BEFORE THE HON'BLE NATIONAL GREEN TRIBUNAL, PRINCIPAL BENCH, AT NEW DELHI

IN OA NO 477/2022

IN THE MATTER OF:

RAJENDER GANGSARI ...APPLICANT

VERSUS

STATE OF UTTARAKHAND & ORS ...RESPONDENT

INDEX

Dated: 05.11.2025

Adv Anjali Rajput

Counsel for State of Uttarakhand

BEFORE THE HON'BLE NATIONAL GREEN TRIBUNAL, PRINCIPAL BENCH, AT NEW DELHI

IN OA NO 477/2022

IN THE MATTER OF:

RAJENDER GANGSARI ...APPLICANT

VERSUS

STATE OF UTTARAKHAND & ORS ...RESPONDENT

AFFIDAVIT ON BEHALF OF RESPONDENT NO. 7, DISTRICT MAGISTRATE, DEHRADUN, GOVERNMENT OF UTTARAKHAND IN COMPLIANCE OF THE DIRECTIONS OF THE ORDER DATED 06.08.2026.

Most respectfully showeth:

1. That I Abhinav Shah Aged yrs, currently posted as Chief Development Officer (Incharge ADM) District, Dehradun, State of Uttarakhand do hereby solemnly affirm on oath that in my official capacity, I am acquainted with the facts and circumstances of the present matter, and Iam fully competent to file present affidavit.
2. That the above-mentioned matter was listed before the Hon'ble Tribunal multiple times and on 06.11.2025 and the hon'ble Tribunal was please to pass the following order

> *"4. Learned Counsel appearing for respondent no.7-DistrictMagistrate, Dehradun has submitted that though earlier flood plains of river Asan were defined taking into account the highest flood level 1:100 years but it is not known as to what contour intervals were taken in to account. She has submitted that now the fresh exercise will be taken to define the flood plain with one meter contour taking into account 1:100 highest flood level. She has submitted that committee*

Abhinav

will examine this issue and has sought three weeks' time to file affidavit in this regard.

5. List on 06.11.2025."

Copy of the order is Annexed herewith as **Annexure A.**

3. In compliance of the above order a meeting was duly convened on 09.09.2025 chaired by Additional District Magistrate (F/R) and attended by Superintending Engineer, Irrigation Department Vikasnagar; Executive Engineer, Irrigation Department Vikasnagar and District Government Advocate (Revenue) Dehradun. It was directed that a committee be constituted to conduct a survey of the flood plain area of the Asan river to ensuring strict adherence to the technical guidelines issued by the National Mission for Clean Ganga (NMCG).

4. That in compliance with the directions of the meeting, a communication by Executive Engineer, Irrigation Division bearing no-2331/Si. Kh.V./Flood Zoning, dated 20.09.2025 was received stating that field survey of entire reach of the Asan flood plain zone has been preparedusing advanced techniques, Total Station and Differential Global Positioning System (DGPS), based on the compiled field survey data, a 1-meter hybrid Digital Elevation Model (DEM) having vertical accuracy of 0.30 meters. Copy of the letter number 2331/Si. Kh.V./Flood Zoning, dated 20.09.2025, by Executive Engineer, Irrigation Division along with 1 M contour Map and detailed study report as **Annexure B.**

5. That the present affidavit is being filed in compliance of directions passed by this Hon'ble Tribunal on behalf of District Magistrate, Dehradun, Uttarakhand for kind perusal of this Hon'ble Tribunal.

NOTARY
Birendra Singh (Advocate) Reg.No.58(01)2022 Doiwala, Dehradun
STATE OF UTTARAKHAND

Abhinav

6. In view of the facts and circumstances as explained here in above sincere efforts are taken by the state of Uttarakhand incompliance of the directions passes by this Hon'ble Tribunal.

Abhinav
Deponent

VERIFICATION

I Abhinav Shah, Chief Development Officer (Incharge ADM) District Dehradun, Uttarakhand do here by verify that the contents of this affidavit are true and correctto the best of my knowledge' and belief. No part of this affidavit is false and nothing material has been concealed therefrom.

Verified at Dehradun, Uttarakhand on this 05 day of November 2025.

S.D. MO 221
2025

Abhinav

NOTARY
Birendra Singh
(Advocate)
Reg.No.58(01)2022
Doiwala,Dehradun
STATE OF UTTARAKHAND

This affidavit is sworn before me by
Shri Abhinav Shah (Adm)
who is identified by Shri D.A.I. Dehradun.
At Doiwala Dehradun on
Birendra Singh
Advocate & Notary
Doiwala,Dehradun
5.11.2025

Item No. 04 Court No. 1

BEFORE THE NATIONAL GREEN TRIBUNAL
PRINCIPAL BENCH, NEW DELHI

Original Application No.477/2022

Rajender Gangsari Applicant

Versus

State of Uttarakhand & Ors. Respondent(s)

Date of hearing: 06.08.2025

CORAM: **HON'BLE MR. JUSTICE PRAKASH SHRIVASTAVA, CHAIRPERSON**
HON'BLE DR. A. SENTHIL VEL, EXPERT MEMBER

Applicant: Mr. Gaurav Kumar Bansal, Ms. Nandita Bansal, Ms. Chandrika Upadhyay & Ms. Atharva Upadhyay, Advs. for Applicant

Respondent: Ms. Anjali Rajput, Adv. for R - 1, 3 & 7 (Through VC)
Mr. Manish Kumar & Ms. Aparajita Jha, Advs. for R - 4
Mr. Mukesh Verma & Ms. Vatsala Tripathi, Advs. for UKPCB (Through VC)

ORDER

1. In compliance of the order dated 03.04.2025, applicant has filed rejoinder dated 05.08.2025.

2. Learned Counsel for the applicant has referred to the photographs filed as annexure A-1 to the rejoinder and has submitted that leachate is flowing from the solid waste dump to Aasan river, therefore, immediate remedial action is required to be taken.

3. Learned Counsel appearing for respondent no.4 submits that a copy of the rejoinder has been received yesterday and has sought two weeks' time to obtain instructions. He has also submitted that if leachate is flowing to the river from the dump site, then expeditious remedial action will be taken.

4. Learned Counsel appearing for respondent no.7-District Magistrate, Dehradun has submitted that though earlier flood plains of river Aasan were defined taking into account the highest flood level 1:100 years but it is not known as to what contour intervals were taken into account. She has submitted that now the fresh exercise will be taken to define the flood plain with one meter contour taking into account 1:100 highest flood level. She has submitted that committee will examine this issue and has sought three weeks' time to file affidavit in this regard.

5. List on 06.11.2025.

Prakash Shrivastava, CP

Dr. A. Senthil Vel, EM

August 06, 2025
Original Application No.477/2022
JG.

Annexure B

प्रेषक,

अधिशासी अभियन्ता
सिंचाई खण्ड, विकासनगर

सेवा में,

जिलाधिकारी
देहरादून।

पत्रांकः– २३३ / सि०ख०वि० / बाढ़ परिक्षेत्रण, दिनांक २० / 09 / 2025

विषयः मा० राष्ट्रीय हरित अधिकरण, नई दिल्ली में योजित मूल आवेदन संख्या 477 / 2022 Rajender gangsari vs State of Uttarakhand में आहूत समीक्षा बैठक के सम्बन्ध में।

सन्दर्भ आपका पत्रांक 914 / एल0ओ0सी0 -2025, दिनांक 08 सितम्बर, 2025

महोदय,

उपरोक्त विषयक आपके सन्दर्भित पत्र के कम में अवगत कराना है कि आसन बाढ़ परिक्षेत्रण में सम्पूर्ण रीच में फील्ड सर्वे टोटल स्टेशन एंव DGPS के द्वारा किया गया है, फील्ड सर्वे डाटा एंव DEM के माध्यम से 1 मीटर का हाइब्रिड DEM तैयार किया गया, जिसकी Vertical Accuracy 0.30 मीटर है। 1 मीटर का Contour Map एंव अध्ययन रिपोर्ट सलग्न है।

सलंग्नकः– उपरोक्तानुसार।

20/9/25

अधिशासी अभियन्ता
सिंचाई खण्ड विकासनगर

OC/LBC

24.09.25

कार्यालय
अधिशासी अभियंता
जल विज्ञान खण्ड, बहादराबाद

पत्रांक - 812 / ज.वि.ख./FPZ दिनांक – 15.09.2025

विषय – मा० राष्ट्रिय हरित अधिकरण, नई दिल्ली में योजित मूल आवेदन संख्या 477/2022 Rajender Ganasari vs State of Uttarakhand में आहूत समीक्षा बैठक के सम्बन्ध में।

सन्दर्भ- आपका पत्रांक 2298/सि०ख०वि०डा०/बा०मै०परि०(आसन) दिनांक 15/09/2025।

अधिशासी अभियंता, सिंचाई खंड, विकासनगर।

कृपया उपरोक्त विषयक संदर्भित पत्र का अवलोकन करने का कष्ट करें जिसके द्वारा यह अवगत कराया गया है कि मा० राष्ट्रिय हरित अधिकरण, नई दिल्ली में योजित मूल आवेदन संख्या 477/2022 Rajender Ganasari vs State of Uttarakhand के सम्बन्ध में मा० एन० जी० टी० द्वारा दिनांक 06.08.2025 को पारित आदेश के क्रम में बाढ़ मैदान परिक्षेत्रण 1.00 मी. Contour Interval के साथ परिभाषित करने हेतु आदेश दिए गए है।

उक्त के क्रम के अवगत कराना है कि आसन नदी का बाढ़ मैदान परिक्षेत्रण में सम्पूर्ण रीच में फील्ड सर्वे टोटल स्टेशन एवं DGPS के द्वारा किया गया है। फील्ड सर्वे डाटा एवं DEM के माध्यम से 1 मीटर का हाइब्रिड DEM तैयार किया गया है जिसकी Vertical Accuracy 0.30 मी० है। 1 मी० का Contour Map एवं अध्ययन रिपोर्ट इस पत्र के साथ संलग्न कर ई-मेल के माध्यम से प्रेषित है।

