146.60	88.15	50.91	34.88	23.20	19.94	21.90	29.99	91.41	2509.51
1983-84	117.73	198.49	173.72	207.98	138.66	69.53	40.02	23.18	19.62	20.48	28.64	77.67	2946.65
1984-85	225.11	324.07	269.99	292.36	134.66	60.42	30.61	24.64	23.15	23.00	27.29	36.62	3884.09
1987-88	110.65	248.60	319.09	218.74	113.99	63.02	40.43	30.22	24.96	24.28	31.97	50.82	3376.56
1988-89	109.99	253.34	344.25	181.11	75.37	42.23	30.78	26.27	24.69	34.57	56.44	148.67	3516.03
1989-90	277.63	296.58	244.22	269.96	126.83	56.50	37.14	28.99	25.74	24.62	44.94	71.79	3968.09
1990-91	106.61	230.51	224.32	153.11	111.15	52.81	34.45	29.57	25.28	29.84	37.12	51.00	2871.33
1991-92	150.69	189.44	303.39	325.68	82.77	46.23	32.93	25.61	22.04	23.85	25.33	39.92	3342.85
1992-93	64.08	186.09	239.74	150.32	72.40	40.82	27.83	25.27	23.61	21.40	38.69	73.26	2549.16
1993-94	108.68	147.81	258.40	204.66	91.26	46.63	31.41	26.36	24.51	30.20	39.09	52.04	2801.04
1994-95	121.97	140.53	230.17	180.75	67.73	38.90	27.81	23.14	22.57	30.03	36.80	60.09	2587.58
1995-96	134.30	252.87	232.15	209.46	117.98	84.50	45.11	34.81	28.99	35.03	46.83	62.46	3391.81
1996-97	107.54	241.01	237.58	198.42	103.47	52.46	34.31	25.85	23.96	26.74	34.71	58.00	3024.01
1997-98	114.06	231.01	251.08	193.68	75.90	42.53	32.95	24.52	21.33	22.63	45.82	60.18	2948.51
1998-99	102.71	286.29	330.95	183.02	89.38	46.26	32.08	25.01	21.64	20.87	32.25	57.03	3250.58
1999-2000	153.54	251.89	293.42	230.27	182.02	80.46	46.57	32.75	27.64	27.72	48.30	83.11	3852.80
2000-2001	152.08	220.23	313.08	242.00	74.78	43.77	31.28	24.78	22.31	21.59	37.38	62.01	3288.48
2001-2002	140.96	167.66	264.87	209.89	141.51	53.63	34.89	26.90	23.70	22.62	32.91	52.78	3095.96
2002-2003	99.16	266.14	273.88	153.81	81.60	46.35	32.95	27.02	25.01	24.38	45.47	46.12	2968.58
2003-2004	136.79	271.98	240.36	234.16	126.62	65.69	41.28	32.12	27.15	30.97	44.80	62.22	3471.11
2004-2005	139.99	277.10	257.53	143.44	118.78	49.63	33.79	26.92	25.73	27.80	34.61	52.78	3143.77
2005-2006	53.22	206.21	241.45	121.99	134.47	58.16	36.52	27.12	23.49	22.28	34.06	61.79	2704.82
2006-2007	129.98	201.74	197.77	187.43	89.97	48.50	33.38	25.17	24.20	29.67	42.17	49.97	2797.45
2007-2008	67.78	194.14	213.24	221.64	83.59	44.59	29.98	22.98	19.87	21.60	35.07	40.60	2628.11

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Annex-3.3 - Final 10 daily discharge series (in cumec) at Dam site												(Sheet 1 of 3)	
Month	Days	1962-63	1963-64	1964-65	1965-66	1966-67	1967-68	1968-69	1969-70	1970-71	1971-72	1972-73	1973-74
JUN 1	10	177.24	153.58	92.02	94.71	102.74	127.88	123.66	76.80	142.36	83.68	141.56	95.81
JUN 2	10	275.91	263.56	124.12	102.05	149.95	186.02	270.74	67.31	222.75	131.33	221.50	150.22
JUN 3	10	309.47	220.97	196.76	212.77	155.13	155.13	226.92	67.61	264.84	156.28	263.34	178.70
JUL 1	10	304.07	230.56	262.31	232.14	346.45	356.14	286.79	98.00	291.30	220.34	285.68	236.47
JUL2	10	255.77	312.49	395.57	210.42	319.33	376.92	394.38	127.21	342.88	259.42	336.25	278.39
JUL3	11	285.55	501.82	449.81	412.12	313.84	259.86	481.93	99.98	368.67	278.97	361.55	299.37
AUG1	10	470.67	397.75	420.24	527.48	493.94	277.10	369.57	114.80	291.86	274.26	415.12	321.70
AUG2	10	501.74	402.18	376.13	522.77	473.41	382.32	332.08	87.11	302.09	283.87	429.63	332.96
AUG3	11	439.00	354.12	295.00	481.65	481.65	258.08	416.89	88.23	302.09	283.87	429.63	332.96
SEP1	10	354.95	317.24	280.49	223.24	524.37	200.52	237.83	93.76	290.80	346.81	343.02	298.87
SEP2	10	363.42	203.49	283.36	169.50	440.73	219.89	244.05	83.03	256.78	306.28	302.93	263.91
SEP3	10	256.81	293.69	258.18	158.64	201.95	198.91	240.82	87.28	203.75	243.10	240.43	209.41
OCT1	10	147.00	232.02	181.65	136.45	147.24	235.80	103.21	75.86	123.21	162.42	123.63	162.47
OCT2	10	110.37	169.87	128.69	121.77	135.58	140.57	80.98	62.82	97.54	128.69	97.88	128.74
OCT3	11	86.88	148.11	97.58	115.50	119.08	122.50	73.47	55.48	83.77	110.60	84.06	110.64
NOV1	10	80.92	161.83	133.27	140.09	127.53	129.32	68.02	63.43	94.06	81.19	73.89	76.63
NOV2	10	68.97	131.42	127.57	116.08	116.90	120.21	61.13	58.98	81.23	70.11	63.81	66.17
NOV3	10	61.99	114.37	94.43	100.19	100.18	110.63	60.68	55.97	70.50	60.85	55.39	57.43
DEC1	10	55.92	52.22	74.70	86.94	86.01	103.56	59.47	53.29	65.54	58.24	57.82	57.76
DEC2	10	48.81	44.72	65.42	72.69	78.04	86.90	57.10	50.99	59.37	52.76	48.43	52.34
DEC3	11	43.28	43.03	56.77	64.03	66.58	77.18	53.94	48.14	53.33	47.39	47.06	47.01
JAN1	10	41.62	52.21	51.20	78.05	60.40	66.30	56.13	46.94	51.64	35.98	36.41	53.63
JAN2	10	41.29	44.80	57.06	60.13	55.92	59.10	53.80	43.26	47.43	33.05	33.44	49.26
JAN3	11	40.27	38.99	41.96	56.31	53.70	49.41	50.61	41.53	45.17	31.48	31.85	46.91
FEB1	10	40.09	38.69	40.54	51.64	52.15	42.27	46.31	40.68	40.83	31.15	29.83	39.85
FEB2	10	36.83	40.99	39.53	59.60	45.58	37.92	46.13	43.56	39.42	30.08	28.80	38.48
FEB3	8	32.92	40.31	38.15	52.55	46.79	36.68	44.63	43.01	37.65	28.72	27.51	36.74
MAR1	10	41.22	39.46	37.78	52.59	43.34	37.34	42.31	45.79	25.83	29.45	25.37	38.97
MAR2	10	46.43	39.32	37.87	52.29	43.88	61.22	43.22	46.41	26.77	30.52	26.29	40.38
MAR3	11	42.47	40.14	39.32	95.81	59.70	54.00	47.16	57.01	31.28	35.67	30.73	47.20
APR1	10	69.53	60.85	41.79	81.12	85.93	50.03	47.14	46.11	20.02	57.46	50.62	72.34
APR2	10	77.47	69.38	104.28	87.27	67.88	89.26	49.70	64.75	23.21	66.58	58.66	83.81
APR3	10	88.60	69.39	88.14	95.79	81.96	91.08	55.03	65.72	26.41	75.77	66.75	95.37
May-01	10	86.78	104.20	96.39	144.58	144.23	143.75	53.07	51.05	38.89	87.86	112.98	134.18
May-02	10	107.44	80.56	108.41	118.68	159.58	99.86	64.91	62.13	43.15	97.23	124.98	148.40
May-03	11	135.36	79.44	89.19	129.23	154.65	159.30	69.21	53.45	56.17	125.94	161.74	191.94
Volume MCM		4949	4925	4670	4875	5402	4574	4427	2076	4017	3908	4646	4299

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Annex-3.3 - Final 10 daily discharge series (in cumec) at Dam site										(Sheet 2 of 3)			
1974-75	1975-76	1976-77	1977-78	1978-79	1979-80	1980-81	1981-82	1982-83	1983-84	1984-85	1985-86	1986-87	1987-88
122.26	59.24	95.36	112.19	127.53	34.68	98.92	92.23	101.03	125.10	197.75	82.54	107.05	72.42
191.44	93.29	141.12	165.85	177.03	69.64	198.93	119.82	197.01	82.87	254.16	98.98	160.12	87.77
227.66	111.09	112.43	152.09	186.84	128.73	225.42	172.29	166.01	186.61	309.72	160.81	172.87	212.27
256.30	153.95	200.72	193.59	167.66	121.48	229.59	337.40	156.11	293.73	275.46	255.66	224.31	249.39
301.70	181.34	270.53	259.82	244.07	223.61	313.98	293.34	171.52	142.03	400.60	300.70	265.67	244.26
324.42	195.06	162.01	289.03	313.16	391.94	400.85	319.09	210.08	225.57	417.42	292.35	299.70	342.03
415.37	413.76	209.79	336.54	457.82	402.92	335.66	343.15	151.67	153.74	318.65	261.76	312.92	405.83
429.89	428.23	310.87	324.05	365.33	278.17	260.32	333.28	161.10	221.47	303.14	236.20	309.35	404.96
429.89	428.23	255.27	404.05	249.71	244.64	240.10	341.90	176.86	191.83	293.68	279.05	278.02	286.25
389.97	210.25	259.11	291.91	210.17	248.32	271.85	386.34	170.64	214.65	390.36	287.41	250.01	277.64
344.43	185.61	194.45	275.91	277.60	165.60	199.09	277.60	177.48	251.32	353.57	306.65	228.88	245.96
273.42	147.17	128.39	167.14	207.14	74.26	128.76	184.53	145.97	233.09	246.69	253.31	183.73	215.68
232.19	119.82	119.73	265.71	173.95	118.96	114.97	158.60	100.93	188.86	167.22	162.92	182.74	124.07
184.14	94.86	96.60	149.95	121.46	95.25	91.70	113.05	70.45	174.01	172.29	239.06	145.86	139.39
158.36	81.46	74.01	103.41	92.89	58.98	82.17	101.13	121.30	108.85	127.70	211.12	113.60	120.29
136.87	68.69	77.06	106.20	96.89	56.42	73.64	105.79	77.63	109.14	101.50	164.74	110.75	102.94
118.21	59.32	69.53	84.60	86.55	48.33	67.41	91.78	70.70	91.64	80.47	135.34	74.44	82.47
102.59	51.49	64.47	66.60	78.83	46.21	68.39	76.32	57.47	80.47	62.73	114.64	72.92	69.54
71.86	56.06	56.58	58.42	69.71	55.96	66.20	69.90	52.05	69.02	50.16	97.25	52.48	61.97
65.12	50.79	52.68	51.63	65.76	48.09	64.60	67.39	50.39	50.41	38.07	88.02	49.41	54.53
58.48	45.62	39.77	47.55	56.97	52.93	63.28	62.60	38.19	43.53	36.13	85.04	44.14	47.63
48.42	44.58	32.72	45.09	44.01	43.28	61.01	56.17	32.70	33.74	34.02	80.59	39.77	43.97
44.47	40.95	31.11	45.09	40.34	34.65	57.75	52.72	30.88	31.24	33.42	79.19	36.95	40.29
42.36	38.99	32.49	40.95	36.31	28.72	56.97	48.87	30.35	29.01	32.26	79.73	34.28	37.00
39.44	33.36	31.68	37.78	35.10	28.71	46.56	36.66	27.15	27.10	32.20	75.95	33.44	34.65
38.08	32.21	29.61	37.96	33.11	27.68	45.90	33.48	26.48	26.28	30.68	56.76	31.13	33.67
36.37	30.76	28.55	38.51	30.02	27.54	43.20	32.18	27.05	25.90	30.65	40.83	31.31	32.59
36.27	38.16	28.09	36.54	28.59	26.69	23.26	32.20	26.76	26.77	32.46	39.56	30.60	30.85
37.59	39.55	32.13	40.38	29.91	25.77	26.02	31.61	31.93	28.09	30.97	39.63	33.59	33.83
43.93	46.23	29.61	40.89	29.83	35.47	22.06	40.78	30.22	27.07	29.73	37.36	57.06	33.11
68.40	53.41	41.57	55.61	37.15	40.58	24.63	94.38	34.76	30.89	34.73	38.14	55.30	39.32
79.25	61.88	47.94	80.73	38.81	59.56	37.57	70.73	34.33	35.47	39.23	38.47	45.04	40.78
90.20	70.42	53.17	102.45	46.74	61.86	52.07	77.04	52.48	49.86	36.41	38.47	49.83	49.22
131.36	117.71	57.06	98.49	58.21	67.37	57.71	95.00	107.73	80.98	36.91	82.36	61.43	65.42
145.27	130.19	90.09	140.57	65.31	71.98	65.95	91.45	138.33	122.19	44.84	88.02	72.07	70.26
187.92	168.47	129.01	140.00	45.91	78.32	82.59	86.90	118.63	105.44	60.30	107.70	70.65	64.77
5202	3695	3242	4308	3891	3203	3789	4338	2973	3444	4519	4439	3806	3960

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Annex-3.3 - Final 10 daily discharge series (in cumec) at Dam site									(Sheet 3 of 3)	
1988-89	1989-90	1990-91	1991-92	1992-93	1993-94	1994-95	1995-96	1996-97	1997-98	1998-99
54.83	241.50	108.70	65.99	102.96	114.92	143.41	121.84	123.70	133.67	158.39
198.16	460.11	84.40	261.14	161.39	180.00	224.38	190.77	358.00	175.62	182.04
116.37	240.53	163.62	139.04	191.96	214.05	266.76	226.86	267.46	231.48	297.12
196.83	340.70	213.04	240.63	241.76	279.98	226.70	310.19	340.79	393.27	530.85
325.28	363.32	311.38	244.72	284.62	329.54	266.90	365.09	461.43	363.93	390.69
324.75	293.90	250.94	170.69	306.05	354.35	287.01	392.55	457.26	294.72	332.45
329.73	306.09	281.97	269.26	285.44	216.73	203.67	327.27	361.20	297.88	399.03
456.52	267.26	306.89	380.43	295.43	224.34	210.82	338.73	395.32	552.65	656.46
379.06	255.36	173.37	375.20	295.43	224.34	210.82	338.73	340.63	302.07	381.75
269.44	256.68	159.58	532.39	222.08	194.44	320.54	212.51	344.90	322.92	321.85
199.48	306.94	178.23	397.39	196.06	171.63	283.08	187.60	337.94	303.72	214.82
142.72	342.48	178.53	174.80	155.47	136.05	224.64	148.75	296.01	241.76	184.94
108.82	220.59	160.83	118.06	211.27	197.75	136.33	104.31	249.00	153.31	130.33
81.13	118.79	127.82	89.93	167.52	156.78	107.98	82.53	203.46	133.92	89.63
64.59	92.80	88.28	70.78	144.04	134.79	92.76	70.83	192.82	104.72	98.45
67.24	88.06	83.23	71.10	131.96	102.28	79.02	80.26	106.53	89.18	92.93
55.23	74.96	71.08	61.38	113.96	88.32	68.25	69.30	88.26	93.43	106.68
48.38	65.74	59.31	54.41	98.91	76.65	59.23	60.15	85.42	63.74	99.16
45.07	55.39	53.22	48.72	77.04	74.34	63.39	51.24	72.10	75.29	81.96
40.97	49.70	45.24	43.44	69.80	67.36	57.43	46.43	75.98	90.61	80.63
38.54	45.22	41.40	41.15	62.69	60.50	51.59	41.70	64.87	76.15	68.65
37.54	40.59	44.29	36.93	51.14	62.82	51.12	28.21	63.03	72.63	57.16
35.18	39.14	38.49	34.32	46.98	57.71	46.95	25.91	45.57	67.57	62.67
33.71	37.66	36.75	32.49	44.74	54.97	44.72	24.67	49.12	51.93	67.68
33.52	34.28	33.11	31.38	39.90	45.82	41.29	25.85	57.91	56.38	69.97
30.98	36.00	33.34	28.84	38.53	44.25	39.86	24.95	56.48	72.02	58.78
37.08	32.45	36.50	27.75	36.80	42.25	38.07	23.83	63.16	63.26	39.85
38.97	31.13	35.28	31.07	40.67	29.12	33.70	34.89	64.02	55.63	37.42
41.92	32.43	40.78	30.97	42.15	30.18	34.93	36.16	61.13	45.82	33.53
58.53	36.01	48.76	34.16	49.26	35.27	40.83	42.25	58.21	70.20	58.65
66.07	42.10	51.55	33.61	47.01	32.97	29.53	53.16	66.11	77.97	96.43
80.51	68.55	48.13	33.19	54.46	38.20	34.20	61.59	64.56	74.61	99.28
79.03	72.47	53.53	35.14	61.97	43.48	38.93	70.09	70.00	86.80	150.93
89.14	84.55	76.54	52.55	113.96	70.61	91.62	88.36	87.44	100.56	104.74
69.55	113.94	57.96	52.42	126.05	78.17	101.39	97.79	87.44	82.58	150.42
416.02	87.40	66.62	51.28	163.13	101.36	131.30	126.67	92.78	144.40	368.21
4160	4625	3375	3861	4209	3849	3855	4001	5463	4932	5602

4 DESIGN FLOOD STUDIES

4.1 General

Wangchu HE Project is the lower most major hydro electric project on the Wangchu river Bhutan. The catchment area at the proposed dam site is about 4147 sq.km out of which 95.5 sq.km is snowfed for permanent snowline at EL 5000m . The FRL and MDDL of the project are at EL 494m and 484m respectively. The project envisages construction of 134 m high dam with gross storage capacity of 53.60 MCM at FRL.