अधिशासी अभियंता
जल विज्ञान खण्ड, बहादराबाद

पत्रांक - 812 / ज.वि.ख./FPZ तददिनांक – 15.09.2025

प्रतिलिपि अधीक्षण अभियंता, जल विज्ञान मंडल, बहादराबाद को सूचनार्थ एवं आवश्यक अग्रिम कार्यवाही हेतु प्रेषित है।

अधिशासी अभियंता
जल विज्ञान खण्ड, बहादराबाद

2816

TOPOGHAPHICAL SURVEY PLAN OF ASAN RIVER

SHEET-1/11

Annexure A

LEGEND	
DESCRIPTION	SYMBOL
1.RIVER BED	
2.RIVER BANK	
3.WATER LINE	
4.DEEPEST BED LINE	
5.TBM	
6.HIGH TENSION LINE	
7.BRIDGE	
8. HOUSE	
9. CONTOUR	240.0
10.ROAD	

GOVERNMENT OF UTTRAKHAND
IRRIGATION DEPARTMENT UTTRAKHAND

CLIENT
EXECUTIVE ENGINEER HYDRAULIC DIVISION BAHADRABAD, HARIDWAR

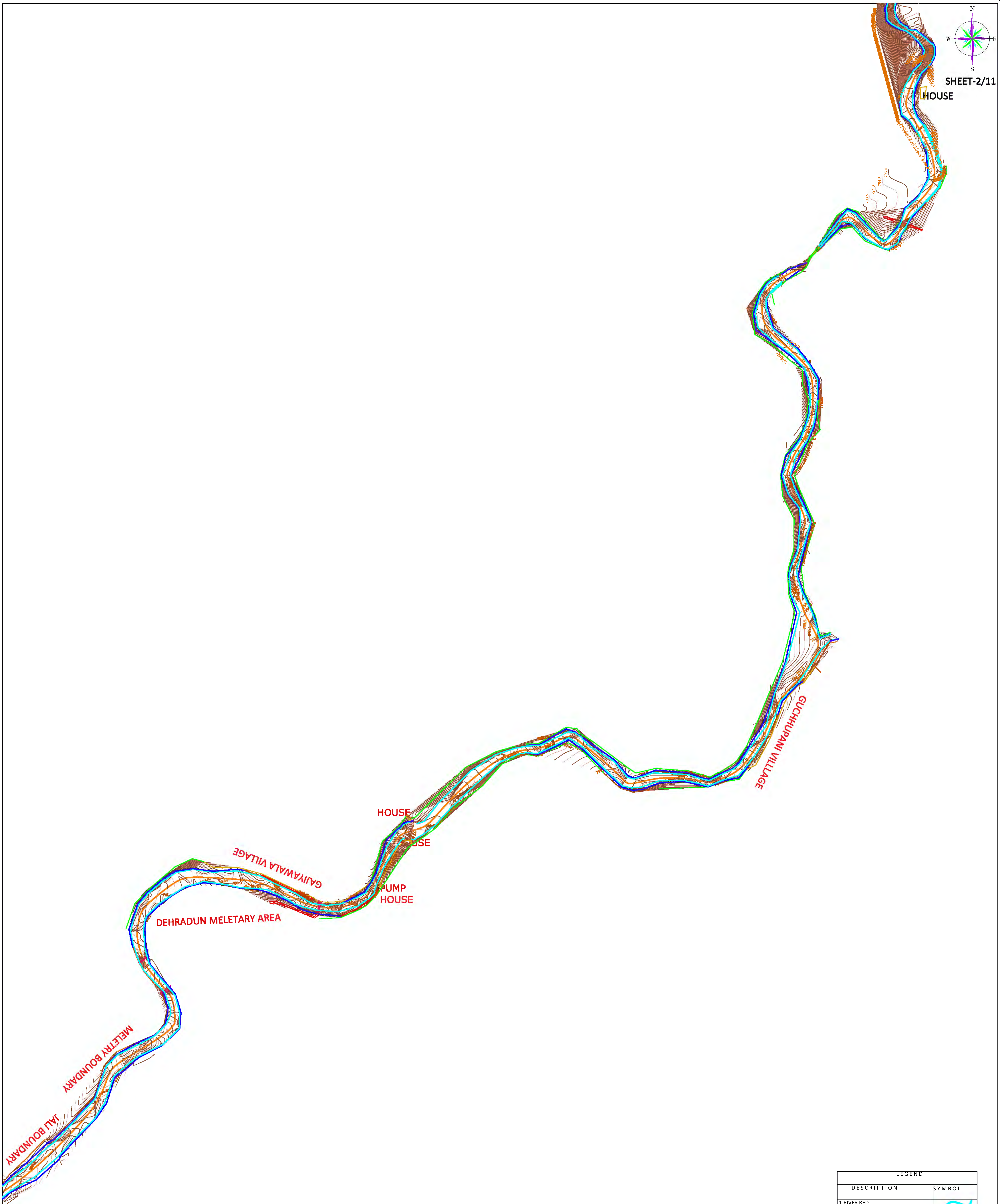
NAME OF THE WORK:
"CONSULTANCY WORK FOR FLOOD PLAIN ZONING IN ACCORDANCE WITH UTTARAKHAND FLOOD PLAIN ZONING ACT-2012 IN RIVERS YAMUNA, ASAN, NIMI , NUN, SWARNA,SITLA RAO,JHAKHAN & CHANDRABHAGA".

TITLE: TOPOGHAPHICAL SURVEY PLAN OF ASAN RIVER

CONSULTANT : VISIONTEK CONSULTANCY SERVICES PVT.LTD.
(AN ISO 9001-2008 CERTIFIED COMPANY)

DRAWN BY:-ER. N PRADHAN	SCALE :-1:5000
CHECKED BY:-ER. R BEHERA	DATE: 3.06.2025
DWG NO:	REV.

2817



LEGEND

DESCRIPTION	SYMBOL
1.RIVER BED	
2.RIVER BANK	
3.WATER LINE	
4.DEEPEST BED LINE	
5.TBM	
6.HIGH TENSION LINE	
7.BRIDGE	
8. HOUSE	
9. CONTOUR	240.0
10.ROAD	

GOVERNMENT OF UTTRAKHAND
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SHEET-3/11

LEGEND	
DESCRIPTION	SYMBOL
1.RIVER BED	
2.RIVER BANK	
3.WATER LINE	
4.DEEPEST BED LINE	
5.TBM	
6.HIGH TENSION LINE	
7.BRIDGE	
8. HOUSE	
9. CONTOUR	
10.ROAD	

GOVERNMENT OF UTTRAKHAND
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7.BRIDGE	
8. HOUSE	
9. CONTOUR	240.0
10.ROAD	

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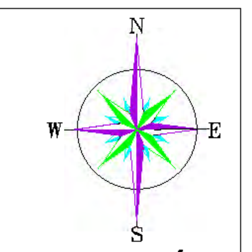

SHEET-5/11

LEGEND	
DESCRIPTION	SYMBOL
1.RIVER BED	
2.RIVER BANK	
3.WATER LINE	
4.DEEPEST BED LINE	
5.TBM	
6.HIGH TENSION LINE	
7.BRIDGE	
8. HOUSE	
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GOVERNMENT OF UTTRAKHAND
IRRIGATION DEPARTMENT UTTRAKHAND

CLIENT
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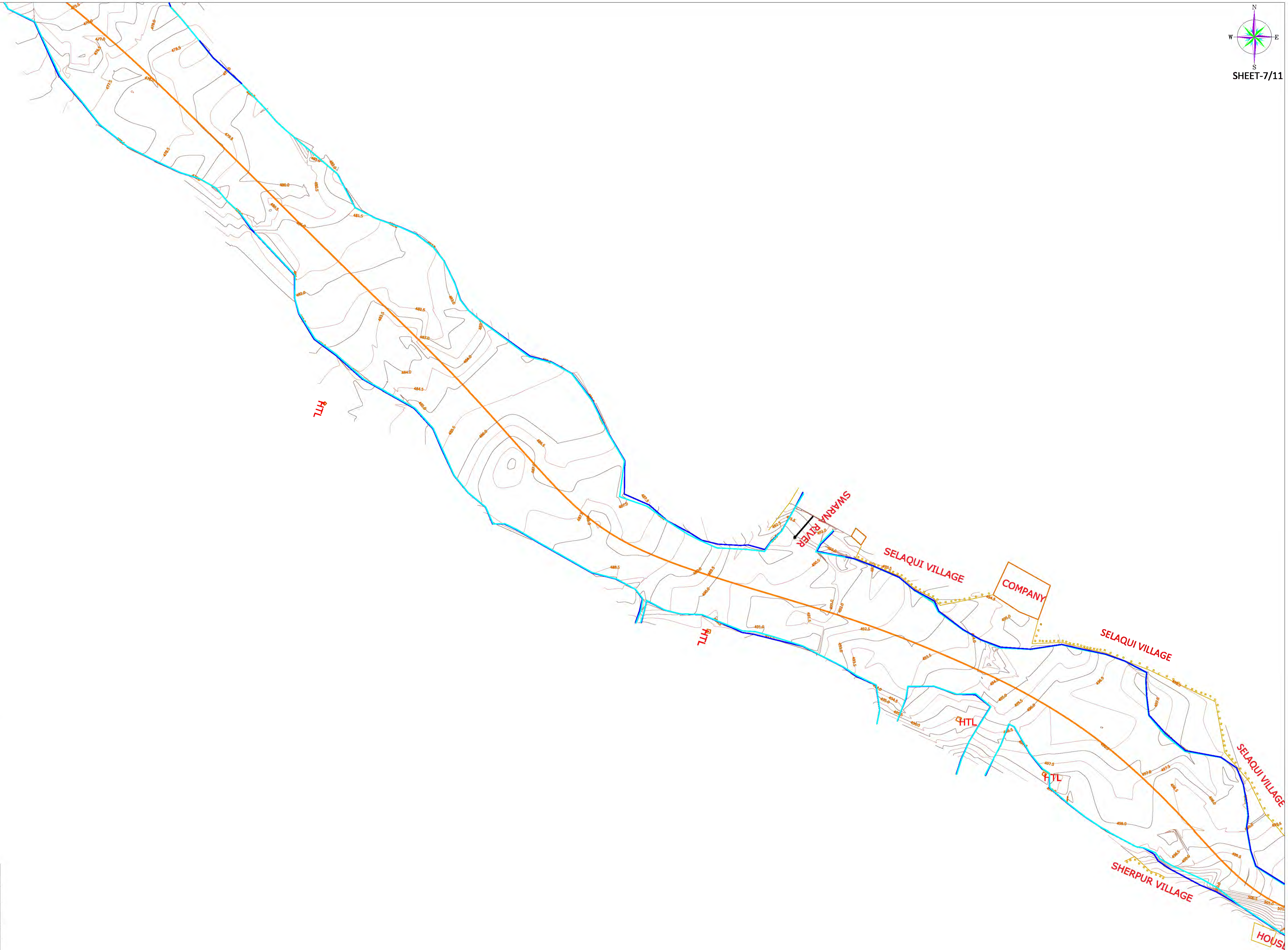

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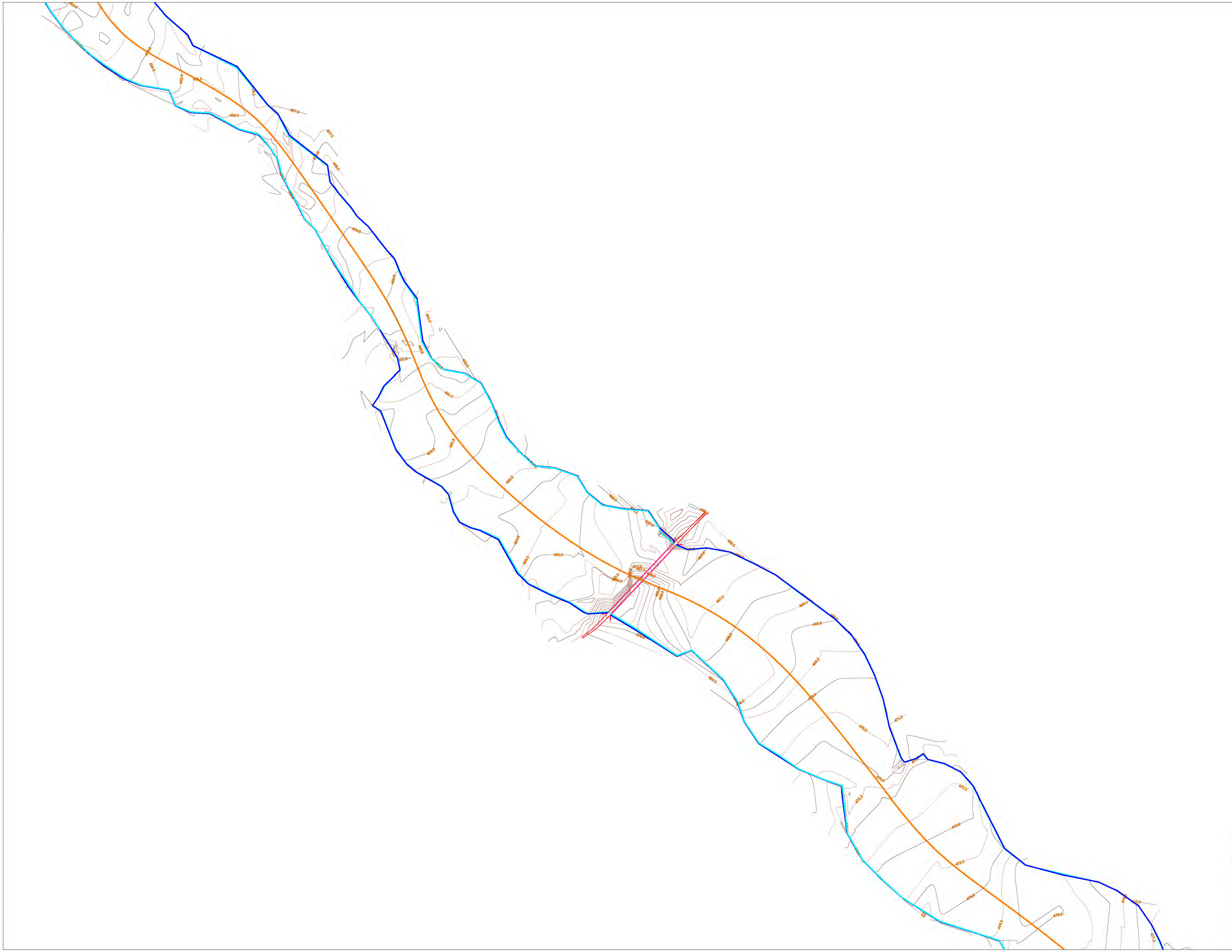
SHEET-8/11



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DESCRIPTION	SYMBOL
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10.ROAD	

Govt. of Uttarakhand

GOVERNMENT OF UTTRAKHAND
IRRIGATION DEPARTMENT UTTRAKHAND

CLIENT
EXECUTIVE ENGINEER HYDRAULIC DIVISION BAHADRABAD, HARIDWAR

NAME OF THE WORK:
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Govt. of Uttarakhand

GOVERNMENT OF UTTRAKHAND
IRRIGATION DEPARTMENT UTTRAKHAND

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SHEET-10/11

LEGEND

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5.TBM	
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GOVERNMENT OF UTTRAKHAND
IRRIGATION DEPARTMENT UTTRAKHAND

CLIENT
EXECUTIVE ENGINEER HYDRAULIC DIVISION BAHADRABAD, HARIDWAR

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GOVERNMENT OF UTTRAKHAND
IRRIGATION DEPARTMENT UTTRAKHAND

CLIENT
EXECUTIVE ENGINEER HYDRAULIC DIVISION BAHADRABAD, HARIDWAR

NAME OF THE WORK:
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CONSULTANT : VISIONTEK CONSULTANCY SERVICES PVT.LTD.
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DRAWN BY:-ER. N PRADHAN	SCALE :-1:5000
CHECKED BY:-ER. R BEHERA	DATE: 3.06.2025
DWG NO:	REV.

CONSULTANCY WORK FOR FLOOD PLAIN ZONING IN ACCORDANCE WITH UTTARAKHAND FLOOD PLAIN ZONING ACT-2012 FOR YAMUNA, JHAKHAN, CHANDRABHAGA, ASAN AND ITS TRIBUTARIES, (NIMI, NUN, SWARNA & SITLA RAO) RIVERS

उत्तराखण्ड राज्य

Superintending Engineer, Hydraulic Circle, Bahadarabad

(IRI Roorkee), Haridwar Uttarakhand

Submitted by

VISIONTEK CONSULTANCY SERVICES

(Committed for Better Environment)

Plot No-M22 and 23 Chandaka, Industrial Estate Patia, Bhubaneswar, Distt- Khurda State – Odisha India Pin code- 751024

Visiontek Consultancy Services		Irrigation Department Uttarakhand	
R.Behera Rajalaxmi Project Engineer	Nagaraju GIS Expert	Assistant Engineer	Executive Engineer
Sanjeev Singh Parihar Hydrology Expert	Manmath Mohanty HOD	Superintending Engineer	Chief Engineer

Contents

List of Figures

List of Tables

Abbreviation

S.No.	Abbreviation	Description
1	CWC	Central Water Commission
2	DEM	Digital Elevation Model
3	DTM	Digital Terrain Model
4	DGPS	Differential Global Positioning System
5	HFL	Highest Flood Level
6	GCP	Ground Control Points
7	PMP	Probable Maximum Precipitation
8	SUH	Synthetic Unit Hydrograph
9	LULC	Land Use land Cover
10	NDMA	National Disaster Management Authority
11	FPZ	Flood Plain Zoning
12	FFA	Flood Frequency Analysis

EXECUTIVE SUMMARY: -

India as a country has much of its concern towards natural calamities due to its location, topography, hydro-meteorological conditions. Out of many numbers of natural calamities flood constitutes one of the major national calamities faced almost every year resulting in substantial loss of life, large scale damage to property, disruption of community lifelines besides entailing untold misery to the millions. Concerted efforts have been made over the years to reduce the damage due to floods and mitigate the sufferings of the people. Various structural flood control measures were taken-up in the past including construction of reservoirs, embankments, drainage channels, etc. It is however, now realized that absolute and permanent protection to all flood prone areas and for all magnitudes of floods by structural measures alone is impossible due to constraints of time, money and land. So, the emphasis will be on non-structural measures like Flood Plain Zoning and regulation, flood risk mapping, flood forecasting etc. to effectively supplement the structural measures for providing sustainable protection to flood affected areas.

Uttarakhand is an Indian Himalayan State known for its rich spiritual and religious tourism, ecological richness & diversity, and cultural ethos rooted in traditions, but it is also known for growing frequency and intensity of natural disasters and for its fragility of ecological and geological systems. Consisting mostly of uplifted sedimentary & metamorphic rocks and tectonically very active, the region is vulnerable to natural disasters. Due to its geo-climatic, ecological and socio-economic settings, Uttarakhand is one of the most disaster-prone States of the country.

Floods of varying magnitude, affect low lying areas and river valleys in Uttarakhand, due to variability in the monsoonal rainfall. However, the rapid increase of population and developmental activities in this hilly state aggravated the situation.