4.2 Design flood approach

The probable maximum flood (PMF) for Wangchu HE Project has been estimated by hydro-meteorological approach, dividing the total catchment of Wangchu at Wangchu HE Project in to two sub catchments SB-1 and SB-2 and setting up a quasi distributed hydrological model on HEC-HMS . Sub catchment SB-1 correspond to Wangchu river catchment at Bunakha HE Project, while SB-2 is the catchment of Wangchu river between Bunakha and Wangchu HE Projects. The flood hydrograph of SB-1 has been channel routed through river reach R-1 and added to SB-2 flood hydrograph to get the probable maximum flood hydrograph (PMF) for Wangchu HE Project. The HEC-HMS model set up is given in Fig.4.1.

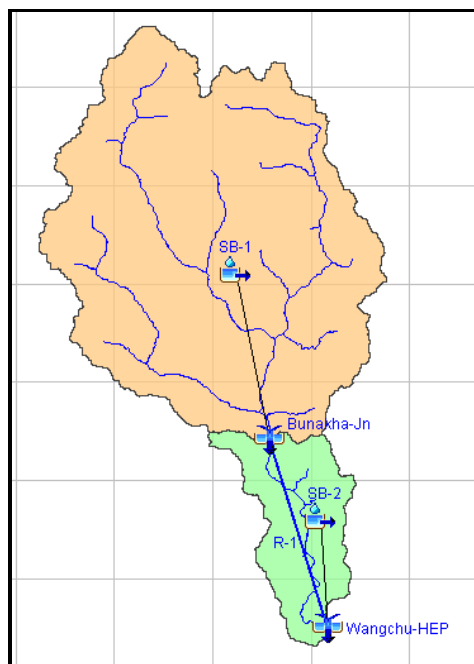


Fig.4.1: Quasi-distributed hydrological Model set up for design flood study of Wangchu HE Project

4.2.1 Physiographic parameters

The catchment area plan of Wangchu HE project is given in **Plate-4.1**. The sub-catchment physiographic parameters obtained from GIS processing of SRTM DEM are given in Table-1.

Table-4.1: Sub-basin physiographic parameters

Sub catchment	Catchment area (km ²)	L (km)	Lc (km)	Equivalent stream slope (m/km)
SB-1 (Catchment area of Wangchu up to Bunakha HE Project)	3445 (rainfed) 95 (snowfed)	112.95	47.69	15.53
SB-2 (Catchment area of Wangchu between Wangchu and Bunakha HE projects)	607 (rainfed) 0 (snowfed)	60.81	25.38	31.60
Sum Total	4147			

4.2.2 Unit hydrograph for sub catchments

The unit hydrographs for different sub catchments have been worked out as per FER-2(a) of Central Water Commission. The UH parameters adopted for different sub catchments is given in **Table-4.1**. The unit hydrographs of sub catchments are given in **Table-4.2**. The plots of UH are given in Fig.4.2 and 4.3.

Table-4.2: Unit hydrograph parameters

	SB-1	SB-2
q _p (cumec)	0.21	0.46
T _p (hr)	9.48	4.46
W ₅₀ (hr)	11.12	4.73
W ₇₅ (hr)	5.53	2.34
WR ₅₀ (hr)	3.33	1.67
WR ₇₅ (hr)	1.86	0.89

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T _B (hr)	36.95	19.55
Q _p (cumec)	716	281
T _m (hr)	11	5

Table-4.3: Unit hydrograph for sub catchments

Time (hour)	UH ordinates (cumec)	
	SB1	SB2
0	0	0
1	34	18
2	66	44
3	106	98
4	162	194
5	222	281
6	296	240
7	398	177
8	536	141
9	650	112
10	716	90
11	680	74
12	626	60
13	558	48
14	508	39
15	456	28
16	408	19
17	374	13
18	342	7
19	313	3
20	288	0
21	261	
22	238	
23	214	
24	192	
25	172	
26	151	
27	132	
28	115	
29	95	
30	79	
31	61	
32	47	
33	33	
34	22	
35	13	
36	5	
37	0	

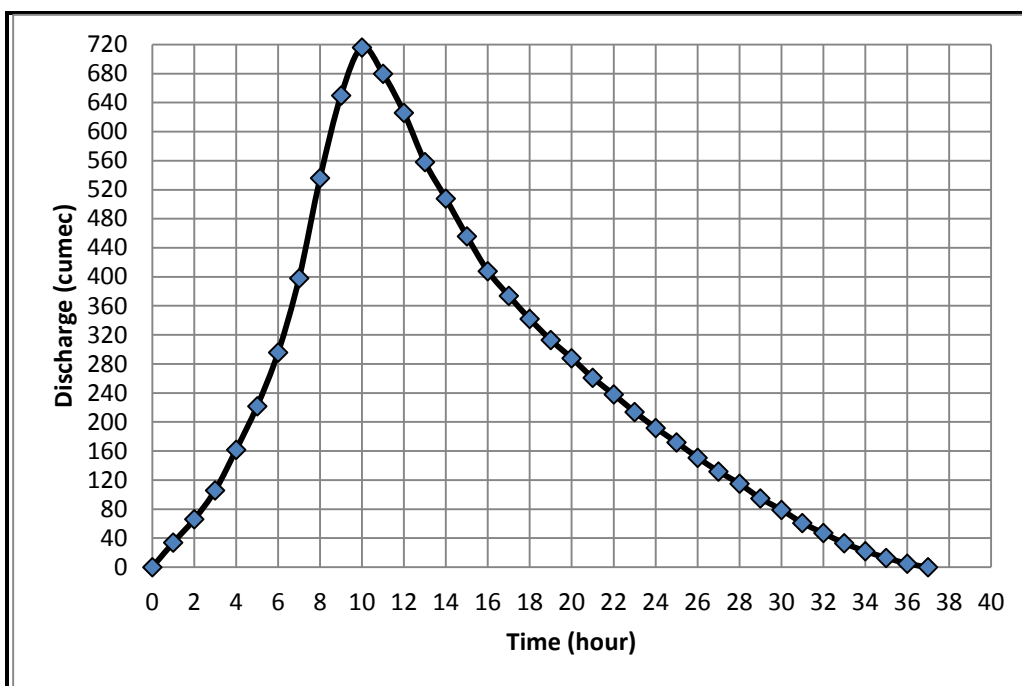


Fig.4.2: Unit hydrograph for SB-1

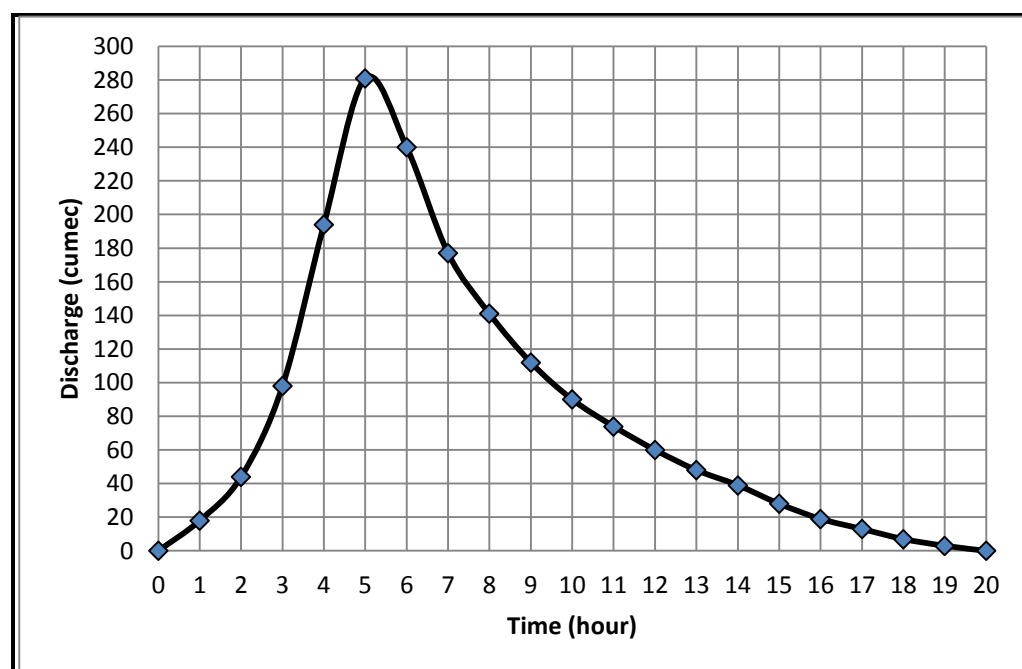


Fig.4.3: Unit hydrograph for SB-2

4.3 Design Storm

4.3.1 Storm Depth

For the purpose of estimation of PMP, the severest storms recorded in the area during 4th and 5th October 1968 has been considered. The PMP estimate for each sub-catchment have been worked out based on isohyetal pattern (**Fig.4.4(a) to 4.4(d)**) of above 4th and 5th Oct 1968 storm. The moisture adjustment factor (MAF) has been estimated as 1.35. The probable maximum precipitation (PMP) values for Wangchu HE Project and its contribution in SB-1 and SB-2 of quasi-distributed hydrological model is given in **Table-4.4**.

Table-4.4: 1day and 2day SPS and PMP values

Duration	Wangchu HE Project (CA-4147 sq.km)		SB-1 (Rainfed CA-3445 sq.km)		SB-2 (Rainfed CA-607 sq.km)	
	SPS (mm)	PMP (mm)	SPS (mm)	PMP (mm)	SPS (mm)	PMP (mm)
1 day	151	205	131	177	196	265
2 day	296	400	233	315	653	881

The present PMF study qualifies for 2 day PMP. The hourly distribution of 2 day PMP for bells of 12 hour each for sub-catchment SB-1 is given in **Table-4.5**. The same for SB-2 is given in **Table-4.6**. As 2-day PMP has been used for estimating the design flood, the incremental daily PMP for each sub catchment has been worked out as follows:

$$2^{\text{nd}} \text{ day PMP} = (2 \text{ day PMP}) - (1 \text{ day PMP})$$

4.4 Loss rate and base flow

A loss rate of 0.20 cm /hour has been adopted. A design base flow of 0.05 cumec/sq.km has been adopted as per FER-2(a).

4.5 Critical sequencing of rainfall

To keep the rainfall sequence in proper order the critical sequencing of the hourly rainfall excess of the bells need to be carried out with respect to UH of one of the sub catchment preferably the sub catchment having the more catchment area. For the present case the critical sequencing of hourly rainfall excess of the bells of all the sub catchments have been carried out with respect to UH of sub catchment SB-1. The critical sequencing of hourly effective rainfall of SB-1 and SB-2 is given in Table-4.7 and 8 respectively. The bell sequence B1-B2-B3-B4 has been used for convolution with respective UH.

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Table-4.5: Hourly distribution of rainfall of SB-1

Bell	Rainfall (PMP) depth (cm)
1st 12 hr bell	13.45
2nd 12 hr bell	4.25
3rd 12 hr bell	10.49
4th 12 hr bell	3.31

Time (hr)	Dist. coeff (%)	Normalised distribution coeff (%)	Cumulative rainfall depth				Incremental rainfall depth				Loss rate 0.1 cm/hr	Effective rainfall depth			
			1st 12 hr bell	2nd 12 hr bell	3rd 12 hr bell	4th 12 hr bell	1st 12 hr bell	2nd 12 hr bell	3rd 12 hr bell	4th 12 hr bell		1st 12 hr bell	2nd 12 hr bell	3rd 12 hr bell	4th 12 hr bell
			cm	cm	cm	cm	cm	cm	cm	cm		cm	cm	cm	cm
1	13	17	2.30	0.73	1.79	0.57	2.30	0.73	1.79	0.57	0.20	2.10	0.53	1.59	0.37
2	25	33	4.43	1.40	3.45	1.09	2.12	0.67	1.66	0.52	0.20	1.92	0.47	1.46	0.32
3	32	42	5.66	1.79	4.42	1.39	1.24	0.39	0.97	0.31	0.20	1.04	0.19	0.77	0.11
4	40	53	7.08	2.24	5.52	1.74	1.42	0.45	1.10	0.35	0.20	1.22	0.25	0.90	0.15
5	47	62	8.32	2.63	6.49	2.05	1.24	0.39	0.97	0.31	0.20	1.04	0.19	0.77	0.11
6	52	68	9.20	2.91	7.18	2.27	0.89	0.28	0.69	0.22	0.20	0.69	0.08	0.49	0.02
7	56	74	9.91	3.13	7.73	2.44	0.71	0.22	0.55	0.17	0.20	0.51	0.02	0.35	-0.03

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8	61	80	10.80	3.41	8.42	2.66	0.89	0.28	0.69	0.22	0.20	0.69	0.08	0.49	0.02
9	65	86	11.51	3.63	8.97	2.83	0.71	0.22	0.55	0.17	0.20	0.51	0.02	0.35	-0.03
10	69	91	12.21	3.86	9.52	3.01	0.71	0.22	0.55	0.17	0.20	0.51	0.02	0.35	-0.03
11	73	96	12.92	4.08	10.07	3.18	0.71	0.22	0.55	0.17	0.20	0.51	0.02	0.35	-0.03
12	76	100	13.45	4.25	10.49	3.31	0.53	0.17	0.41	0.13	0.20	0.33	-0.03	0.21	-0.07

Note: All negative values of effective rainfall has been taken as zero during convolution

Table-4.6: Hourly distribution of rainfall of SB-2

Bell	Rainfall (PMP) depth (cm)
1st 12 hr bell	20.14
2nd 12 hr bell	6.36
3rd 12 hr bell	46.82
4th 12 hr bell	14.78

Time (hr)	Dist. coeff (%)	Normalised distribution coeff (%)	Cumulative rainfall depth				Incremental rainfall depth				Loss rate 0.1 cm/hr	Effective rainfall depth			
			1st 12 hr bell	2nd 12 hr bell	3rd 12 hr bell	4th 12 hr bell	1st 12 hr bell	2nd 12 hr bell	3rd 12 hr bell	4th 12 hr bell		1st 12 hr bell	2nd 12 hr bell	3rd 12 hr bell	4th 12 hr bell
			cm	cm	cm	cm	cm	cm	cm	cm		cm	cm	cm	cm