Cloudburst and related floods during August 1998 at Ukhimath (Rudraprayag) and Malpa (Pithoragarh), August 2001 at Phata (Rudraprayag), August 2002 at Burakedar (Tehri), August, 2012 in Asi Ganga (Uttarkashi), September, 2012 at Ukhimath (Rudraprayag) and June 2013 at Kedarnath (Rudraprayag), Feb 2021 in Rishi ganga and Dhauliganga and the flood over most part of Uttarakhand during 2023 are some of the examples of recent flood. Out of all the disasters the Kedarnath flood remain the worst.

There are number of measures to mitigate the effect of flood like Structural and Non-structural measures. Due to the involvement higher cost, time and land requirements the structural measures are scarcely used whereas due to easy implementation processes the non-structural measures like flood plain zoning, flood risk mapping, flood warning/forecasting are largely implemented. While flood plain zoning is a proven technique for reducing the flood damages, the state of Uttarakhand has adopted this in principle to delineate the flood plain zoning lines in order to demarcate the areas along the flood plains according to the effect of flood damages as per NDMA guidelines. The entire rivers selected for flood plain zoning are divided in three lots. Rivers like Yamuna, Asan and its Tributaries, Jhakhan, Chandrabhaga falls under Lot-1. The assigned reaches for the corresponding rivers are mentioned in the Table below and a total of 287 km is processed for Flood Plain Zoning.

Sl. No.	Reach/River	Length Covered (Km.)	Name of Lot
1	Yamuna	145	Lot-I
2	Asan and its Tributaries	106	Lot-I
3	Jhakhan	28	Lot-I
4	Chandrabhaga	8	Lot-I
	Total	287 KM	

Initially the survey work of the flood plain is done by using DGPS, Total Station as well as Drone Survey. The appropriate Digital Elevation Model is also procured for use in Hydraulic model. The rainfall and discharge data is collected from respective sources. Due to non-availability of sufficient discharge data, the two rivers (Jhakhan & Chandrabhaga) are treated as ungauged and the discharge calculation is done on the concept of Synthetic Unit Hydrograph. The maximum rainfalls have been obtained from PMP ATLAS and disaggregation of the data is done as per the defined process. The design discharge is obtained after performing critical sequencing of the rainfall. The discharge values are obtained for the 5-, 25-, 50- and 100-year return periods.

The hydrodynamic modelling is applied to the obtained design discharge. The HEC-RAS software is used to make the analysis. Both 1-D and 2-D modelling analysis is done to the given data. The cross-sections obtained at 50 m interval, the DEM data, DGPS survey & Drone data are combined together for a hybrid DEM which remain the input for our model. The design discharge data remain the hydrologic input for the model. The local Manning's Constant (n) values are taken as per the river stretch configuration. The outputs in the form of flood lines corresponding to 5, 25, 50 and 100-year flood lines are obtained which are communicated to field staff for putting the marks at field at 50 m intervals. The same has been done in presence of field staff as well as the Survey team.

Vertical accuracy of the flood extents was assessed as up to 0.3m, which was further validated through field inputs at the time of joint field validation

The task of placing the flood lines in the Shajra map is essential for finalising the flood inundation lines as well as fixing the flood zones i.e. the restrictive, prohibitive and warning zones. The same has also been done and submitted to appropriate authority. Mean time two workshops were held at Irrigation Dept. Seminar Hall, one on 7th Oct. 2023 where the discussion on study area and approach & methodologies were discussed and in the second workshop on 12th March, 2024, the outcomes of the analysis basically the flood lines and implementations are discussed. The remarks and suggestions for improvements/corrections were gladly accepted and rectified in the present report. The flood plain zoning work is highly essential for the rivers as the utility of flood plain is important due to the land constraints. Further the frequency of flood and climate change driven floods are more frequent now. So, in one hand the safety of life and property and in other the increasing the utility of land have to be balanced. In that context, making flood plain zoning for sensitive rivers is the foremost step.

This study regarding flood plain zoning completes all the scopes assigned to the specific problem.

Expecting a healthy co-operation from all

Warm Regards

VISIONTEK CONSULTANCY SERVICES PVT LTD

BHUBANESWAR

1.0 INTRODUCTION:

The whole of Uttarakhand State is extremely vulnerable to severe natural hazards. Located on the southern slope of the Himalayan range, Uttarakhand is one of the most disaster-prone states in India. Due to its topography and geology, the state faces the risk of calamitous events like flash floods/ floods, cloudbursts, avalanches, landslides, mudflows, and earthquakes, among others. Furthermore, it must be noted that the frequency and intensity of these hazards have increased in the fragile state over the last few decades. This has happened due to anthropological factors, scientists have documented. The floods are usual phenomena at Uttarakhand state. The network of rivers coming from hills, passing through a tough terrain and finally reaching at plains and the high slope encountered during their travel makes the scenario difficult when a high intense rainfall continues for a significant duration. Many damages and loss of lives and properties are recorded during past and few of them of recent times are presented.

1.1 Kedarnath Flood (June 16-17, 2013)

Over Sunday and Monday, June 16-17, 2013, when a series of cloudbursts wreaked havoc in 5 districts of Rudraprayag, Uttarkashi, Chamoli, Pithoragarh and Tehri, there were nearly 12,000 people at Kedarnath and Gaurikund the stretch that bore the brunt of the deluge. Ten days later, about 6,000 had been rescued from Kedarnath. More than 800 bodies were recovered in and around Kedarnath. Hundreds were reported missing.

Figure 1. Flood at Rishikesh

The cloudbursts led to flash floods that swept away mountainsides, villages, people, animals, houses, trucks, cars, roads, nothing escaped. Nothing survived, it had no hope of surviving. The first of the cloudbursts-signalled by something that sounded like a sudden explosion that shook most of the houses--at Kedarnath took place around 7.30 pm on June 16. The check dam behind the temple crumbled and water gushed towards the temple. A second cloudburst on the morning of June 17 made the Chorabari Tal breaches its walls. The massive amount of water released from the lake, combined with that of the incessant rain, flowed down and brought with it a massive mudslide that dislodged boulders and brought them down. All those structures that had withstood the previous night's onslaught perished under the sheer speed and weight of the water.

The floodwaters weren't content with ravaging the town of Kedarnath. As it flowed downhill towards flat land, it went through nearly 200 villages with such terrifying speed that the

villagers had little or no time to escape. The result: houses, two-three storey buildings came crashing down as the floodwaters washed away the earth they were standing on, people and livestock were no exceptions. Roads and bridges soon became part of the debris the water was carrying with it.

1.2 Flood of Year 2021

On Sunday morning of 7th February 2021 at 10:08 Hrs, a massive flash flood took place along Rishi Ganga River valley of Chamoli district. As per the official records, among 204 died people only 80 dead bodies retrieved and 124 people's bodies still missing which were later declared dead after long search operation. In this flood, Rishiganga Hydropower project and under construction Tapovan Vishnugad Hydropower project were also extremely damaged. In addition, flood also dismantled a bridge near the confluence of Dhauliganga and the Rishiganga (1985m.a.s.l.). Several disturbing live footages recorded by eyewitness were surfaced online through news channels and social media platforms. In the immediate aftermath of the event, based on the recorded videos, it was speculated that the flood was most probably triggered by

Glacial Lake Outburst Flood (GLOF) event. However, early aerial surveys and available satellite imagery data confirmed that the flash flood was triggered by failure of a massive rockslide just below Ronti peak in the Nanda Devi massif (Source: Singh et.al.2022).

Among the places most severely hit by the floods are Joshimath, Rini, Nanda Devi National Park, Tapovan Vishnugad Hydropower Plant and Sridhar.

The disaster left over 200 killed or missing. As of May 2021, "83 bodies and 36 human body parts out of a total of 204 people missing have been recovered so far. Of the missing and dead, 140 were workers at the Tapovan Hydropower Plant site.

Measures to Control Flood Disasters: The flood related disasters are generally controlled through structural and non-structural measures. The non-structural measures like flood forecasting, flood, flood risk mapping, flood plain zoning are mostly preferred over the structural measures due to its cost and time-consuming effects. Out of all the non-structural measures the flood plain zoning is a well-accepted due its simplicity in application and long-term planning for reduction of disaster related losses.

1.3 Flood Plain Zoning

The basic concept of flood plain management is to regulate the land use in the flood plains in order to restrict the damage due to floods, while deriving maximum benefits from the same. This is done by determining the locations and the extent of areas likely to be affected by floods of different magnitudes/ frequencies and to develop those areas in such a fashion that the resulting damage is minimum in case the floods do occur. Flood Plain Zoning, therefore aims at disseminating, such 'potential loss' information on a wider basis so as to regulate indiscriminate and unplanned development in flood plains and is relevant both for unprotected as well as protected areas.

Flood Plain Zoning recognizes the basic fact that the flood plains are essentially the domain of the river, and as such all developmental activities in flood plains must be compatible with the flood risk involved. Heavy encroachment of flood plains has been responsible for increasing trend of damage over the years. The need for Flood Plain Zoning has received recognition at various fora in the past also.

As far back as 1973-74, the Central Water Commission (CWC) had prepared guidelines 18 for Flood Plain Zoning which were approved by the Central Flood Control Board. Since the implementation of these guidelines needed statutory backing, CWC also prepared a model draft bill which was circulated in 1975 by the then Ministry of Irrigation, Government of India, to all the States advising them for enactment of a suitable legislation. In pursuance of the provisions of clause (3) of Article 348 of the constitution of India, the Uttarakhand Government passed the Uttarakhand Flood Plain Zoning Act 2012. The aftermath of 2013 Kedarnath flood, the Honorable Supreme Court and the Honorable National Green Tribunal (N.G.T.) has taken a serious note of that and in the lights of the directions passed by Honorable Supreme Court and subsequently by the Honorable N.G.T., it becomes imperative to decide the limiting boundary for rivers/streams in Uttarakhand. For regulating land use in different flood zones, the National Disaster Management Authority (N.D.M.A.) has classified following priorities in respect of construction of buildings and other utility services (Table 1).

1.4 Objective of Study

Flood-plain zoning is a concept for flood plain management. It recognizes the basic fact that the flood plain of a river is essentially its domain and any intrusion into or developmental activity therein must recognize the river's 'right of way'. Flood plain zoning measures aim at demarcating zones or areas likely to be affected by floods of different magnitudes or frequencies and probability levels, and specify the types of permissible developments in these zones. The objective is to document flood plain boundaries based on channel configuration, geometry, bed form and profile characteristics of the identified major rivers of Uttarakhand together with their hydraulic characteristics and to identify areas/stretches where the stream flow is likely to have adverse impact on human interests during spells of high discharge caused by flood or flash flood. It will include flood plain Zoning based on the modelling results for the characteristic discharges calculated for the said streams (flood frequencies of say 5 years, 25 years, 50 years, and 100 years return period). The study is also intended to provide detailed account/database for engineering design and others, of the various flood control/mitigation measures and channel improvement measures near habitations along the river course so as to reduce the impact of the flood disaster on human life, property and adjoining habitation.

1.5 Scope of Works

The scope of work in the light of objectives discussed above shall include stipulated tasks under following heads which shall be completed as per NDMA guidelines.

1. Preparation of Digital /Survey maps of the streams as mentioned above, showing all the major cities, towns, semi urban development using satellite imageries or suitable latest techniques.

2. Preparation of Detailed Maps showing habitation around the rivers.

3. Calculation of Characteristic flood discharges of all the major streams based on flood frequency analysis.

4. Defining the streams in the sensitive reaches based on the results found as per para 4 above.

5. The prime objective of this assignment is to restrict/prohibit the human activities in the river flood plains. Since the reserve forests/national parks are already protected by law hence the river reaches falling in these areas will be excluded from the study. However civil lands having forest cover will be included.

6. Tabulation of flood plain boundary limit in various cities /towns villages, in general depending on desired waterway to pass the characteristic discharge.

7. Preparation of digital /GIS map showing the defined prohibitive, regulating, and warning zone as per NDMA flood plain zoning guidelines.

8. Preparation of digital GIS maps showing flood plain boundaries for floods of return periods and the map will be prepared showing the defined zone boundary.

9. To estimate water surface profiles employing hydro-dynamic river flow model.

10. All survey work & data acquisition from different agencies will be done by the consultant.

11. Consultant shall assist the department to clarify the methodology and other technical issues related to the task, before the Govt., Honorable N.G.T. or any other court if required.

12. River Cross-section Interval in habitations the cross-section interval should not be more than 50 m c/c. In other habitable reaches this interval should not be more than 500m. In hilly/forest areas the cross-section interval may be chosen suitably for the required level of accuracy.

1.6 NDMA Guidelines

The scope of work provided above and the expected deliverables are inline to meet the guidelines provided by national Disaster Management Act Jan 2008. Below are the guidelines from the NDMA document: In the regulation of land use in flood plains, different types of buildings and utility services can be grouped under three priorities from the point of view of the damage likely to occur and the flood plain zone in which they are to be located:

Table 1: NDMA guidelines for Flood Plain & Land Utilization

Priority	Reach
Priority 1	• Defence installations, • Industries, • Public utilities like hospitals, electricity installations, water supply, telephone exchanges, aerodromes, railway stations, commercial centres, etc. Buildings should be located in such a fashion that they are above the levels corresponding to a 100-year frequency or the maximum observed flood levels. Similarly, they should also be above the levels corresponding to a 50-year rainfall and the likely submersion due to drainage congestion.
Priority 2	• Public institutions, • Government offices, universities, public libraries and residential areas. -Buildings should be above a level corresponding to a 25-year flood or a 10-year rainfall with stipulation that all buildings in vulnerable zones should be constructed on columns or stilts as indicated above.
Priority 3	• Parks and playgrounds. -Infrastructure such as playgrounds and parks can be located in areas vulnerable to frequent floods. • Since every city needs some open areas and gardens, by restricting building activity in a vulnerable area, it will be possible to develop parks and play grounds, which would provide a proper environment for the growth of the city.

1.7 Methodology: -

Whenever we are going for the flood Plain zoning works so in that case, we have two types of catchments first one is gauged catchment and the other one is ungauged catchment so the discharge calculation will depend on the type of catchment weather it is gauged or ungauged. Here we will mention the discharge preparation steps for different return period and modeling steps for gage catchment and engagement catchment separately.

For Gauged Catchment:

To estimate the design flood using flood frequency approach, the following procedures shall be adopted:

(a) The flood peak series shall be checked for randomness, homogeneity, trend, jump, outliers etc using appropriate statistical methods.

(b) Flood frequency analysis shall be carried out using time series of instantaneous annual flood peak. Based on the hourly gauge data the observed annual flood peak shall be converted into instantaneous flood peak.

(c) Using the instantaneous annual flood peak time series, the flood frequency analysis shall be carried out using standard frequency distributions such as Gumbel, log Pearson type-III and Log Normal distributions etc. to estimate the desired return period flood.

(d) Goodness of fit test for the frequency distribution shall be carried out using standard statistical tests such as Chi Square, D-Index etc. to assess the appropriate frequency distribution for the data set and decide the appropriate design flood.

a) Normal Distribution

Analysis by using the Normal distribution uses the formula as below:

$$Q_T = \underline{Q} + K_T\sigma$$

Where:

Q_T = the probable discharge with a return period of T years

$\bar{Q}$ =mean flood (for n years)

K_T= frequency factor

σ = Standard deviation of data

The tables presented below summarize calculated discharges for different return period based on the Normal distribution.

b) Log-Normal Distribution

The formula used for estimation of discharges for any return period in the method is written as:

$$\log Q_T = \log(Q)_{avg} + K_T\sigma$$

Where:

Q_T = the probable discharge with a return period of T years

log(Q)avg. = average of the log Q discharge values

K_T= frequency factor (referred from for return period)

σ = the standard deviation of the log Q values

c) Log Pearson Type III Distribution

The formula used for estimation of discharges for any return period in the method is written as:

$$\log Q_T = \log\left(\underline{Q}\right) + K_T\sigma$$

Where:

Q_T = the probable discharge with a return period of T years

$\log(\underline{Q})$ = average of the log Q discharge values

K_T= frequency factor (referred from standard table based on skewness coefficient Cs and return period)

σ = the standard deviation of the log Q values

d) Gumbel Extreme Value Type 1 Distribution (GEVT – 1)

The formula used for estimation of discharges for any return period in the method is written as:

$$Q_T = \underline{Q} + K_T\sigma$$

Where:

Q_T= the probable discharge with a return period of T years

$\bar{Q}$ = mean flood (for n years)

K_T= frequency factor = $(Y_T$ - $Y_n)/\ \sigma_n$

σ_n = Standard deviation of data

Y_T = - Ln (Ln (T/T- 1))

Y_n, σ_n = expected mean and standard deviations of reduced extremes to be found from Gumbel's table based on number of year of data available.

Here also mentioning below the flow chart which explains the holistic approach for flood plain zoning works for Gauged catchments

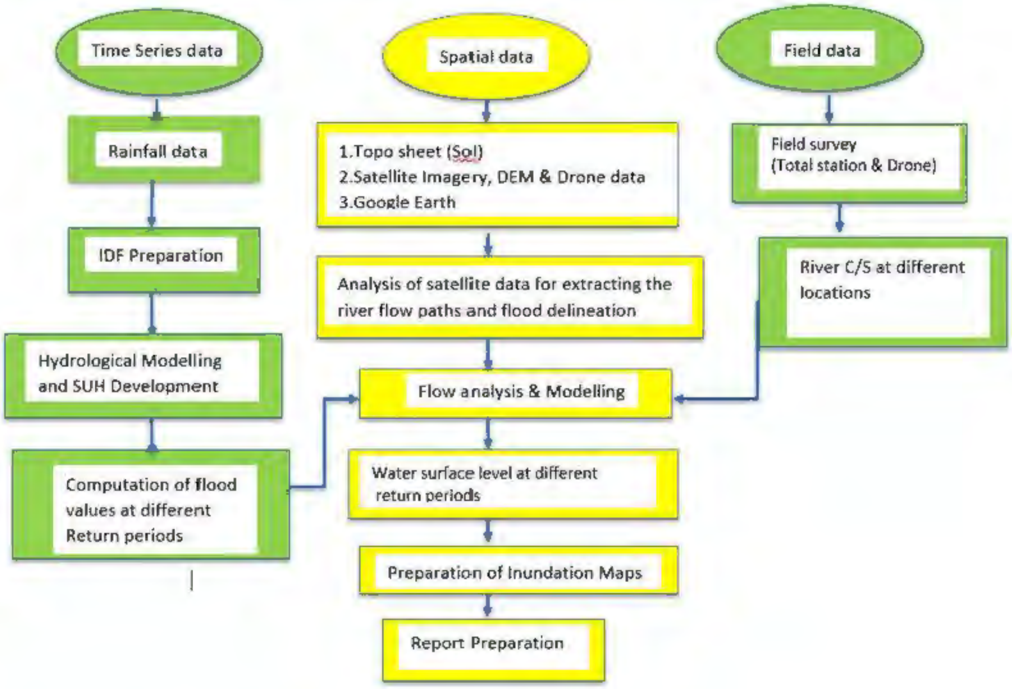


Figure 2 Flowchart of methodology of Flood Plain Zoning

For Ungauged Catchment

The availability of historical discharge data is the prime information required to proceed for Flood Plain Zoning (FPZ) analysis. The major sites sensitive to FPZ are not within the vicinity of the gauged site. So, the analysis for ungauged analysis is to be taken care of. Besides the gauged locations the other locations where scanty or intermittent flow data are available does not give a clear scenario of the flow pattern. At ungauged locations, determining the discharge is always a challenge for doing subsequent hydrological analyses. Simultaneously it is also difficult to put the gauges at all salient locations. Numbers of techniques are used in resolving the problems of data availability at ungauged locations such as:

One of the most frequently used events in hydrology is the relation between rainfall and runoff. It determines the runoff which leaves the watershed from the rainfall received by the basin. In it, a part of the hydrological cycle has been studied to express the process of runoff from the catchment as a function of the rainfall and other catchment characteristics. It helps to extend stream flow time series both spatially and temporally to estimate management strategies and catchment response to climate.