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1	13	17	3.45	1.09	8.01	2.53	3.45	1.09	8.01	2.53	0.20	3.25	0.89	7.81	2.33
2	25	33	6.63	2.09	15.40	4.86	3.18	1.00	7.39	2.33	0.20	2.98	0.80	7.19	2.13
3	32	42	8.48	2.68	19.71	6.22	1.86	0.59	4.31	1.36	0.20	1.66	0.39	4.11	1.16
4	40	53	10.60	3.35	24.64	7.78	2.12	0.67	4.93	1.56	0.20	1.92	0.47	4.73	1.36
5	47	62	12.46	3.93	28.95	9.14	1.86	0.59	4.31	1.36	0.20	1.66	0.39	4.11	1.16
6	52	68	13.78	4.35	32.03	10.12	1.33	0.42	3.08	0.97	0.20	1.13	0.22	2.88	0.77
7	56	74	14.84	4.69	34.50	10.89	1.06	0.33	2.46	0.78	0.20	0.86	0.13	2.26	0.58
8	61	80	16.17	5.10	37.58	11.87	1.33	0.42	3.08	0.97	0.20	1.13	0.22	2.88	0.77
9	65	86	17.23	5.44	40.04	12.64	1.06	0.33	2.46	0.78	0.20	0.86	0.13	2.26	0.58
10	69	91	18.29	5.77	42.50	13.42	1.06	0.33	2.46	0.78	0.20	0.86	0.13	2.26	0.58
11	73	96	19.35	6.11	44.97	14.20	1.06	0.33	2.46	0.78	0.20	0.86	0.13	2.26	0.58
12	76	100	20.14	6.36	46.82	14.78	0.80	0.25	1.85	0.58	0.20	0.60	0.05	1.65	0.38

Table-4.7 Critical sequencing for Effective hourly rainfall of SB-1 with respect to UH of SB-1

Time	UH ordinate of SB-1	Critical sequence of hourly effective rainfall depths of SB-5				Reversed critical sequence			
		1st 12 hr bell	2nd 12 hr bell	3rd 12 hr bell	4th 12 hr bell	1st 12 hr bell [B1]	2nd 12 hr bell [B2]	3rd 12 hr bell [B3]	4th 12 hr bell [B4]
(hr)	(cumec)	(cm)	(cm)	(cm)	(cm)	(cm)	(cm)	(cm)	(cm)
0	0								
1	34								
2	66								
3	106								
4	162								
5	222								
6	296								
7	398								
8	536	0.51	0.02	0.35	-0.03	0.33	0.00	0.21	0.00
9	650	0.69	0.08	0.49	0.02	0.51	0.02	0.35	0.00
10	716	1.22	0.25	0.90	0.15	0.51	0.02	0.35	0.00
11	680	2.10	0.53	1.59	0.37	0.51	0.02	0.35	0.00
12	626	1.92	0.47	1.46	0.32	0.69	0.08	0.49	0.02
13	558	1.04	0.19	0.77	0.11	1.04	0.19	0.77	0.11
14	508	1.04	0.19	0.77	0.11	1.04	0.19	0.77	0.11
15	456	0.69	0.08	0.49	0.02	1.92	0.47	1.46	0.32
16	408	0.51	0.02	0.35	-0.03	2.10	0.53	1.59	0.37
17	374	0.51	0.02	0.35	-0.03	1.22	0.25	0.90	0.15
18	342	0.51	0.02	0.35	-0.03	0.69	0.08	0.49	0.02
19	313	0.33	-0.03	0.21	-0.07	0.51	0.02	0.35	0.00
20	288								
21	261								
22	238								
23	214								
24	192								
25	172								
26	151								
27	132								
28	115								
29	95								
30	79								
31	61								
32	47								
33	33								
34	22								
35	13								
36	5								
37	0								

Note1: All negative values of effective rainfall has been taken as zero during convolution

Note 2 : Sequence B1-B2-B3-B4 has been used for convolution with UH of SB-1

Table-4.8 Critical sequencing for Effective hourly rainfall of SB-2 with respect to UH of SB-1

Time	UH ordinate of SB-1	Critical sequence of hourly effective rainfall depths of SB-5				Reversed critical sequence			
		1st 12 hr bell	2nd 12 hr bell	3rd 12 hr bell	4th 12 hr bell	1st 12 hr bell [B1]	2nd 12 hr bell [B2]	3rd 12 hr bell [B3]	4th 12 hr bell [B4]
(hr)	(cumec)	(cm)	(cm)	(cm)	(cm)	(cm)	(cm)	(cm)	(cm)
0	0								
1	34								
2	66								
3	106								
4	162								
5	222								
6	296								
7	398	0.86	0.13	2.26	0.58	0.60	0.05	1.65	0.38
8	536	1.13	0.22	2.88	0.77	0.86	0.13	2.26	0.58
9	650	1.92	0.47	4.73	1.36	0.86	0.13	2.26	0.58
10	716	3.25	0.89	7.81	2.33	0.86	0.13	2.26	0.58
11	680	2.98	0.80	7.19	2.13	1.13	0.22	2.88	0.77
12	626	1.66	0.39	4.11	1.16	1.66	0.39	4.11	1.16
13	558	1.66	0.39	4.11	1.16	1.66	0.39	4.11	1.16
14	508	1.13	0.22	2.88	0.77	2.98	0.80	7.19	2.13
15	456	0.86	0.13	2.26	0.58	3.25	0.89	7.81	2.33
16	408	0.86	0.13	2.26	0.58	1.92	0.47	4.73	1.36
17	374	0.86	0.13	2.26	0.58	1.13	0.22	2.88	0.77
18	342	0.60	0.05	1.65	0.38	0.86	0.13	2.26	0.58
19	313								
20	288								
21	261								
22	238								
23	214								
24	192								
25	172								
26	151								
27	132								
28	115								
29	95								
30	79								
31	61								
32	47								
33	33								
34	22								
35	13								
36	5								
37	0								

Note: Sequence B1-B2-B3-B4 has been used for convolution with UH of SB-2

4.6 Snowmelt contribution

Snowmelt contribution has been computed using the following formula of *Guide to Hydrological Practices, WMO No.168-1994*:

$$h = (0.30 + 0.012P) \cdot T_{avg} + 1.0 \text{ mm}$$

Where,

h- Daily snowmelt in mm

P- Daily rainfall in mm

T_{avg} -Mean daily temperature (assumed as 4°C)

By assuming the daily rainfall above 3000m as 60 mm and Mean daily temperature as 4°C the daily snowmelt contribution works out to be as follows;

$$\text{i.e } h = ((0.30 + 0.012 \cdot 60) \cdot 4.0 + 1.0) = 5 \text{ mm / day}$$

4.7 Design flood hydrograph (PMF) for Wangchu HE Project

The effective rainfall of the different sub catchment as given in Table-3.7 and 3.8 have been convoluted with UH of respective sub catchment. The base flow contribution of the sub catchments and snowmelt contribution have been added to get the flood hydrograph at the outlet of sub catchments. Further the flood hydrograph of SB-1 has been channel routed through reach R-1 (Refer Fig.1). The channel routing has been carried out using Muskingum method. The length of channel routing reach is about 49.7 km. The Muskingum K and x has been adopted as 6 hour and 0.2 respectively. In order to get a stable routing algorithm the channel routing has been performed in 3 steps by dividing the routing reach in 3 sub reaches of equal lengths.

The channel routed flood hydrograph of SB-1 has been added to flood hydrograph of SB-2 to get the PMF hydrograph for Wangchu HE Project. The Probable Maximum Flood (PMF) thus estimated for Wangchu HE Project is **11441 cumec**. The same has been used for the design of the project. The PMF hydrograph is given in **Table-3.9** and its plot is given in **Fig.3.4**.

Table-4.9: PMF hydrograph for Wangchu HE Project

Time (hr)	Discharge (cumec)	Time (hr)	Discharge (cumec)	Time (hr)	Discharge (cumec)	Time (hr)	Discharge (cumec)
0	210	25	6903	50	6999	75	446
1	221	26	6699	51	6369	76	404
2	252	27	6513	52	5740	77	369
3	323	28	6507	53	5146	78	340
4	467	29	6739	54	4650	79	316
5	698	30	7045	55	4246	80	295
6	951	31	7342	56	3901	81	277
7	1197	32	7764	57	3593	82	261
8	1499	33	8409	58	3304	83	248
9	1914	34	9228	59	3022	84	237
10	2433	35	10154	60	2748	85	229
11	3041	36	11080	61	2484	86	223
12	3702	37	11441	62	2232	87	219
13	4178	38	11039	63	1997	88	216
14	4382	39	10293	64	1782	89	214
15	4488	40	9489	65	1585	90	212
16	4609	41	8725	66	1406	91	212
17	4778	42	8213	67	1241	92	211
18	5073	43	7923	68	1092	93	211

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19	5464	44	7780	69	956	94	211
20	5892	45	7762	70	835	95	211
21	6311	46	7792	71	729	96	210
22	6657	47	7805	72	638		
23	6882	48	7771	73	561		
24	6973	49	7519	74	498		