There are various popular flood hydrograph modelling techniques for ungauged basins, like the synthetic unit hydrograph (SUH). The SUH models are grouped into four main classes, as follows:

(a) Conceptual models

(b) Traditional or empirical models

(c) Probabilistic models

(d) Geomorphologic models.

The unit hydrograph (UH) theory is a potentially (geomorphological model used) powerful tool in watershed hydrology similar to the unit-impulse response function in fields such as electrical, electronics and telecommunication or and structural engineering (Gavahne and Londhe, 2021).

The Synthetic Unit Hydrograph approach is used in many studies in order to find the design floods of different ungauged catchments. The parameters related to physiographic as well as hydrometeorology based on the regionalization property has been well defined by CWC. Accordingly, CWC divided entire India in to 7 hydro-meteorological zones and 26 sub zones as mentioned in the Figure-3 below:

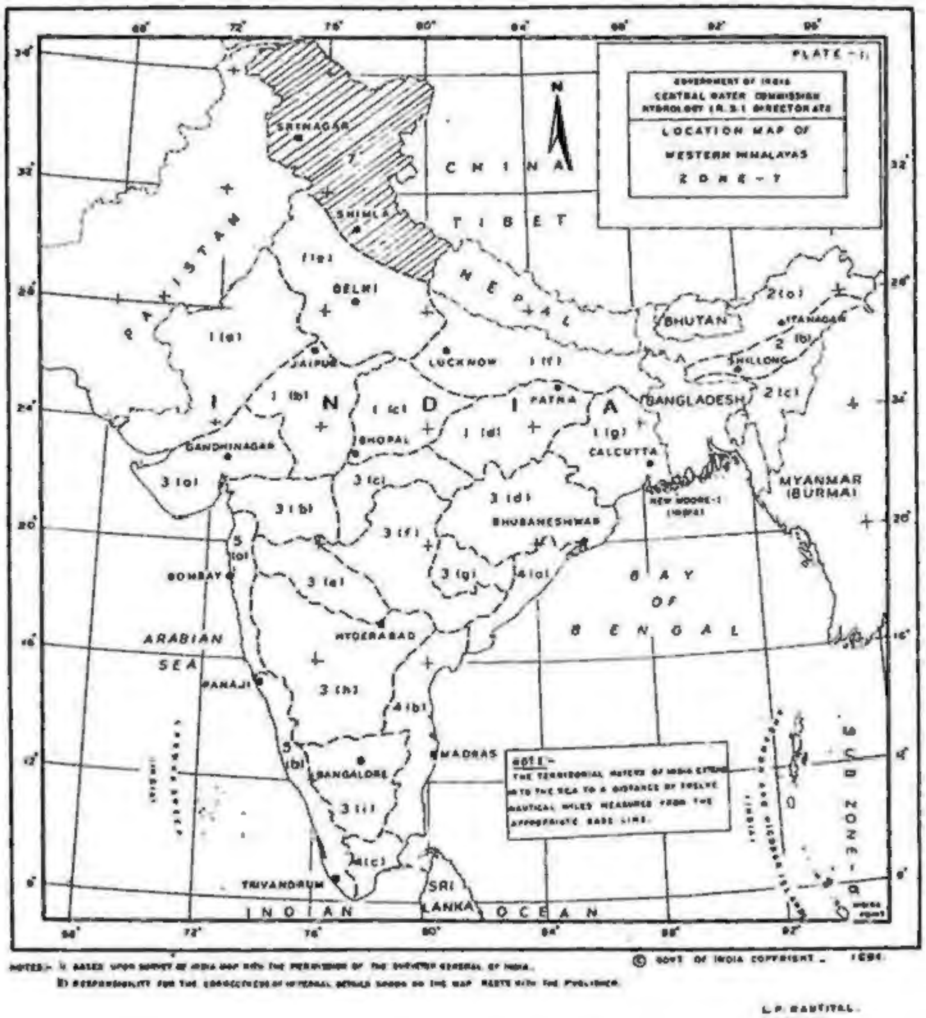


Figure 3. Hydro-meteorological sub-divisions of India

As our study area, falls under Western Himalayas it comes at Zone-7. The equations for developing the Synthetic Unit Hydrograph have to be followed by the guidelines provided by CWC. The steps to be followed regarding the calculation of parameters for individual ungauged sites are shown in Fig. 4, Fig.5 and the parameters are calculated through the equations mentioned in Table 2.

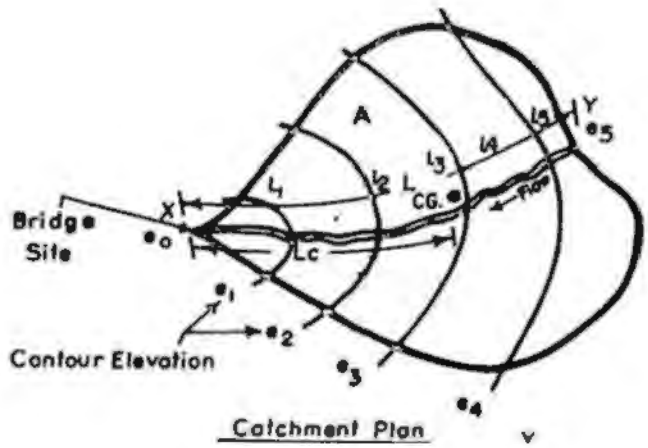


Figure-4 Catchment plan for ungauged sites

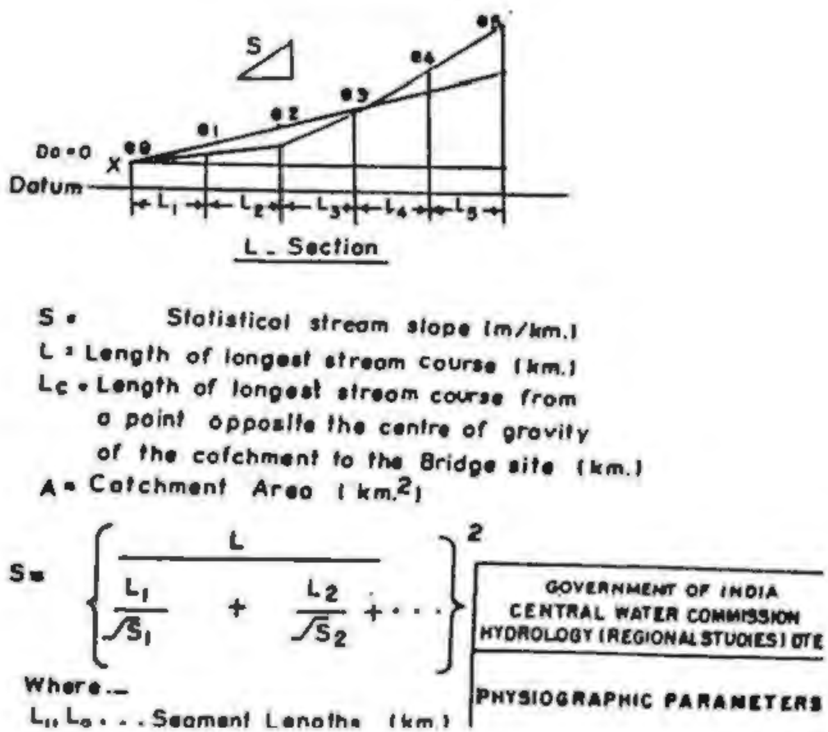


Figure-5 Slope and other physiographic parameter calculation

Table 2: Parameter calculation according to the equation for Western Himalayan Zone-7
Time from the centre of effective rainfall duration to the UH peak $t_p = 2.498*(L*L_c/S)^{0.156}$
Peak discharge of unit hydrograph per unit area $qp = 1.048*(tp)^{-0.178}$
Width of the UH measured at 50% of peak discharge ordinate $W_{50} = 1.954*(L*L_c/S)^{0.099}$
Width of the UH measured at 75% of peak discharge ordinate $W_{75} = 0.972*(L*L_c/S)^{0.124}$
Width of the rising limb of UH measured at 50% of peak discharge ordinate $W_{R50} = 0.189(W_{50})^{1.769}$
Width of the rising limb of UH measured at 75% of peak discharge ordinate $W_{R75} = 0.419(W_{75})^{1.246}$
Base width of UH $T_B = 7.845*(t_p)^{0.453}$
Peak Discharge of UH $Q_p = q_p \times A$
Unit duration of unit hydrograph t_r
Time from the start of rise to the peak of the UH $Tm = t_p + t_r/2$
$Q_{theoretical} = A*d/0.36*t_r$ here d= 1 cm depth and t_r = 1 hr