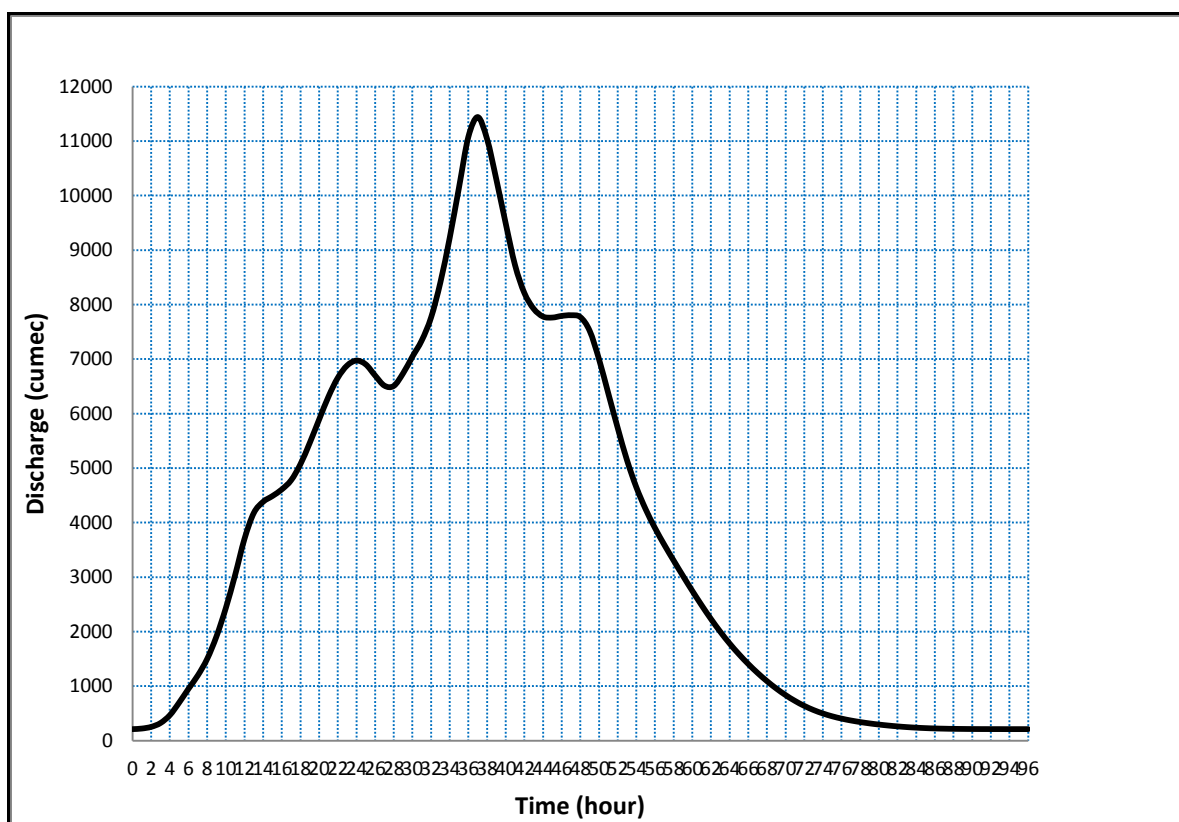


Fig.4.4: PMF Hydrograph for Wangchu HE Project

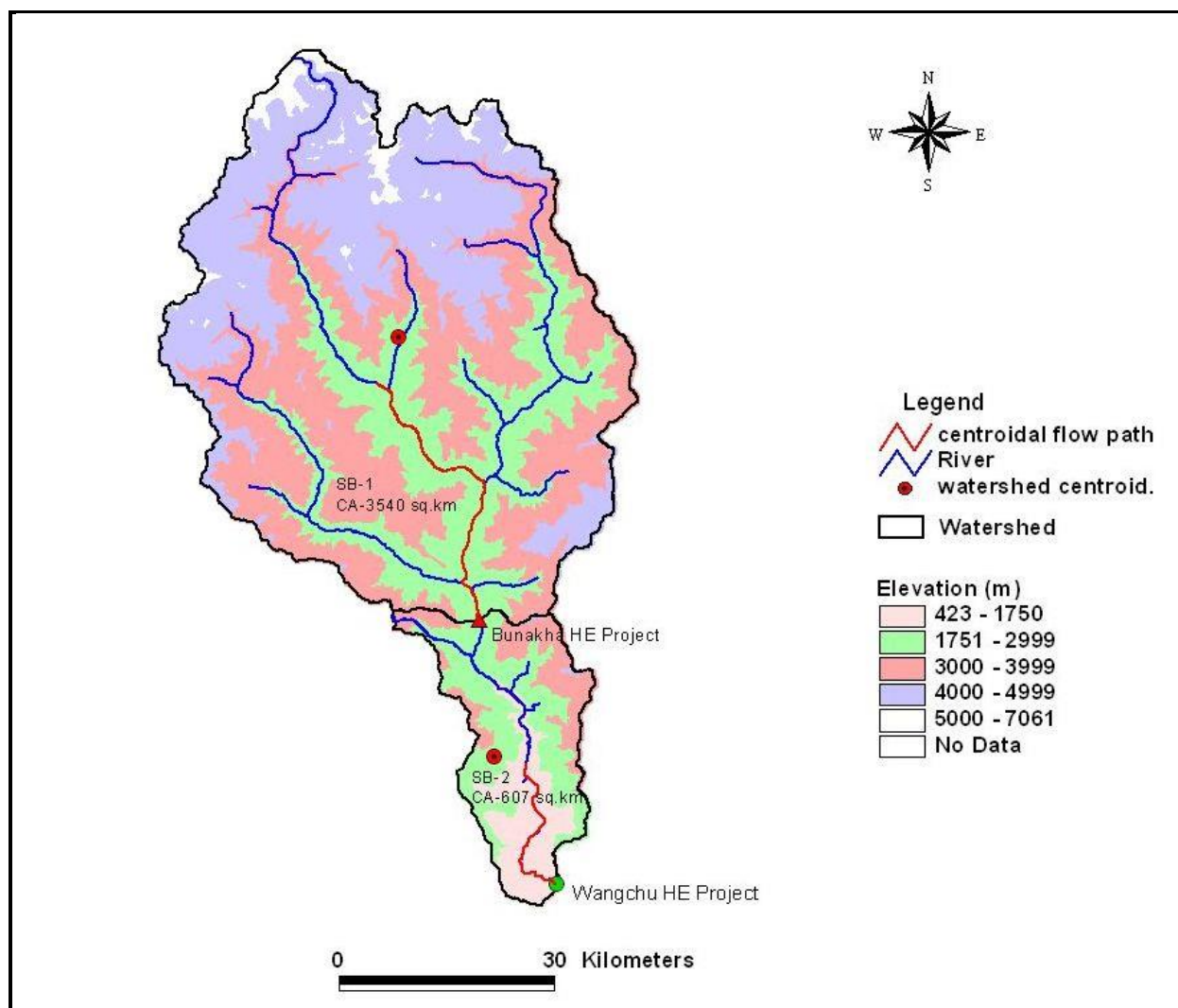
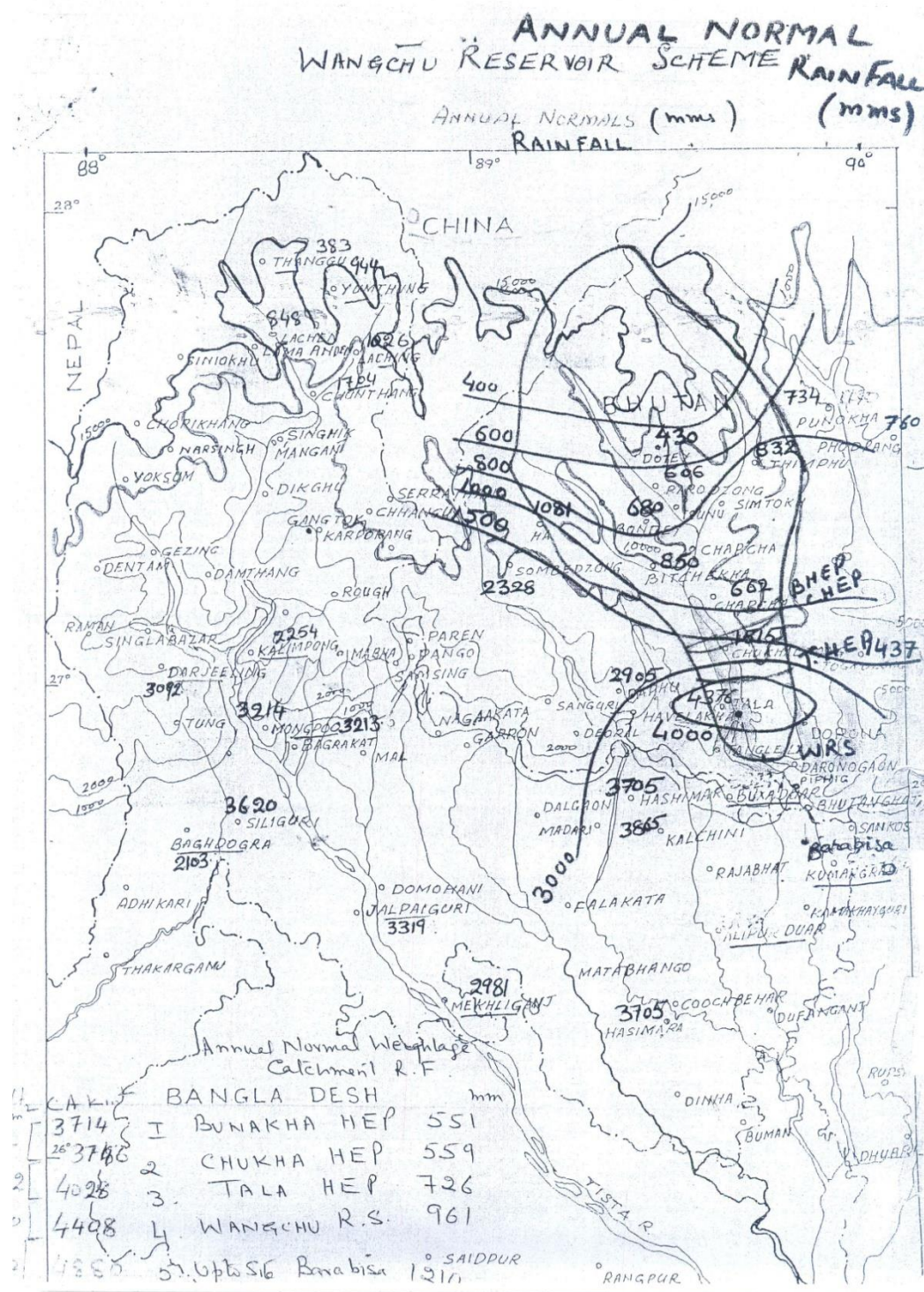
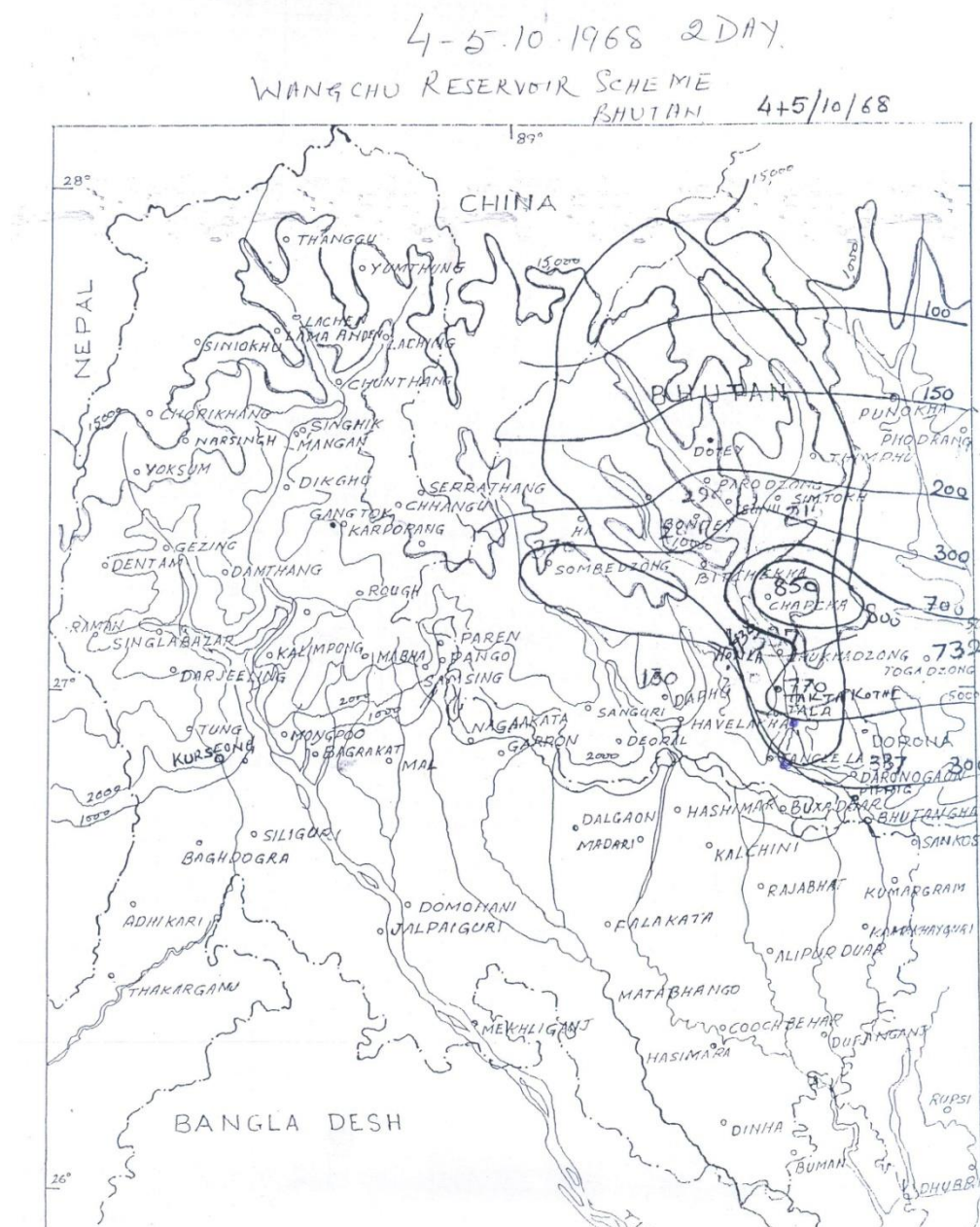
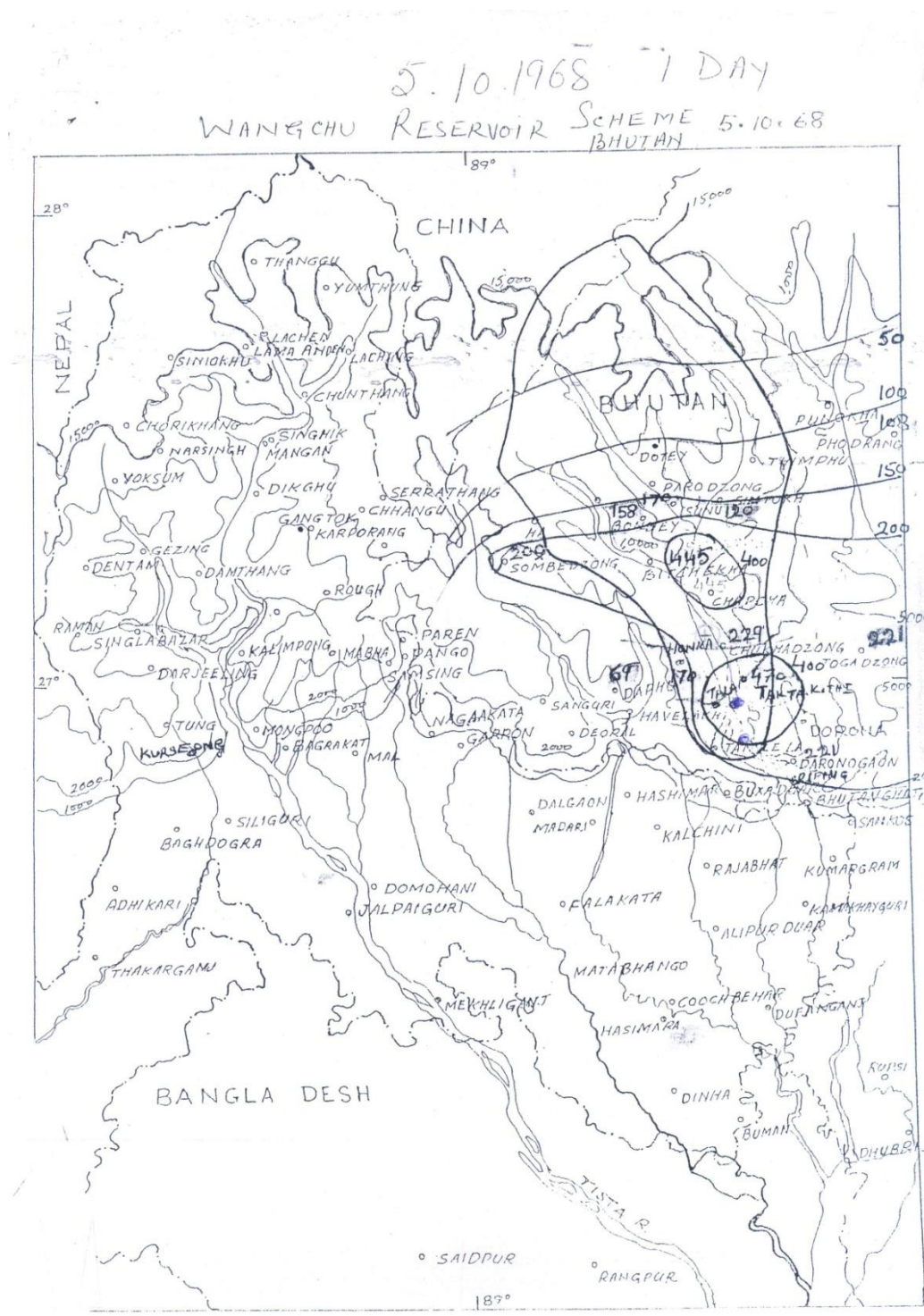


Plate-4.1: Catchment area plan of Wangchu HE Project along with sub-catchments

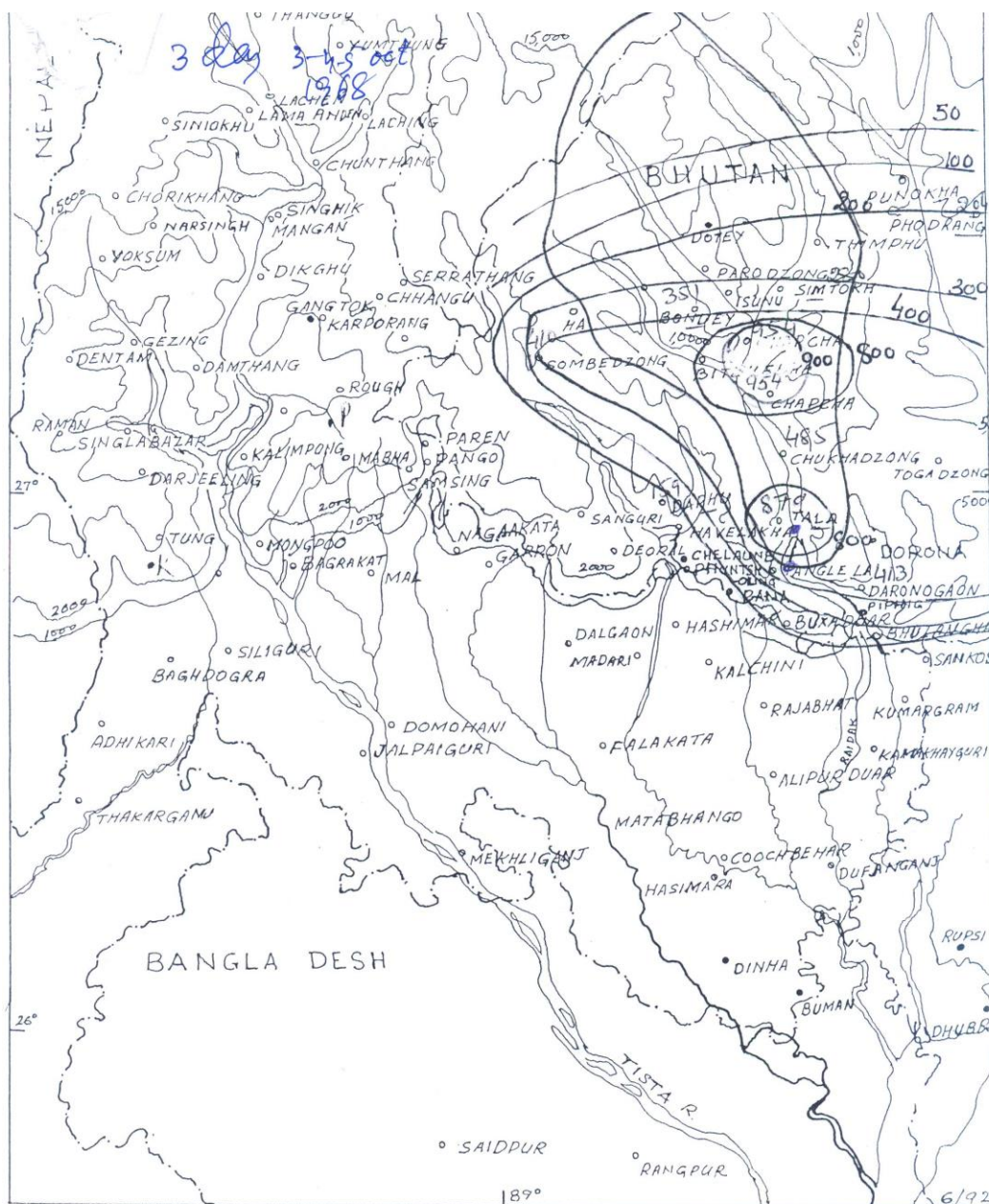






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Plate-4.2(d)



4.8 Flood Frequency Analysis

Flood frequency analysis provides a quick estimate of the design flood and is also useful for checking the design flood values computed by other methods. It is carried out in two methods viz. – The Annual Maximum method and the Peak Over Threshold (POT) method (also known as partial duration method). For the present study daily annual maximum values are used for carrying out flood frequency studies.

The long term annual instantaneous peak flow series at project site is not available. As such the 13 year annual peak discharge series of Piping G & D site on the river Wangchu for the period 1994-2009 has been used for frequency analysis. The results obtained were increased by 15% (to account for instantaneous annual series) and transposed to proposed dam sites with due consideration to the variation of catchment size. The available data has been subjected to randomness check, stationary test, outlier test. Extreme value distribution also known as Gumbel distribution attempted for the present study. The flood magnitude for various return periods as calculated by Gumbel method are as follows in **Table- 4.10**.

Table- 4.10

Return Period Flood by Gumbel's Method for Wangchu HEP

Sl. No.	Return Period (T) Years	$Y_T = -\ln \ln \left(\frac{T}{T-1} \right)$	$K = \frac{Y_T - \bar{Y}_n}{S_n}$	$X_T = \bar{x} + Kx * \sigma x$ (cumecs)	Diversion Flood for Wangchu(Cumecs)
1	2	0.367	-0.1404	514.67	549.49
2	10	2.250	1.7479	1515.89	1618.44
3	25	3.198	2.6986	2019.96	2156.61
4	50	3.902	3.4045	2394.29	2556.27
5	100	4.600	4.1045	2765.43	1750.00
6	500	6.213	5.7220	3623.09	3868.19
7	1000	6.907	6.4180	3992.10	4262.17
8	10000	9.210	8.7274	5216.65	5569.56

The final results of various return period floods estimated at Piping have been transposed to proposed scheme dam site using catchment area proportioning.

4.9 Diversion Flood

The diversion flood for the proposed project has been computed using non monsoon peaks for the period 1994-2009 of Piping G & D site. The diversion flood for various return periods as calculated using Gumbel distribution, which is found to be the best fit is given in **Table-4.11** as follows:

Table-4.11

S. No.	Return Period Years	Diversion Flood for Wangchu (Cumecs)
1	2	549.49
2	10	1618.44
3	25	2156.61
4	50	2556.27
5	100	1750.00
6	500	3868.19

The risk factors involved in adoption of such floods have also been estimated as per different probable construction periods using the following relationship:

$$Risk(P_r) = 1 - \left(\frac{1 - T_d}{T_d} \right)^L$$

Where T_d = Return Period of design flood

L = Construction period in years

The risk factors corresponding to different return period flood and probable construction period of 5 yrs, 8 yrs, 10 yrs, 15 yrs & 20 yrs have been worked out and given below in **Table- 4.12**.

Table- 4.12

S. No.	Return Period (Yrs)	Magnitude of Flood (Cumec)	Risk percentage during construction period of				
			5 Yrs	8 Yrs	10 Yrs	15 Yrs	20 Yrs
1	10	1618.44	40.95%	56.95%	65.13%	79.41%	87.84%
2	25	2156.61	18.46%	27.86%	33.52%	45.79%	55.80%
3	50	2556.27	9.61%	14.92%	18.29%	26.14%	33.24%

A 25 year non-monsoon return period flood of 2157 Cumec has been adopted for as diversion flood.

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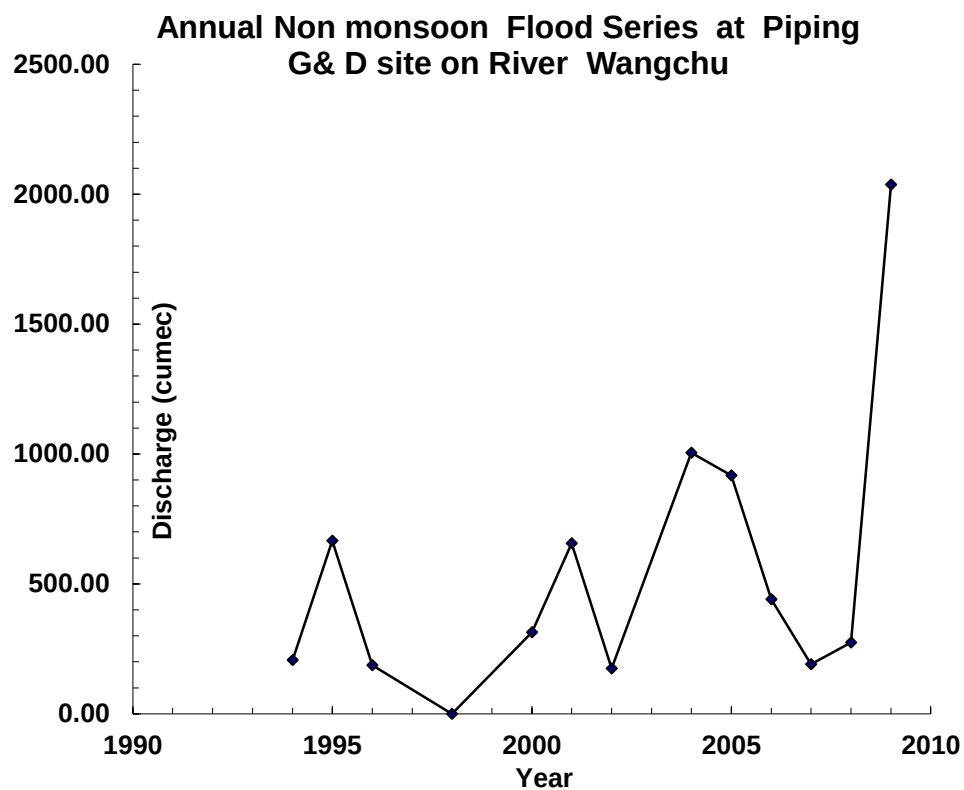
Annexure-4.1

(Sheet 1 of 2)

Return Period Flood by Gumbel's Method for Wangchu HEP

Sl. No.	Return Period (T) Years	$Y_T = -\ln \ln \left(\frac{T}{T-1} \right)$	$K = \frac{Y_T - \bar{Y}_n}{S_n}$	$X_T = \bar{x} + Kx * \sigma x$ (cumecs)	Diversion Flood for Wangchu(Cumecs)	$\bar{Y}_n =$	0.507
1	2	0.367	-0.1404	514.67	549.49	$\sigma n =$	0.9972
2	10	2.250	1.7479	1515.89	1618.44	$\sigma_{n-1} =$	530.23
3	25	3.198	2.6986	2019.96	2156.61	$\bar{x}_t =$	589.11
4	50	3.902	3.4045	2394.29	2556.27	$n =$	13
5	100	4.600	4.1045	2765.43	1750.00		
6	500	6.213	5.7220	3623.09	3868.19		
7	1000	6.907	6.4180	3992.10	4262.17	Add 15% for instantaneous Peaks	
8	10000	9.210	8.7274	5216.65	5569.56		

Details of Non Monsoon Maximum Daily Flood Series at Piping G& D site on River Wangchu											
S.No.	Year	Max.Flood (cumec) x	$x-\bar{x}$	$Z=\log X$	$Z-\bar{Z}$	$(Z-\bar{Z})^2$	$(Z-\bar{Z})^3$	$(x-\bar{x})^2$	$(x-\bar{x})^3$	$(x-\bar{x})^4$	$(Z-\bar{Z})^4$
1	1994	206.32	-382.79	5.329	-0.68	0.458	-0.309	1.47E+05	-5.61E+07	2.15E+10	0.20932
2	1995	666.47	77.37	6.502	0.50	0.246	0.122	5.99E+03	4.63E+05	3.58E+07	0.06062
3	1996	186.38	-402.73	5.228	-0.78	0.605	-0.471	1.62E+05	-6.53E+07	2.63E+10	0.36645
4	1998	202.383	-386.73	5.310	-0.70	0.484	-0.337	1.50E+05	-5.78E+07	2.24E+10	0.23419
5	2000	313.36	-275.75	5.747	-0.26	0.067	-0.017	7.60E+04	-2.10E+07	5.78E+09	0.00446
6	2001	656.79	67.68	6.487	0.48	0.232	0.112	4.58E+03	3.10E+05	2.10E+07	0.05377
7	2002	174.81	-414.30	5.164	-0.84	0.709	-0.597	1.72E+05	-7.11E+07	2.95E+10	0.50291
8	2004	1004.82	415.71	6.913	0.91	0.822	0.746	1.73E+05	7.18E+07	2.99E+10	0.67600
9	2005	917.30	328.19	6.821	0.82	0.665	0.543	1.08E+05	3.54E+07	1.16E+10	0.44255
10	2006	440.45	-148.66	6.088	0.08	0.007	0.001	2.21E+04	-3.29E+06	4.88E+08	0.00005
11	2007	190.88	-398.23	5.252	-0.75	0.569	-0.429	1.59E+05	-6.32E+07	2.51E+10	0.32349
12	2008	274.52	-314.59	5.615	-0.39	0.153	-0.060	9.90E+04	-3.11E+07	9.79E+09	0.02332
13	2009	2037.21	1448.10	7.619	1.61	2.603	4.201	2.10E+06	3.04E+09	4.40E+12	6.77806
TOTAL		7.07E+03	-3.87E+02	7.81E+01	-1.87E-14	7.62E+00	3.50E+00	3.37E+06	2.78E+09	4.58E+12	9.68E+00
Average		589.108	-29.748	6.006	0.000	0.586	0.269	259516.186	213519084.509	352290863676	0.744
								3.37E+06	2.78E+09	4.58E+12	9.68E+00



5 SEDIMENTATION STUDIES

5.1 Sedimentation Aspects

There is very limited sediment data at the silt observation sites proximate to the proposed dam location. The average sedimentation rates in the adjoining northern tributaries of river Brahmaputra are given in **Table 5.1** as follows:

Table 5.1

S.No	Name of the River	Sedimentation Rate mm/year
1	Subansiri	1.13
2	Lohit	1.20
3	Dibang	1.26
4	Puthimari	1.40
5	Pagladiya	1.60

All the sediment data available in around the proposed project catchment has been collected and the sediment rate derived is given in **Table 5.2** as follows:

Table 5.2

S.NO.	Name of Site	Period of Availability	Average Sediment Rate (mm/year)	Remarks
1	Hongkha	1994-2002	0.0851	Complete data not available for 1996 &2000
2	Chukha TRT	2005-2009	0.0709	Complete data not available for 2006,2008 &2009

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3	Chukha	2005-2009	0.0017	Complete data not available for 2006
4	Chukha D/S Of Confluence With Lobichu	2005-2009	0.0678	Complete data not available for 2009
5	Chukha At 180 D/S From Wangchu	2009	0.6846	
6	Lobichu	1994-2007	0.0763	Complete data not available for 2005
7	Piping	1994-1995	0.5601	
8	Bunakha	1993-1995	0.0499	

5.2 Sedimentation Approaches

There are three approaches to de-silting for hydropower projects. The first is to have a large reservoir for permanent sedimentation, such as at Bhakra Dam. The second is to have a smaller reservoir for temporary sedimentation and then periodically flush the reservoir. The third is to pass water through sedimentation chambers in the headrace system and flush these back into the river channel. An alternative approach would be not to de-silt or to partially de-silt, either in the reservoir and/or in sedimentation chambers, and to accept increased turbine damage and hence greater repair costs and outages, providing that the project remains economically viable and that generating commitments are met.

IS Code 12182-1987 envisages that for assessment of reservoir sedimentation problem, in a particular case, may be made by comparing the expected average volume of sediment deposition with gross capacity of the reservoir. If ratio is more than 0.5 percent per year, the problem is usually said to be serious and special care is required in estimating the

sediment yields from the catchment. If it is less than 0.1 percent per year the problem of siltation may be insignificant and changes in reservoir capacity can be neglected for studies of reservoir performance. Also, as per IS Code IS: 12182 – 1987 for hydro power projects supplying power to a grid, full service time shall not be less than 25 years. Feasible service time shall not be less than 70 years.

Since the expected average volume of sediment deposition with gross capacity of the reservoir for this scheme works out to be more than 0.5 percent hence the Reservoir Sedimentation Problem has been classified as serious.

The 134 m high concrete gravity dam provides the total storage capacity of 53.6 MCM upto the TRC outfall of Tala HEP. The length of the reservoir works out to be about 7.5 km. The sill level of Spillway Gates have been kept at EL 430.00m. Power intake has been kept at EL 470.00 m

The proposed Wangchu HE Project is downstream of Tala H.E. Project which is under operation. The sedimentation rate in the sedimentation studies for Tala HEP was taken as 0.2 mm/year/sq. km area and same rate was considered in Wangchu HEP also initially, but keeping in view the sedimentation rate in the other basins in the vicinity and also as recommended by CWC, rate of sedimentation for the present studies for Wangchu HEP has been taken as 1.0 mm/year/ sq. km area.

The New zero elevation after 25, 50 & 70 years of sedimentation has been estimated by Empirical Area Reduction method and Area increment method for the proposed scheme for various time horizons. The results are as shown in **Table- 5.3**

Table- 5.3

Name of Scheme	70 year NZE (in m)	50 year NZE (in m)	25 year NZE (in m)
Wangchu H.E.Scheme	457 m	458 m	458 m

The detailed calculations sedimentation studies along with the various data used is presented as **Annexure- 5.1 and Annexure 5.2.**

In view of the above, Wangchu HEP scheme combines the first and second approaches and no provision for desilting chamber has been made. As recommended by the CMDDD Directorate of CWC, minimum two reservoir flushings shall be carried out in a year, one the onset of monsoons and other in receding phase of monsoon.

The studies carried out by considering the data from neighborhood G&D sites in the absence of data from the present dam location it has been observed that the New Zero Elevation after 70 years, 50 years and 25 years will be 458 m, 458 m and 457 m respectively.

Further, Mathematical modelling to assess the behavior of sediment in the reservoir of proposed Wangchu HEP, have also been carried out by IIT, Roorkee. On the basis of mathematical model studies conducted relating to reservoir sedimentation from the assumed starting year of 2019 till the year 2050, the following findings could be summarized

- a) The extent of sedimentation is mainly restricted within a zone of about 3 km from the dam axis beyond which significant sedimentation is not likely to occur.
- b) The maximum depth of sedimentation which is likely to take place within the aforesaid 3 km zone is found to be of the order of about 10m at a distance of about 1.5 km from the dam axis.
- c) The mathematical modeling study has indicated that even after about three decades of reservoir operation, the extent of sedimentation will still remain restricted below the invert level of the under-sluice gates well within the dead storage zone of the reservoir. This is considered to be a favourable finding of the study as because generally higher rate of sediment deposition takes place in the initial years of reservoir filling and operation, which usually tapers off in the later years.
- d) On the basis of above study finding, it is felt that comprehensive and elaborate desilting arrangements may not be warranted for the Wangchu project, probably favoured by well-preserved watershed area. However, it is recommended that

regular annual monitoring of the Land Use Land Cover (LULC) status of the watershed area may be undertaken with the help of satellite imageries for suitable measures after identifying any undesirable changes in the vegetative covers which may contribute to sediment supply to the Wangchu reservoir.

- e) It may be recommended here that the present mathematical modeling study may ideally be supplemented by physical model studies for evolving appropriate and effective sediment flushing arrangement in consonance with overall reservoir operation schedule for the project. The above observation is opined considering the fact that almost all established mathematical models are primarily oriented for 1-D flow phenomena covering almost unrestricted length of fluvial reach, whereas physical modeling is often resorted to represent 3-D flow behavior in a very restricted fluvial domain such as for sediment flushing.

In view of above, comprehensive desilting chambers have not been provided in this scheme. However, regular annual monitoring of the Land Use Land Cover (LULC) status of the watershed area may be undertaken with the help of satellite imageries for suitable measures after identifying any undesirable changes in the vegetative covers which may contribute to sediment supply to the Wangchu reservoir.

Sedimentation Studies for Wangchu H.E.Project (570 MW), Bhutan							
Gross Capacity at F.R.L (C)	=	53.6	MCM				
Annual Inflow (I)	=	4203.0	MCM				
Rate of Sedimentation (r)	=	1.00	mm/sq km/year				
Catchment Area (A)	=	4184.2	Sq Km				
Deepest River B.L at Dam Site	=	405.00	m				
F.R.L	=	494.00	m				
Average annual sediment volume = A*r =				4.1842	MCM		
Period (years)	Capacity (MCM)	C/I	Trap Efficiency (From fig.1-page 16 of IS : 12182)	Sediment inflow in 10 years (MCM)	Sediment trapped in 10 years (MCM)	Revised capacity after 10 years (MCM)	Accumulated sediment volume (MCM)
1 to 10	53.60	0.012753	49.0%	41.84	20.50	33.097	20.5026
10 to 20	33.10	0.007875	40.0%	41.84	16.74	16.361	37.2394
20 to 30	16.36	0.003893	23.0%	41.84	9.62	6.737	46.8630
30 to 40	6.74	0.001603	4.0%	41.84	1.67	5.063	48.5367
40 to 50	5.06	0.001205	0.0%	41.84	0.00	5.063	48.5367
50 to 60	5.06	0.001205	0.0%	41.84	0.00	5.063	48.5367
60 to 70	5.06	0.001205	0.0%	41.84	0.00	5.063	48.5367
30 Years expected Sediment Volume =				4686.30	Ha-m		
50 Years expected Sediment Volume =				4853.67	Ha-m		
70 Years expected Sediment Volume =				4853.67	Ha-m		

Sediment deposition computation by Empirical Area Reduction Method (As per IS 5477(Part 2) and CBIP Technical Report No. 19)			
Elevation - Area - Capacity			
Elevation (m)	Area (Km ²)	Capacity M.C.M	
494	1.600	53.60	
492	1.540	50.47	
490	1.480	47.45	
488	1.420	44.55	
486	1.360	41.76	
484	1.310	39.1	
482	1.250	36.54	
480	1.200	34.08	
478	1.140	31.75	
476	1.070	29.54	
474	1.020	27.45	
472	0.970	25.47	
470	0.920	23.59	
468	0.870	21.8	
466	0.830	20.09	
464	0.790	18.47	
462	0.740	16.94	
460	0.700	15.49	
458	0.660	14.13	
456	0.620	12.85	
454	0.590	11.64	
452	0.550	10.5	
450	0.510	9.43	
448	0.470	8.45	
446	0.440	7.55	
444	0.390	6.72	
442	0.360	5.97	
440	0.320	5.3	
438	0.300	4.68	
436	0.270	4.1	
434	0.250	3.58	
432	0.220	3.11	
430	0.200	2.68	
428	0.180	2.3	
426	0.170	1.95	
424	0.150	1.63	
422	0.140	1.35	
420	0.120	1.1	
418	0.110	0.87	
416	0.090	0.67	
414	0.080	0.5	
412	0.070	0.35	
410	0.060	0.23	
408	0.050	0.12	
406	0.040	0.03	
From the, depth - capacity plot on log -log scale, this reservoir falls in category-III.			