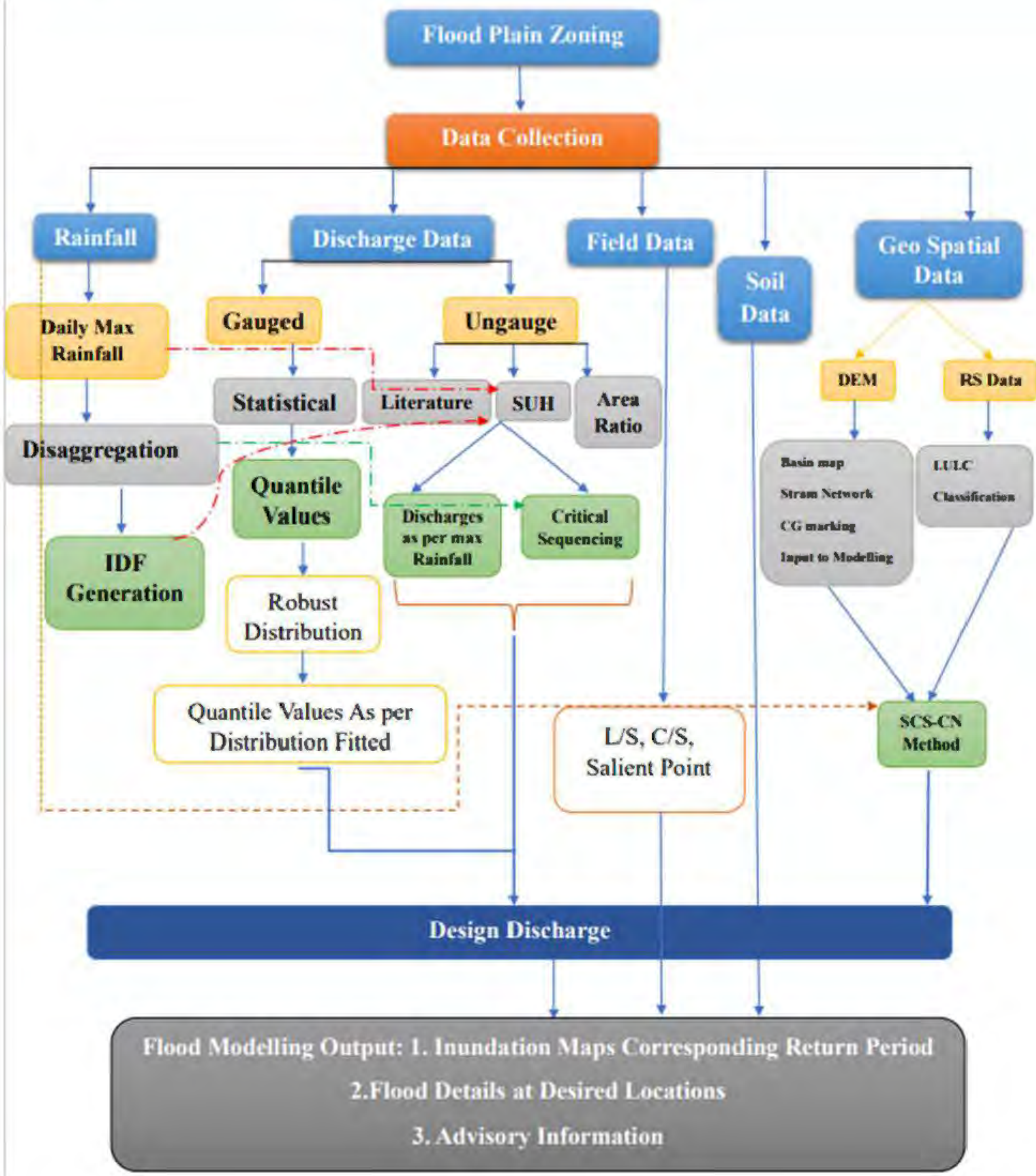


Figure 6. Steps for Design Discharge calculations and subsequent modelling

1.8 Hydraulic Modelling

Hydraulic characteristics like Water Surface Elevation have great importance to study the behavior of Flood Plain zone in response to flow hydrograph. A hydrodynamic model is a tool to describe or represent the motion of water. Before the advent of widely available computer systems, a hydrodynamic model could in fact be a physical model built to scale. However, virtually all hydrodynamic models in use today are computational numerical models. Here, HEC-RAS has been employed to study the hydrodynamics of the river. Hydraulic Models Simulating the fluvial hydraulics of a reach of river, including the channel and over bank, can be performed using a variety of mathematical computer models depending on the type of study and model the user wants to employ.

The United States and many other developed countries utilize hydraulic modelling as a tool to gain an in-depth perspective of hydraulic systems so that they can more effectively develop different mitigation measures at the time of flood, planning for bridges, embankment, levees and dams. Numerical hydraulic modelling involves the use of mathematical equations representing the fundamental physics of how water moves in order to gain a better understanding of the hydraulic system's behavior. It takes into account more than just the topography of the land and the amount of water in the system. Hydraulic modelling takes into account time, land use/land cover, conveyance area, basic physics of water behavior, and water volume to portray the effects a river can have on the surrounding community.

1.9 HECRAS Model

HEC-RAS, a hydraulic model developed by the USACE, is extensively applied in calculating the hydraulic characteristics of rivers. It is an integrated program and uses the following energy equation for calculating water surface profiles.

$$Y_2 + Z_2 + \frac{\alpha_2 V_2^2}{2g} = Y_1 + Z_1 + \frac{\alpha_1 V_1^2}{2g} + h_e$$

Y, Z, V, α, he, and g represent water depth, channel elevation, average velocity, velocity weighting coefficient, energy head loss, and gravitational acceleration; and subscripts 1 and 2, respectively, show cross sections at locations 1 and 2.

This program provides user to input data, data correction, to receive output display and analysis. HEC-RAS model needs details of river cross sections and upstream flow rate. The water depth and mean velocity are calculated for a given cross section using the energy conservation equation HEC-RAS calculates the water levels variation along the channel and the water level values are overlaid on a Digital Elevation Model (DEM) of the area to get the extent and flood depth using GIS. Spatial data like cross section, river reach, stream network, flow paths, and others have been obtained using HEC-Geo-RAS (Arc-GIS extension) and these data then transferred to HEC-RAS.

The U. S. Army Corps of Engineers (USACE) developed HEC-RAS, and it is the latest product of 90 years of hydraulic modelling experience in the United States. Hydraulic modelling development began in the United States after a major flood event on the Mississippi River in 1927 prompting the USACE to begin exploring options to prevent flooding. The Hydrologic Engineering Center (HEC) is a branch of the USACE that was established for the purpose of researching and developing new techniques to deal with the effects of floods (US Army Corps of Engineers). HEC originally began developing physical models to simulate river flow, but as technology progressed, computer programs that could simulate floods were developed. The computer models were then used to predict water surface profiles in response to potential future flood events and better prepare. The latest update on the program, HEC-RAS 5.0.3 includes capabilities to model the hydraulics of a river both one and two dimensionally. The three governing equations of hydraulics are the energy equation, the momentum equation, and the continuity equation. One-dimensional HEC-RAS uses a variation of the energy equation in a procedure called the standard step method to calculate the water surface elevation corresponding to different discharges flowing through the hydraulic system being modelled.

Two dimensional HEC-RAS takes into account mass conservation using the continuity equation and momentum conservation using variations of the momentum equation called the Saint Venant equations, based on Newton’s second law of motion and assuming incompressible flow. The area being two-dimensionally modelled is divided into a grid where each cell is treated as a control volume. Each cell is a polygonal prism with irregular terrain on the bottom, developed from the topography data. The lateral flows are calculated in the x and y direction using the Saint Venant equations, which account for internal and external forces on the fluid, specifically hydrostatic pressure, turbulence, and friction. Then using the continuity equation, the lateral flows in and out of every side of the cell, expressed as velocities, are used to calculate the volume of water in the cell and area of each cell face, as a function of water surface elevation.

Both one-dimensional and two-dimensional models were considered plausible options for the project and desired outcomes because HEC-RAS one dimensional and two-dimensional models are on the Federal Emergency Management Agency's (FEMA) list of nationally accepted hydraulic models for developing flood mitigation measures. The most significant challenge in developing hydraulic models for India is that many of the country's rivers are not gauged and hydrologic/hydraulic data are not widely collected. Moreover, the data that are collected are not easily accessible and not always of the quality preferred for hydraulic model development The Hydrologic Engineering Center – River Analysis System (HEC-RAS), is a hydraulic modelling software widely accepted and used because it has proven to be reliable software and is freely available making it easily used by countries with limited resources (US Army Corps of Engineers). Both one-dimensional and two-dimensional version were chosen for the work described in this report. HEC-RAS 5.0.3, which includes two-dimensional capabilities, was recently released and is expected to become as prominent as the one-dimensional version (Brunner, HEC-RAS River Analysis System, 2D Modelling User's Manual Version 5.0.3).

The general data required to build a hydraulic model are

1.) Surface roughness values typically derived from land use/land cover (LULC) data
2.) A digital elevation model (DEM) derived from topographic data, and computed hydraulic data (discharge and stage).

The surface roughness values can be estimated from satellite imagery if LULC datasets are not available. The DEM forms the conveyance area of the model, and thus, can greatly affect the output of hydraulic models.

1.10 Data Needed for Model Development

There are three main data inputs required to build a model. First is the discharge or flow of water entering and exiting the model. The discharge flowing into or out of the model and the corresponding locations along the outer perimeter of the flow area are referred to as boundary conditions. Second is the Manning's "n" roughness coefficients representing the land's frictional resistance to flow derived from land use data. Third is the topography of the model area in the form of a digital elevation model (DEM), used to derive the irregular terrain on the bottom of the flow area grid.

HEC-RAS models do not account for infiltration or evaporation so those data are not needed. It is preferred to have data for at least two flood events for the hydraulic system of interest, one to calibrate the model and the other to validate the calibrated model. The calibration of a HEC-RAS model entails making sure the geometry and discharge, flow in and out, are correctly representing the true hydraulic system and then adjusting the Manning's "n" values, and maybe other parameters, to fine-tune the simulated water surface elevations (stage) to match observed water surface elevations (measured stage) from the event. The validation of a HEC-RAS model requires observed data for a different event. It entails running the calibrated model using discharge data from the validation event to see if the simulated water surface elevations match up to the observed water surface elevations for that event. If the stages match up, the model is validated, but if they do not, further adjustment to the model is needed. The validation proves the model is trustworthy and accurately portraying the hydraulic system of interest by producing correct results for a different flood event. The topography data are usually best representative of the hydraulic system if it consists of surveyed cross-sections. The surveyed cross-sections are preferably measured at reasonable intervals to capture the general topography and channel bathymetry. The DEM did not capture the general conveyance area because it did not have a well-defined channel.