Annexure – 5.1
(Sheet 3 of 8)

Computations for NZE corresponding to 30 years expected Sediment volume									
Assuming NZE =		457	m						
Area corres. to assumed NZE =		64	Ha						
K= A/Ap (for corres. To assumed NZE)=		53.62							
Elevation (m)	Area (Ha)	Capacity (Ha m)	Relative depth (p)	For type III, Ap = $16.967 \cdot (p)^{1.15}$ $\cdot (1-p)^{2.32}$	Sediment Area		Accumulate d sediment volume (Ha m)	Revised Area (Ha)	Revised Capacity (Ha m)
					Area (Ha)	Volume (Ha m)			
1	2	3	4	5	6	7	8	9	10
494	160.0	5360.0	1.000	0.000	0.000	0.000	4771.94	160.000	588.06
493	157.0	5203.5	0.989	0.001	0.027	0.013	4771.93	156.973	431.57
492	154.0	5047.0	0.978	0.002	0.133	0.080	4771.85	153.867	275.15
491	151.0	4896.0	0.966	0.006	0.336	0.234	4771.61	150.664	124.39
490	148.0	4745.0	0.955	0.012	0.646	0.491	4771.12	147.354	0.00
489	145.0	4600.0	0.944	0.020	1.069	0.858	4770.26	143.931	0.00
488	142.0	4455.0	0.933	0.030	1.610	1.340	4768.93	140.390	0.00
487	139.0	4315.5	0.921	0.042	2.270	1.940	4766.99	136.730	0.00
486	136.0	4176.0	0.910	0.057	3.051	2.661	4764.32	132.949	0.00
485	133.5	4043.0	0.899	0.074	3.953	3.502	4760.82	129.547	0.00
484	131.0	3910.0	0.888	0.093	4.975	4.464	4756.36	126.025	0.00
483	128.0	3782.0	0.876	0.114	6.116	5.546	4750.81	121.884	0.00
482	125.0	3654.0	0.865	0.138	7.374	6.745	4744.07	117.626	0.00
481	122.5	3531.0	0.854	0.163	8.746	8.060	4736.01	113.754	0.00
480	120.0	3408.0	0.843	0.191	10.230	9.488	4726.52	109.770	0.00
479	117.0	3291.5	0.831	0.220	11.822	11.026	4715.49	105.178	0.00
478	114.0	3175.0	0.820	0.252	13.518	12.670	4702.82	100.482	0.00
477	110.5	3064.5	0.809	0.286	15.315	14.417	4688.40	95.185	0.00
476	107.0	2954.0	0.798	0.321	17.208	16.262	4672.14	89.792	0.00
475	104.5	2849.5	0.787	0.358	19.192	18.200	4653.94	85.308	0.00
474	102.0	2745.0	0.775	0.397	21.262	20.227	4633.72	80.738	0.00
473	99.5	2646.0	0.764	0.437	23.414	22.338	4611.38	76.086	0.00
472	97.0	2547.0	0.753	0.478	25.642	24.528	4586.85	71.358	0.00
471	94.5	2453.0	0.742	0.521	27.940	26.791	4560.06	66.560	0.00
470	92.0	2359.0	0.730	0.565	30.303	29.122	4530.94	61.697	0.00
469	89.5	2269.5	0.719	0.610	32.725	31.514	4499.42	56.775	0.00
468	87.0	2180.0	0.708	0.656	35.199	33.962	4465.46	51.801	0.00
467	85.0	2094.5	0.697	0.703	37.719	36.459	4429.00	47.281	0.00
466	83.0	2009.0	0.685	0.751	40.280	38.999	4390.00	42.720	0.00
465	81.0	1928.0	0.674	0.800	42.873	41.576	4348.43	38.127	0.00
464	79.0	1847.0	0.663	0.848	45.493	44.183	4304.24	33.507	0.00
463	76.5	1770.5	0.652	0.898	48.134	46.814	4257.43	28.366	0.00
462	74.0	1694.0	0.640	0.947	50.787	49.460	4207.97	23.213	0.00
461	72.0	1621.5	0.629	0.997	53.446	52.117	4155.85	18.554	0.00
460	70.0	1549.0	0.618	1.046	56.104	54.775	4101.08	13.896	0.00
459	68.0	1481.0	0.607	1.096	58.754	57.429	4043.65	9.246	0.00
458	66.0	1413.0	0.596	1.145	61.389	60.071	3983.58	4.611	0.00
457	64.0	1349.0	0.584	1.194	64.000	62.694	3920.88	0.000	0.00
456	62.0	1285.0	0.573	1.242	66.581	65.291	3855.59	0.000	0.00
455	60.5	1224.5	0.562	1.289	69.125	67.853	3787.74	0.000	0.00

Annexure – 5.1
(Sheet 4 of 8)

Elevation (m)	Area (Ha)	Capacity (Ha m)	Relative depth (p)	For type III, $A_p = 16.967 \cdot (p)^{1.15} \cdot (1-p)^{2.32}$	Sediment Area		Accumulate d sediment volume (Ha m)	Revised Area (Ha)	Revised Capacity (Ha m)
					Area (Ha)	Volume (Ha m)			
454	59.0	1164.0	0.551	1.336	71.623	70.374	3717.36	0.000	0.00
453	57.0	1107.0	0.539	1.381	74.069	72.846	3644.52	0.000	0.00
452	55.0	1050.0	0.528	1.426	76.454	75.261	3569.26	0.000	0.00
451	53.0	996.5	0.517	1.469	78.771	77.612	3491.65	0.000	0.00
450	51.0	943.0	0.506	1.511	81.013	79.892	3411.75	0.000	0.00
449	49.0	894.0	0.494	1.551	83.171	82.092	3329.66	0.000	0.00
448	47.0	845.0	0.483	1.590	85.238	84.205	3245.46	0.000	0.00
447	45.5	800.0	0.472	1.626	87.207	86.223	3159.23	0.000	0.00
446	44.0	755.0	0.461	1.661	89.070	88.138	3071.10	0.000	0.00
445	41.5	713.5	0.449	1.694	90.818	89.944	2981.15	0.000	0.00
444	39.0	672.0	0.438	1.724	92.445	91.631	2889.52	0.000	0.00
443	37.5	634.5	0.427	1.752	93.942	93.194	2796.33	0.000	0.00
442	36.0	597.0	0.416	1.777	95.303	94.623	2701.70	0.000	0.00
441	34.0	563.5	0.404	1.800	96.520	95.911	2605.79	0.000	0.00
440	32.0	530.0	0.393	1.820	97.584	97.052	2508.74	0.000	0.00
439	31.0	499.0	0.382	1.837	98.490	98.037	2410.70	0.000	0.00
438	30.0	468.0	0.371	1.851	99.228	98.859	2311.84	0.000	0.00
437	28.5	439.0	0.360	1.861	99.793	99.511	2212.33	0.000	0.00
436	27.0	410.0	0.348	1.868	100.177	99.985	2112.35	0.000	0.00
435	26.0	384.0	0.337	1.872	100.372	100.275	2012.07	0.000	0.00
434	25.0	358.0	0.326	1.872	100.373	100.373	1911.70	0.000	0.00
433	23.5	334.5	0.315	1.868	100.172	100.272	1811.43	0.000	0.00
432	22.0	311.0	0.303	1.861	99.762	99.967	1711.46	0.000	0.00
431	21.0	289.5	0.292	1.849	99.137	99.450	1612.01	0.000	0.00
430	20.0	268.0	0.281	1.833	98.292	98.715	1513.30	0.000	0.00
429	19.0	249.0	0.270	1.813	97.219	97.755	1415.54	0.000	0.00
428	18.0	230.0	0.258	1.789	95.913	96.566	1318.98	0.000	0.00
427	17.5	212.5	0.247	1.760	94.369	95.141	1223.84	0.000	0.00
426	17.0	195.0	0.236	1.727	92.581	93.475	1130.36	0.000	0.00
425	16.0	179.0	0.225	1.689	90.545	91.563	1038.80	0.000	0.00
424	15.0	163.0	0.213	1.646	88.256	89.400	949.40	0.000	0.00
423	14.5	149.0	0.202	1.598	85.710	86.983	862.42	0.000	0.00
422	14.0	135.0	0.191	1.546	82.904	84.307	778.11	0.000	0.00
421	13.0	122.5	0.180	1.489	79.835	81.370	696.74	0.000	0.00
420	12.0	110.0	0.169	1.427	76.502	78.168	618.57	0.000	0.00
419	11.5	98.5	0.157	1.360	72.902	74.702	543.87	0.000	0.00
418	11.0	87.0	0.146	1.287	69.035	70.968	472.90	0.000	0.00
417	10.0	77.0	0.135	1.210	64.903	66.969	405.93	0.000	0.00
416	9.0	67.0	0.124	1.128	60.507	62.705	343.23	0.000	0.00
415	8.5	58.5	0.112	1.042	55.853	58.180	285.05	0.000	0.00
414	8.0	50.0	0.101	0.950	50.944	53.398	231.65	0.000	0.00
413	7.5	42.5	0.090	0.854	45.792	48.368	183.28	0.000	0.00
412	7.0	35.0	0.079	0.754	40.407	43.099	140.18	0.000	0.00
411	6.5	29.0	0.067	0.649	34.808	37.608	102.57	0.000	0.00
410	6.0	23.0	0.056	0.541	29.020	31.914	70.66	0.000	0.00
409	5.5	17.5	0.045	0.430	23.076	26.048	44.61	0.000	0.00
408	5.0	12.0	0.034	0.318	17.032	20.054	24.56	0.000	0.00
407	4.5	7.5	0.022	0.205	10.975	14.004	10.55	0.000	0.00
406	4.0	3.0	0.011	0.095	5.079	8.027	2.53	0.000	0.00
405	0.0	0.0	0.000	0.000	0.000	2.539	0.00	0.000	0.00
						4771.9408			
Therefore, NZE obtained corresponding to 30 years expected sediment volume =							457 m		

Annexure – 5.1
(Sheet 5 of 8)

Computations for NZE corresponding to 50 years expected Sediment volume									
Assuming NZE =		458	m						
Area corres. to assumed NZE =		64	Ha						
K= A/Ap (for corres. To assumed NZE)=		57.65							
Elevation (m)	Area (Ha)	Capacity (Ha m)	Relative depth (p)	For type III, Ap = $16.967*(p)^{1.15}$ $*(1-p)^{2.32}$	Sediment Area		Accumulate d sediment volume (Ha m)	Revised Area (Ha)	Revised Capacity (Ha m)
					Area (Ha)	Volume (Ha m)			
1	2	3	4	5	6	7	8	9	10
494	160.0	5360.0	1.000	0.000	0.000	0.000	5130.41	160.000	229.59
493	157.0	5203.5	0.989	0.001	0.029	0.014	5130.39	156.971	73.11
492	154.0	5047.0	0.978	0.002	0.143	0.086	5130.31	153.857	0.00
491	151.0	4896.0	0.966	0.006	0.361	0.252	5130.05	150.639	0.00
490	148.0	4745.0	0.955	0.012	0.694	0.528	5129.53	147.306	0.00
489	145.0	4600.0	0.944	0.020	1.150	0.922	5128.60	143.850	0.00
488	142.0	4455.0	0.933	0.030	1.731	1.440	5127.16	140.269	0.00
487	139.0	4315.5	0.921	0.042	2.441	2.086	5125.08	136.559	0.00
486	136.0	4176.0	0.910	0.057	3.280	2.861	5122.22	132.720	0.00
485	133.5	4043.0	0.899	0.074	4.250	3.765	5118.45	129.250	0.00
484	131.0	3910.0	0.888	0.093	5.349	4.800	5113.65	125.651	0.00
483	128.0	3782.0	0.876	0.114	6.576	5.962	5107.69	121.424	0.00
482	125.0	3654.0	0.865	0.138	7.928	7.252	5100.44	117.072	0.00
481	122.5	3531.0	0.854	0.163	9.403	8.666	5091.77	113.097	0.00
480	120.0	3408.0	0.843	0.191	10.999	10.201	5081.57	109.001	0.00
479	117.0	3291.5	0.831	0.220	12.710	11.854	5069.72	104.290	0.00
478	114.0	3175.0	0.820	0.252	14.534	13.622	5056.10	99.466	0.00
477	110.5	3064.5	0.809	0.286	16.466	15.500	5040.60	94.034	0.00
476	107.0	2954.0	0.798	0.321	18.501	17.483	5023.11	88.499	0.00
475	104.5	2849.5	0.787	0.358	20.634	19.567	5003.55	83.866	0.00
474	102.0	2745.0	0.775	0.397	22.860	21.747	4981.80	79.140	0.00
473	99.5	2646.0	0.764	0.437	25.173	24.016	4957.78	74.327	0.00
472	97.0	2547.0	0.753	0.478	27.568	26.371	4931.41	69.432	0.00
471	94.5	2453.0	0.742	0.521	30.039	28.804	4902.61	64.461	0.00
470	92.0	2359.0	0.730	0.565	32.580	31.309	4871.30	59.420	0.00
469	89.5	2269.5	0.719	0.610	35.183	33.881	4837.42	54.317	0.00
468	87.0	2180.0	0.708	0.656	37.843	36.513	4800.90	49.157	0.00
467	85.0	2094.5	0.697	0.703	40.553	39.198	4761.71	44.447	0.00
466	83.0	2009.0	0.685	0.751	43.305	41.929	4719.78	39.695	0.00
465	81.0	1928.0	0.674	0.800	46.094	44.700	4675.08	34.906	0.00
464	79.0	1847.0	0.663	0.848	48.911	47.502	4627.58	30.089	0.00
463	76.5	1770.5	0.652	0.898	51.750	50.330	4577.25	24.750	0.00
462	74.0	1694.0	0.640	0.947	54.602	53.176	4524.07	19.398	0.00
461	72.0	1621.5	0.629	0.997	57.461	56.032	4468.04	14.539	0.00
460	70.0	1549.0	0.618	1.046	60.319	58.890	4409.15	9.681	0.00
459	68.0	1481.0	0.607	1.096	63.168	61.743	4347.40	4.832	0.00
458	66.0	1413.0	0.596	1.145	66.000	64.584	4282.82	0.000	0.00
457	64.0	1349.0	0.584	1.194	68.808	67.404	4215.42	0.000	0.00
456	62.0	1285.0	0.573	1.242	71.583	70.195	4145.22	0.000	0.00
455	60.5	1224.5	0.562	1.289	74.317	72.950	4072.27	0.000	0.00

Annexure – 5.1
(Sheet 6 of 8)

Elevation (m)	Area (Ha)	Capacity (Ha m)	Relative depth (p)	For type III, $A_p = 16.967 \cdot (p)^{1.15} \cdot (1-p)^{2.32}$	Sediment Area		Accumulate d sediment volume (Ha m)	Revised Area (Ha)	Revised Capacity (Ha m)
					Area (Ha)	Volume (Ha m)			
454	59.0	1164.0	0.551	1.336	77.003	75.660	3996.61	0.000	0.00
453	57.0	1107.0	0.539	1.381	79.633	78.318	3918.29	0.000	0.00
452	55.0	1050.0	0.528	1.426	82.197	80.915	3837.38	0.000	0.00
451	53.0	996.5	0.517	1.469	84.688	83.443	3753.94	0.000	0.00
450	51.0	943.0	0.506	1.511	87.098	85.893	3668.04	0.000	0.00
449	49.0	894.0	0.494	1.551	89.419	88.258	3579.78	0.000	0.00
448	47.0	845.0	0.483	1.590	91.641	90.530	3489.25	0.000	0.00
447	45.5	800.0	0.472	1.626	93.758	92.700	3396.55	0.000	0.00
446	44.0	755.0	0.461	1.661	95.760	94.759	3301.80	0.000	0.00
445	41.5	713.5	0.449	1.694	97.640	96.700	3205.09	0.000	0.00
444	39.0	672.0	0.438	1.724	99.389	98.515	3106.58	0.000	0.00
443	37.5	634.5	0.427	1.752	100.999	100.194	3006.39	0.000	0.00
442	36.0	597.0	0.416	1.777	102.462	101.731	2904.65	0.000	0.00
441	34.0	563.5	0.404	1.800	103.770	103.116	2801.54	0.000	0.00
440	32.0	530.0	0.393	1.820	104.915	104.343	2697.20	0.000	0.00
439	31.0	499.0	0.382	1.837	105.888	105.401	2591.79	0.000	0.00
438	30.0	468.0	0.371	1.851	106.682	106.285	2485.51	0.000	0.00
437	28.5	439.0	0.360	1.861	107.289	106.986	2378.52	0.000	0.00
436	27.0	410.0	0.348	1.868	107.702	107.496	2271.03	0.000	0.00
435	26.0	384.0	0.337	1.872	107.912	107.807	2163.22	0.000	0.00
434	25.0	358.0	0.326	1.872	107.913	107.913	2055.31	0.000	0.00
433	23.5	334.5	0.315	1.868	107.697	107.805	1947.50	0.000	0.00
432	22.0	311.0	0.303	1.861	107.256	107.476	1840.03	0.000	0.00
431	21.0	289.5	0.292	1.849	106.585	106.920	1733.11	0.000	0.00
430	20.0	268.0	0.281	1.833	105.675	106.130	1626.98	0.000	0.00
429	19.0	249.0	0.270	1.813	104.522	105.099	1521.88	0.000	0.00
428	18.0	230.0	0.258	1.789	103.118	103.820	1418.06	0.000	0.00
427	17.5	212.5	0.247	1.760	101.458	102.288	1315.77	0.000	0.00
426	17.0	195.0	0.236	1.727	99.535	100.497	1215.27	0.000	0.00
425	16.0	179.0	0.225	1.689	97.346	98.441	1116.83	0.000	0.00
424	15.0	163.0	0.213	1.646	94.885	96.116	1020.72	0.000	0.00
423	14.5	149.0	0.202	1.598	92.148	93.517	927.20	0.000	0.00
422	14.0	135.0	0.191	1.546	89.132	90.640	836.56	0.000	0.00
421	13.0	122.5	0.180	1.489	85.833	87.482	749.08	0.000	0.00
420	12.0	110.0	0.169	1.427	82.248	84.040	665.04	0.000	0.00
419	11.5	98.5	0.157	1.360	78.378	80.313	584.72	0.000	0.00
418	11.0	87.0	0.146	1.287	74.221	76.300	508.43	0.000	0.00
417	10.0	77.0	0.135	1.210	69.779	72.000	436.43	0.000	0.00
416	9.0	67.0	0.124	1.128	65.053	67.416	369.01	0.000	0.00
415	8.5	58.5	0.112	1.042	60.048	62.550	306.46	0.000	0.00
414	8.0	50.0	0.101	0.950	54.771	57.410	249.05	0.000	0.00
413	7.5	42.5	0.090	0.854	49.232	52.001	197.05	0.000	0.00
412	7.0	35.0	0.079	0.754	43.443	46.337	150.71	0.000	0.00
411	6.5	29.0	0.067	0.649	37.423	40.433	110.28	0.000	0.00
410	6.0	23.0	0.056	0.541	31.200	34.311	75.97	0.000	0.00
409	5.5	17.5	0.045	0.430	24.810	28.005	47.96	0.000	0.00
408	5.0	12.0	0.034	0.318	18.312	21.561	26.40	0.000	0.00
407	4.5	7.5	0.022	0.205	11.800	15.056	11.35	0.000	0.00
406	4.0	3.0	0.011	0.095	5.460	8.630	2.72	0.000	0.00
405	0.0	0.0	0.000	0.000	0.000	2.730	0.00	0.000	0.00
					5130.41				
Therefore, NZE obtained corresponding to 50 years expected sediment volume =							458 m		

Computations for NZE corresponding to 70 years expected Sediment volume									
Assuming NZE =		458	m						
Area corres. to assumed NZE =		64	Ha						
K= A/Ap (for corres. To assumed NZE)=		57.65							
Elevation (m)	Area (Ha)	Capacity (Ha m)	Relative depth (p)	For type III, Ap = $16.967*(p)^{1.15}$ $*(1-p)^{2.32}$	Sediment Area		Accumulate d sediment volume (Ha m)	Revised Area (Ha)	Revised Capacity (Ha m)
					Area (Ha)	Volume (Ha m)			
1	2	3	4	5	6	7	8	9	10
494	160.0	5360.0	1.000	0.000	0.000	0.000	5130.41	160.000	229.59
493	157.0	5203.5	0.989	0.001	0.029	0.014	5130.39	156.971	73.11
492	154.0	5047.0	0.978	0.002	0.143	0.086	5130.31	153.857	0.00
491	151.0	4896.0	0.966	0.006	0.361	0.252	5130.05	150.639	0.00
490	148.0	4745.0	0.955	0.012	0.694	0.528	5129.53	147.306	0.00
489	145.0	4600.0	0.944	0.020	1.150	0.922	5128.60	143.850	0.00
488	142.0	4455.0	0.933	0.030	1.731	1.440	5127.16	140.269	0.00
487	139.0	4315.5	0.921	0.042	2.441	2.086	5125.08	136.559	0.00
486	136.0	4176.0	0.910	0.057	3.280	2.861	5122.22	132.720	0.00
485	133.5	4043.0	0.899	0.074	4.250	3.765	5118.45	129.250	0.00
484	131.0	3910.0	0.888	0.093	5.349	4.800	5113.65	125.651	0.00
483	128.0	3782.0	0.876	0.114	6.576	5.962	5107.69	121.424	0.00
482	125.0	3654.0	0.865	0.138	7.928	7.252	5100.44	117.072	0.00
481	122.5	3531.0	0.854	0.163	9.403	8.666	5091.77	113.097	0.00
480	120.0	3408.0	0.843	0.191	10.999	10.201	5081.57	109.001	0.00
479	117.0	3291.5	0.831	0.220	12.710	11.854	5069.72	104.290	0.00
478	114.0	3175.0	0.820	0.252	14.534	13.622	5056.10	99.466	0.00
477	110.5	3064.5	0.809	0.286	16.466	15.500	5040.60	94.034	0.00
476	107.0	2954.0	0.798	0.321	18.501	17.483	5023.11	88.499	0.00
475	104.5	2849.5	0.787	0.358	20.634	19.567	5003.55	83.866	0.00
474	102.0	2745.0	0.775	0.397	22.860	21.747	4981.80	79.140	0.00
473	99.5	2646.0	0.764	0.437	25.173	24.016	4957.78	74.327	0.00
472	97.0	2547.0	0.753	0.478	27.568	26.371	4931.41	69.432	0.00
471	94.5	2453.0	0.742	0.521	30.039	28.804	4902.61	64.461	0.00
470	92.0	2359.0	0.730	0.565	32.580	31.309	4871.30	59.420	0.00
469	89.5	2269.5	0.719	0.610	35.183	33.881	4837.42	54.317	0.00
468	87.0	2180.0	0.708	0.656	37.843	36.513	4800.90	49.157	0.00
467	85.0	2094.5	0.697	0.703	40.553	39.198	4761.71	44.447	0.00
466	83.0	2009.0	0.685	0.751	43.305	41.929	4719.78	39.695	0.00
465	81.0	1928.0	0.674	0.800	46.094	44.700	4675.08	34.906	0.00
464	79.0	1847.0	0.663	0.848	48.911	47.502	4627.58	30.089	0.00
463	76.5	1770.5	0.652	0.898	51.750	50.330	4577.25	24.750	0.00
462	74.0	1694.0	0.640	0.947	54.602	53.176	4524.07	19.398	0.00
461	72.0	1621.5	0.629	0.997	57.461	56.032	4468.04	14.539	0.00
460	70.0	1549.0	0.618	1.046	60.319	58.890	4409.15	9.681	0.00
459	68.0	1481.0	0.607	1.096	63.168	61.743	4347.40	4.832	0.00
458	66.0	1413.0	0.596	1.145	66.000	64.584	4282.82	0.000	0.00
457	64.0	1349.0	0.584	1.194	68.808	67.404	4215.42	0.000	0.00
456	62.0	1285.0	0.573	1.242	71.583	70.195	4145.22	0.000	0.00
455	60.5	1224.5	0.562	1.289	74.317	72.950	4072.27	0.000	0.00
454	59.0	1164.0	0.551	1.336	77.003	75.660	3996.61	0.000	0.00
453	57.0	1107.0	0.539	1.381	79.633	78.318	3918.29	0.000	0.00
452	55.0	1050.0	0.528	1.426	82.197	80.915	3837.38	0.000	0.00

Annexure – 5.1
(Sheet 8 of 8)

Elevation (m)	Area (Ha)	Capacity (Ha m)	Relative depth (p)	For type III, $A_p = 16.967 \cdot (p)^{1.15} \cdot (1-p)^{2.32}$	Sediment Area		Accumulate d sediment volume (Ha m)	Revised Area (Ha)	Revised Capacity (Ha m)
					Area (Ha)	Volume (Ha m)			
451	53.0	996.5	0.517	1.469	84.688	83.443	3753.94	0.000	0.00
450	51.0	943.0	0.506	1.511	87.098	85.893	3668.04	0.000	0.00
449	49.0	894.0	0.494	1.551	89.419	88.258	3579.78	0.000	0.00
448	47.0	845.0	0.483	1.590	91.641	90.530	3489.25	0.000	0.00
447	45.5	800.0	0.472	1.626	93.758	92.700	3396.55	0.000	0.00
446	44.0	755.0	0.461	1.661	95.760	94.759	3301.80	0.000	0.00
445	41.5	713.5	0.449	1.694	97.640	96.700	3205.09	0.000	0.00
444	39.0	672.0	0.438	1.724	99.389	98.515	3106.58	0.000	0.00
443	37.5	634.5	0.427	1.752	100.999	100.194	3006.39	0.000	0.00
442	36.0	597.0	0.416	1.777	102.462	101.731	2904.65	0.000	0.00
441	34.0	563.5	0.404	1.800	103.770	103.116	2801.54	0.000	0.00
440	32.0	530.0	0.393	1.820	104.915	104.343	2697.20	0.000	0.00
439	31.0	499.0	0.382	1.837	105.888	105.401	2591.79	0.000	0.00
438	30.0	468.0	0.371	1.851	106.682	106.285	2485.51	0.000	0.00
437	28.5	439.0	0.360	1.861	107.289	106.986	2378.52	0.000	0.00
436	27.0	410.0	0.348	1.868	107.702	107.496	2271.03	0.000	0.00
435	26.0	384.0	0.337	1.872	107.912	107.807	2163.22	0.000	0.00
434	25.0	358.0	0.326	1.872	107.913	107.913	2055.31	0.000	0.00
433	23.5	334.5	0.315	1.868	107.697	107.805	1947.50	0.000	0.00
432	22.0	311.0	0.303	1.861	107.256	107.476	1840.03	0.000	0.00
431	21.0	289.5	0.292	1.849	106.585	106.920	1733.11	0.000	0.00
430	20.0	268.0	0.281	1.833	105.675	106.130	1626.98	0.000	0.00
429	19.0	249.0	0.270	1.813	104.522	105.099	1521.88	0.000	0.00
428	18.0	230.0	0.258	1.789	103.118	103.820	1418.06	0.000	0.00
427	17.5	212.5	0.247	1.760	101.458	102.288	1315.77	0.000	0.00
426	17.0	195.0	0.236	1.727	99.535	100.497	1215.27	0.000	0.00
425	16.0	179.0	0.225	1.689	97.346	98.441	1116.83	0.000	0.00
424	15.0	163.0	0.213	1.646	94.885	96.116	1020.72	0.000	0.00
423	14.5	149.0	0.202	1.598	92.148	93.517	927.20	0.000	0.00
422	14.0	135.0	0.191	1.546	89.132	90.640	836.56	0.000	0.00
421	13.0	122.5	0.180	1.489	85.833	87.482	749.08	0.000	0.00
420	12.0	110.0	0.169	1.427	82.248	84.040	665.04	0.000	0.00
419	11.5	98.5	0.157	1.360	78.378	80.313	584.72	0.000	0.00
418	11.0	87.0	0.146	1.287	74.221	76.300	508.43	0.000	0.00
417	10.0	77.0	0.135	1.210	69.779	72.000	436.43	0.000	0.00
416	9.0	67.0	0.124	1.128	65.053	67.416	369.01	0.000	0.00
415	8.5	58.5	0.112	1.042	60.048	62.550	306.46	0.000	0.00
414	8.0	50.0	0.101	0.950	54.771	57.410	249.05	0.000	0.00
413	7.5	42.5	0.090	0.854	49.232	52.001	197.05	0.000	0.00
412	7.0	35.0	0.079	0.754	43.443	46.337	150.71	0.000	0.00
411	6.5	29.0	0.067	0.649	37.423	40.433	110.28	0.000	0.00
410	6.0	23.0	0.056	0.541	31.200	34.311	75.97	0.000	0.00
409	5.5	17.5	0.045	0.430	24.810	28.005	47.96	0.000	0.00
408	5.0	12.0	0.034	0.318	18.312	21.561	26.40	0.000	0.00
407	4.5	7.5	0.022	0.205	11.800	15.056	11.35	0.000	0.00
406	4.0	3.0	0.011	0.095	5.460	8.630	2.72	0.000	0.00
405	0.0	0.0	0.000	0.000	0.000	2.730	0.00	0.000	0.00
					5130.4				
Therefore, NZE obtained corresponding to 70 years expected sediment volume =							458 m		
from above ; As per Empirical Area Reduction Method									
NZE corresponding to 30 years expected sediment volume =							457 m		
NZE corresponding to 50 years expected sediment volume =							458 m		
NZE corresponding to 70 years expected sediment volume =							458 m		

AREA INCREMENT METHOD						
Gross Capacity at F.R.L (C)	=	53.6	MCM			
Annual Inflow (I)	=	4203.0	MCM			
Rate of Sedimentation (r)	=	1.00	mm/sq km /year			
Catchment Area (A)	=	4184.2	Sq Km			
Deepest River B.L at Dam Site	=	405.00	m			
F.R.L	=	494.00	m			
30 Years expected Sediment Volume	=	4686.30	Ha-m			
50 Years expected Sediment Volume	=	4853.67	Ha-m			
70 Years expected Sediment Volume	=	4853.67	Ha-m			
Sediment deposition computation by Area Increment Method (As per IS 5477(Part 2): Reaffirmed 2004)						
1. Computations for NZE corresponding to 30 years expected Sediment						
Assuming NZE	=	446	m			
Area corres. To assumed NZE	=	44	Ha			
Dam Height from River bed level	=	89.00	m			
Elevation (m)	Area (Ha)	Capacity (Ha m)	Ao	Sediment Volume , Vo	Revised Area (Ha)	Revised Capacity (Ha m)
1	2	3	4	5	9	10
494	160.0	5360.0	44.000	4671.000	116.0	689.00
492	154.0	5047.0	44.000	4583.000	110.0	464.00
490	148.0	4745.0	44.000	4495.000	104.0	250.00
488	142.0	4455.0	44.000	4407.000	98.0	48.00
486	136.0	4176.0	44.000	4319.000	92.0	0.00
484	131.0	3910.0	44.000	4231.000	87.0	0.00
482	125.0	3654.0	44.000	4143.000	81.0	0.00
480	120.0	3408.0	44.000	4055.000	76.0	0.00
478	114.0	3175.0	44.000	3967.000	70.0	0.00
476	107.0	2954.0	44.000	3879.000	63.0	0.00
474	102.0	2745.0	44.000	3791.000	58.0	0.00
472	97.0	2547.0	44.000	3703.000	53.0	0.00
470	92.0	2359.0	44.000	3615.000	48.0	0.00
468	87.0	2180.0	44.000	3527.000	43.0	0.00
466	83.0	2009.0	44.000	3439.000	39.0	0.00
464	79.0	1847.0	44.000	3351.000	35.0	0.00
462	74.0	1694.0	44.000	3263.000	30.0	0.00
460	70.0	1549.0	44.000	3175.000	26.0	0.00
458	66.0	1413.0	44.000	3087.000	22.0	0.00
456	62.0	1285.0	44.000	2999.000	18.0	0.00
454	59.0	1164.0	44.000	2911.000	15.0	0.00
452	55.0	1050.0	44.000	2823.000	11.0	0.00
450	51.0	943.0	44.000	2735.000	7.0	0.00
448	47.0	845.0	44.000	2647.000	3.0	0.00
446	44.0	755.0	44.000	755.000	0.0	0.00
444	39.0	672.0	39.000	672.000	0.0	0.00
442	36.0	597.0	36.000	597.000	0.0	0.00
440	32.0	530.0	32.000	530.000	0.0	0.00
438	30.0	468.0	30.000	468.000	0.0	0.00
436	27.0	410.0	27.000	410.000		0.00
434	25.0	358.0	25.000	358.000	0.0	0.00

Annexure – 5.2
(Sheet 2 of 4)

Elevation (m)	Area (Ha)	Capacity (Ha m)	Ao	Sediment Volume , Vo	Revised Area (Ha)	Revised Capacity (Ha m)
432	22.0	311.0	22.000	311.000	0.0	0.00
430	20.0	268.0	20.000	268.000	0.0	0.00
428	18.0	230.0	18.000	230.000	0.0	0.00
426	17.0	195.0	17.000	195.000	0.0	0.00
424	15.0	163.0	15.000	163.000	0.0	0.00
422	14.0	135.0	14.000	135.000	0.0	0.00
420	12.0	110.0	12.000	110.000	0.0	0.00
418	11.0	87.0	11.000	87.000	0.0	0.00
416	9.0	67.0	9.000	67.000	0.0	0.00
414	8.0	50.0	8.000	50.000	0.0	0.00
412	7.0	35.0	7.000	35.000	0.0	0.00
410	6.0	23.0	6.000	23.000	0.0	0.00
408	5.0	12.0	5.000	12.000	0.0	0.00
406	4.0	3.0	4.000	3.000	0.0	0.00
405	0.0	0.0	0.000	0.000	0.0	0.00
Therefore,						
NZE obtained as per 30 years expected sediment load =					446 m	

2. Computations for NZE corresponding to 50 years expected Sediment						
Assuming NZE =			448.0 m			
Area corres. To assumed NZE =			47.0 Ha			
Dam Height from River bed level =			89.00 m			
Elevation (m)	Area (Ha)	Capacity (Ha m)	Ao	Sediment Volume , Vo	Revised Area (Ha)	Revised Capacity (Ha m)
1	2	3	4	5	9	10
494	160.0	5360.0	47.000	5028.000	113.0	332.00
492	154.0	5047.0	47.000	4934.000	107.0	113.00
490	148.0	4745.0	47.000	4840.000	101.0	0.00
488	142.0	4455.0	47.000	4746.000	95.0	0.00
486	136.0	4176.0	47.000	4652.000	89.0	0.00
484	131.0	3910.0	47.000	4558.000	84.0	0.00
482	125.0	3654.0	47.000	4464.000	78.0	0.00
480	120.0	3408.0	47.000	4370.000	73.0	0.00
478	114.0	3175.0	47.000	4276.000	67.0	0.00
476	107.0	2954.0	47.000	4182.000	60.0	0.00
474	102.0	2745.0	47.000	4088.000	55.0	0.00
472	97.0	2547.0	47.000	3994.000	50.0	0.00
470	92.0	2359.0	47.000	3900.000	45.0	0.00
468	87.0	2180.0	47.000	3806.000	40.0	0.00
466	83.0	2009.0	47.000	3712.000	36.0	0.00
464	79.0	1847.0	47.000	3618.000	32.0	0.00
462	74.0	1694.0	47.000	3524.000	27.0	0.00
460	70.0	1549.0	47.000	3430.000	23.0	0.00
458	66.0	1413.0	47.000	3336.000	19.0	0.00
456	62.0	1285.0	47.000	3242.000	15.0	0.00
454	59.0	1164.0	47.000	3148.000	12.0	0.00
452	55.0	1050.0	47.000	3054.000	8.0	0.00
450	51.0	943.0	47.000	2960.000	4.0	0.00
448	47.0	845.0	47.000	845.000	0.0	0.00
446	44.0	755.0	44.000	755.000	0.0	0.00
444	39.0	672.0	39.000	672.000	0.0	0.00
442	36.0	597.0	36.000	597.000	0.0	0.00
440	32.0	530.0	32.000	530.000	0.0	0.00
438	30.0	468.0	30.000	468.000	0.0	0.00
436	27.0	410.0	27.000	410.000	0.0	0.00
434	25.0	358.0	25.000	358.000	0.0	0.00
432	22.0	311.0	22.000	311.000	0.0	0.00
430	20.0	268.0	20.000	268.000	0.0	0.00
428	18.0	230.0	18.000	230.000	0.0	0.00
426	17.0	195.0	17.000	195.000	0.0	0.00
424	15.0	163.0	15.000	163.000	0.0	0.00
422	14.0	135.0	14.000	135.000	0.0	0.00
420	12.0	110.0	12.000	110.000	0.0	0.00
418	11.0	87.0	11.000	87.000	0.0	0.00
416	9.0	67.0	9.000	67.000	0.0	0.00
414	8.0	50.0	8.000	50.000	0.0	0.00
412	7.0	35.0	7.000	35.000	0.0	0.00
410	6.0	23.0	6.000	23.000	0.0	0.00
408	5.0	12.0	5.000	12.000	0.0	0.00
406	4.0	3.0	4.000	3.000	0.0	0.00
405	0.0	0.0	0.000	0.000	0.0	0.00
Therefore,						
NZE obtained as per 50 years expected sediment load =					448 m	

3. Computations for NZE corresponding to 70 years expected Sediment volume						
Assuming NZE =		448 m				
Area corres. To assumed NZE =		47.0 Ha				
Dam Height from River bed level =		89.00 m				
Elevation (m)	Area (Ha)	Capacity (Ha m)	Ao	Sediment Volume , Vo	Revised Area (Ha)	Revised Capacity (Ha m)
1	2	3	4	5	9	10
494	160.0	5360.0	47.000	5028.000	113.0	332.00
492	154.0	5047.0	47.000	4934.000	107.0	113.00
490	148.0	4745.0	47.000	4840.000	101.0	0.00
488	142.0	4455.0	47.000	4746.000	95.0	0.00
486	136.0	4176.0	47.000	4652.000	89.0	0.00
484	131.0	3910.0	47.000	4558.000	84.0	0.00
482	125.0	3654.0	47.000	4464.000	78.0	0.00
480	120.0	3408.0	47.000	4370.000	73.0	0.00
478	114.0	3175.0	47.000	4276.000	67.0	0.00
476	107.0	2954.0	47.000	4182.000	60.0	0.00
474	102.0	2745.0	47.000	4088.000	55.0	0.00
472	97.0	2547.0	47.000	3994.000	50.0	0.00
470	92.0	2359.0	47.000	3900.000	45.0	0.00
468	87.0	2180.0	47.000	3806.000	40.0	0.00
466	83.0	2009.0	47.000	3712.000	36.0	0.00
464	79.0	1847.0	47.000	3618.000	32.0	0.00
462	74.0	1694.0	47.000	3524.000	27.0	0.00
460	70.0	1549.0	47.000	3430.000	23.0	0.00
458	66.0	1413.0	47.000	3336.000	19.0	0.00
456	62.0	1285.0	47.000	3242.000	15.0	0.00
454	59.0	1164.0	47.000	3148.000	12.0	0.00
452	55.0	1050.0	47.000	3054.000	8.0	0.00
450	51.0	943.0	47.000	2960.000	4.0	0.00
448	47.0	845.0	47.000	845.000	0.0	0.00
446	44.0	755.0	44.000	755.000	0.0	0.00
444	39.0	672.0	39.000	672.000	0.0	0.00
442	36.0	597.0	36.000	597.000	0.0	0.00
440	32.0	530.0	32.000	530.000	0.0	0.00
438	30.0	468.0	30.000	468.000	0.0	0.00
436	27.0	410.0	27.000	410.000	0.0	0.00
434	25.0	358.0	25.000	358.000	0.0	0.00
432	22.0	311.0	22.000	311.000	0.0	0.00
430	20.0	268.0	20.000	268.000	0.0	0.00
428	18.0	230.0	18.000	230.000	0.0	0.00
426	17.0	195.0	17.000	195.000	0.0	0.00
424	15.0	163.0	15.000	163.000	0.0	0.00
422	14.0	135.0	14.000	135.000	0.0	0.00
420	12.0	110.0	12.000	110.000	0.0	0.00
418	11.0	87.0	11.000	87.000	0.0	0.00
416	9.0	67.0	9.000	67.000	0.0	0.00
414	8.0	50.0	8.000	50.000	0.0	0.00
412	7.0	35.0	7.000	35.000	0.0	0.00
410	6.0	23.0	6.000	23.000	0.0	0.00
408	5.0	12.0	5.000	12.000	0.0	0.00
406	4.0	3.0	4.000	3.000	0.0	0.00
405	0.0	0.0	0.000	0.000	0.0	0.00
Therefore,						
NZE obtained as per 70 years expected sediment load =					448 m	
from above ; As per Area Increment Method						
NZE corresponding to 30 years expected sediment volume =					446 m	
NZE corresponding to 50 years expected sediment volume =					448 m	
NZE corresponding to 70 years expected sediment volume =					448 m	

6 GLACIAL LAKE OUTBURST FLOOD

6.1 General

GLOF Simulation studies have been carried out by FE & SA division, Central Water Commission (CWC) for estimation of Glacier lake Outburst Flood using MIKE 11 software.

Glacial Hazards relate to hazards associated with glaciers and glacial lakes in high mountain areas and their impacts downstream. Due to extreme hazard potential of GLOF events, it is necessary to take into account GLOF along with Probable Maximum Flood (PMF), while planning, designing & constructing any infrastructure, especially water resources projects, since these are right in the river channel and would be first victim in case of GLOF.

As per the “Inventory of Glaciers, Glacial lakes and Glacial lake Outburst Floods monitoring and early warning system in the Hindu Kush-Himalayan Region, Bhutan” prepared by International Centre for Integrated Mountain Development (ICIMOD), August, 2001 (ICIMOD) Survey, all the potentially dangerous glaciers in the Wangchu basin will be considered for GLOF study. The criteria for identifying potentially dangerous glacial lakes are based on field observations, processes and records of past events, geomorphological and geo-technical characteristics of the lake and surroundings, and other physical conditions. From the ICIMOD Survey, 24 glacial lakes have been identified as potentially dangerous in Bhutan on the basis of analysis of data using different criteria and the study of topographic maps and satellite images.

6.2 Limitations & Assumptions of GLOF Study

Modelling process is an approximation of a physical phenomenon through which the physical phenomenon and its effects can be studied. Thus, as in the case of any other modelling process, dam break modelling has inherent approximations through assumptions. The foremost assumptions are in the hydrodynamic equations (Saint Venant equations), which are derived on the basis of the following assumptions:

1. The water is incompressible and homogeneous i.e. without significant variation in density.

2. The bottom slope is small.
3. The wave lengths are large compared to the water depth. This ensures that the flow everywhere can be regarded as having a direction parallel to the bottom, i.e., vertical accelerations can be neglected and a hydrostatic pressure variation along the vertical can be assumed.
4. The flow is sub-critical.

The other assumptions are associated with the breach parameters, especially, breach width and breach depth, which has great impact on flood peak and arrival times. Bursting mechanism and breach parameters in case of moraine dams are not fully understood. Hence, the estimation of these, though on the basis of available reports and best judgement, remains assumption. Further, the high velocity flows associated with dam break floods can cause significant scour of channels due to bed as well as bank erosion. This enlargement in channel cross sections is neglected due to limitations in modelling such a complicated physical process. Moreover, this limitation has an effect on the conservative side only.

Dam break floods create a large amount of transported debris. This may accumulate at constricted cross sections, where it acts as a temporary dam and partially or completely restricts the flow, resulting variation in flood peak arrival time. This aspect has also been neglected due to limitations in modelling of such a complicated physical process. This limitation also has an effect on the conservative side only.

Even with the assumptions outlined above, hydrodynamic modelling serves very useful purpose, as it provides reasonable estimate of Glacial Lake Outburst Flood.

6.3 Glacial lakes in Wangchu basin

In the Wangchu basin a total of 221 lakes have been identified. The Wangchu river basin consists of three sub-basins viz., Ha Chu, Pa Chu and Thim Chu from west to east. A total of 53 lakes have been identified in Ha chu sub-basin and none of them are associated with glacier. In the Pa chu sub-basin a total of 94 lakes have been identified. The cumulative surface area of lakes in this sub-basin is 1.82 km². In the Thim Chu sub-basin

a total of 74 lakes have been identified with cumulative surface area of the lakes in this sub-basin as 2.82 km².

6.4 GLOF study- as dam break study using MIKE 11

In order to get the maximum GLOF peak for any project, the out-bursting or breaching of moraine dams of glacial lakes located at upstream of the project have to be considered alongwith channel routing. Thus, estimation of GLOF is akin to dam break study of the moraine dams, which assesses the flood hydrograph of discharge from dam breach and maximum water level at different locations of the river downstream of the dam due to propagation of flood waves alongwith their time of occurrence.

MIKE11 model developed by Danish Hydraulic institute, Denmark has been selected for the present study because of its modeling accuracy and wide acceptability in India and abroad. The core of MIKE 11 system consists of the HD (Hydrodynamic) module, which is capable of simulating unsteady flows in a network of open channels.

For GLOF study, the Wangchu river, downstream of glacial lake upto the dam site has been represented in the model by 52 no. cross-sections. The value of Manning's roughness coefficient has been assumed as 0.050 considering the boundary beds and hilly terrain of Himalyan rivers and large debris flow associated with GLOF.

6.5 Breach parameters adopted

Initial breach level	4320 m
Final breach level	4295 m
Breach width (Top)	87.5 m
Breach width (Bottom)	50 m
Side slope of breaching section	0.75H: 1V
Breach development time (t_f)	30 minutes
Average depth of lake	25 m

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Taking the breach parameters as above, the GLOF simulation has been carried out for the following two initial conditions :

- I. Discharge corresponding to average annual flood
- II. Discharge corresponding to 100 year return period flood.

6.6 Recommended GLOF

The attenuation of GLOF peak from its origin till Wangchu HE Project site in case of 100 year return period flood is about 523 cumec less in comparison to average annual flood condition. The possibility of GLOF during extreme flooding condition of the river cannot be ruled out. Hence the Glacial Lake Outburst Flood for Wangchu HE Project may be taken as 1741 cumec. The time of travel of GLOF wave after start of breach from the lake site to project location is about 4 hours and 2 minutes.

7 CONCLUSIONS

7.1 Water Availability Studies:

The discharge data available at Tala G & D sites (Observed by CWC) has been utilized for evolving flow series at project site. The Ten daily flow series at Tala G & D site for the period 1962-63 to 1998-199 (37 Years) have been transposed to the Wangchu dam site using the rainfall variability correction factor and catchment area proportion. The catchment area at Wangchu dam site is 4147 km².

The flow series need to be reviewed, when site specific observed flow series of adequate length is available.

7.2 Design Flood Studies:

For Computing the Probable Maximum Flood (PMF), following approaches have been attempted

- i) Flood Hydrograph using CWC's Sub zone 2(a) flood estimation Report.
- ii) Flood Frequency approach using annual maximum peaks.

The PMF as derived by above method is 11441 cumec, which has been adopted as the design flood. A GLOF of 1741 cumec has been estimated by CWC using MIKE11 model which has been considered for design flood in addition to PMF keeping all the sluice gates open.

It is recommended that site specific short interval rainfall-runoff (hourly) data should be recorded at the project site as well as at suitable upstream site to enable derivation of reliable unit hydrographs from observed data.

7.3 Diversion Flood:

The Diversion Flood has been computed using non monsoon peaks at Piping G & D site for the period 1994-2009 for different return periods. It is recommended that a diversion flood of 2157 cumec (of 25 year return period) may be considered for construction planning.

7.4 Sedimentation Studies:

Sediment data in the Wangchu catchment is available for a few stations for limited time period. On the basis of available limited sediment data in the catchment, an average sediment rate of about 0.20 mm/year/sq. km was derived for Wangchu HEP but keeping in view the sediment rates adopted in Projects in the adjoining regions and as recommended by CWC, a sediment rate of 1.0 mm/year/ sq.km was adopted for sedimentation studies of Wangchu HEP. The New Zero Elevations obtained after 70 year, 50 year and 25 years of sedimentation are 458 m, 458 m and 457 m respectively.

In view of above and mathematical model studies carried out by IIT, Roorkee, comprehensive desilting chambers have not been provided in this scheme. However, regular annual monitoring of the Land Use Land Cover (LULC) status of the watershed area may be undertaken with the help of satellite imageries for suitable measures after identifying any undesirable changes in the vegetative covers which may contribute to sediment supply to the Wangchu reservoir.

The sediment rate needs to be reviewed when observed site specific data of the proposed H.E Scheme for adequate length is available.

7.5 GLOF Studies:

The possibility of GLOF during extreme flooding condition of the river cannot be ruled out. Hence the Glacial Lake Outburst Flood for Wangchu HE Project has been taken as 1741 cumec and used in the project design. The time of travel of GLOF wave after start of breach from the lake site to project location is about 4 hours and 2 minutes.