1.11 Manning's N Value Assignment

The local manning's N values are applied during modeling for different section and mostly it varied depending upon the bed of the river reach in fig. 7 assigned manning's N values for Asan rivers are shown which was further matched by different literatures, Likewise same exercise has been done for other rivers, detailed table also mentioned in Annexure 7

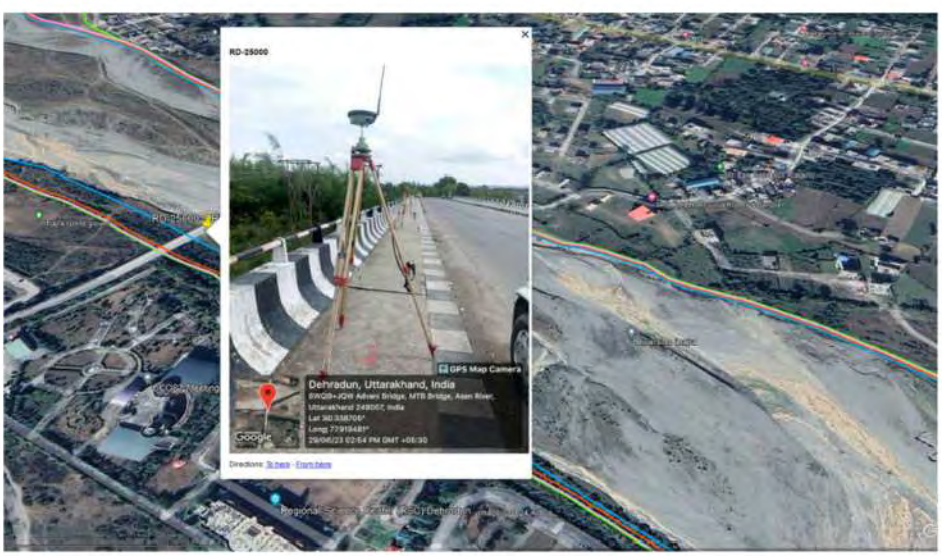


Figure 7. Geotagged photos over the cross section for assigning the Manning's N

Table 3: Mannings N value for Different LU/LC (Asan River)

Reference	Location	River Chainage	Description	Mannings N Value	Reference Photograph
USGS, 1987 & Chow Table	Bisht Gaon	7200	Bed consists of well-rounded boulders; Banks are composed of gravel and boulders, and have tree and brush cover	0.028	
USGS, 1987 & Chow Table	Sudho wala	21400	Bed is composed of sand, gravel, and boulders; Thick undergrowth is along right bank and along the left bank	0.030	
USGS, 1987 & Chow Table	Dkrani	47650	Main Channel is clean, winding, some pools and shoals	0.040	 
USGS, 1987 & Chow Table	Asan Bridge	47600	Bed consists of cobbles and small boulders. Banks are lined with small trees and brush	0.043	

USGS, 1987 & Chow Table	Sabho wala	38550	The bed consists of sand and gravel, and has light cover of brush in some places	0.030	
USGS, 1987 & Chow Table	Sudho wala	25000	The bed consists of sand and gravel, and has light cover of brush in some places	0.03	

2. Geomorphic Description of the Study Reaches: -

The study area under Lot-I belongs to the river Yamuna, Asan and its tributaries like Nimi, Nun, Swarna and Sitala Rao, Jhakhan and Chandrabhaga. The details of these rivers or reaches are given in Table-4

Table 4: Geometric Description of Lot-I Rivers/ Reaches

Sl. No.	Name of the River	Starting Point	End Point Location	Length (km)
1	Yamuna River	Janki Chatti	Up to State border of Uttarakhand	145
2	Asan and its Tributaries (Nimi, Nun, Swarna, Sitla Rao	Bhatta Falls	Confluence with Yamuna For tributaries confluence with Asan	106
3	Jhakhan/Ranikhopri	Ranikhopri Forest Range	Confluence with Song River	28
4	Chandrabhaga	Kudrana Range	Confluence with Ganga River	8

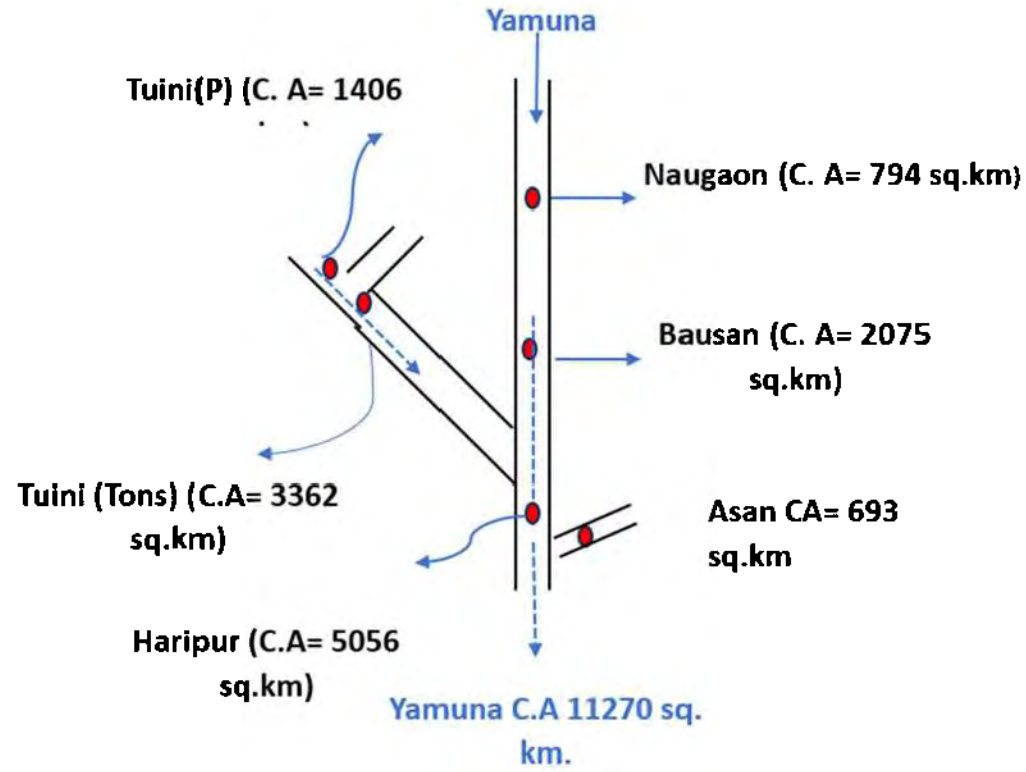


Figure-8 Schematic diagram of Yamuna River reach

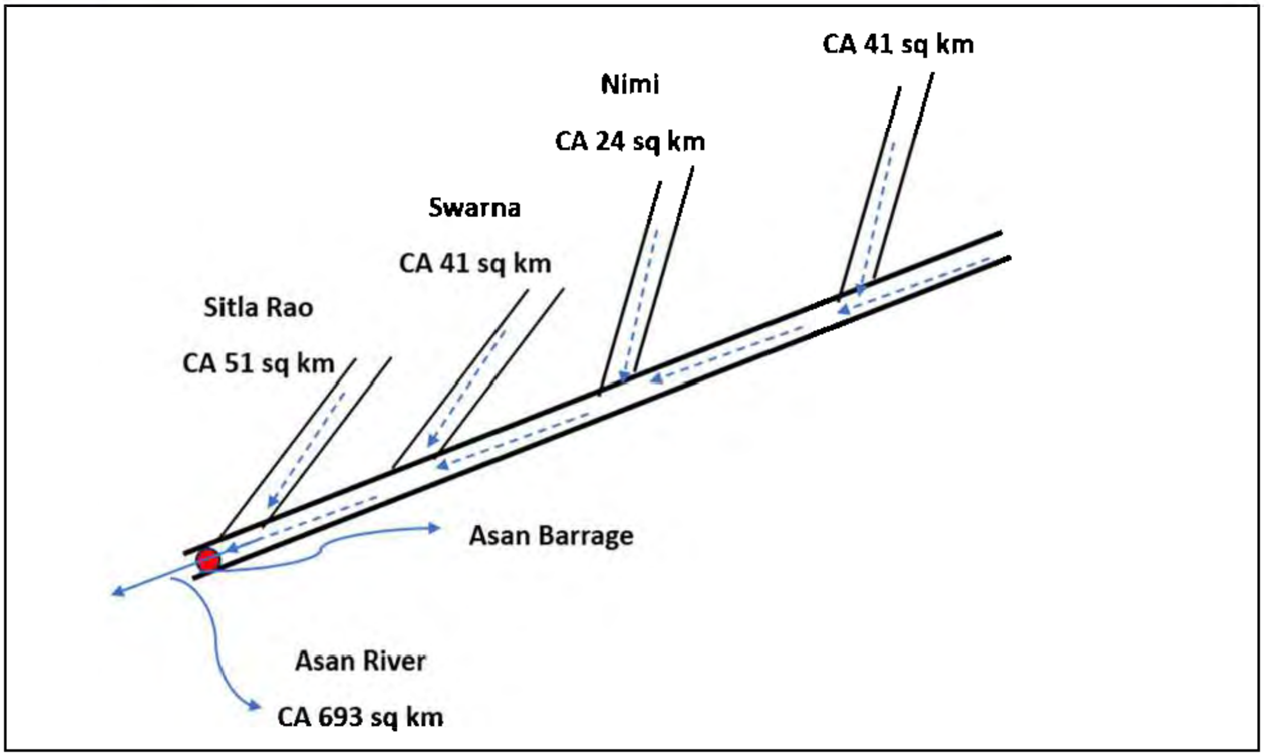


Figure-9 Schematic diagram of Asan River tributaries

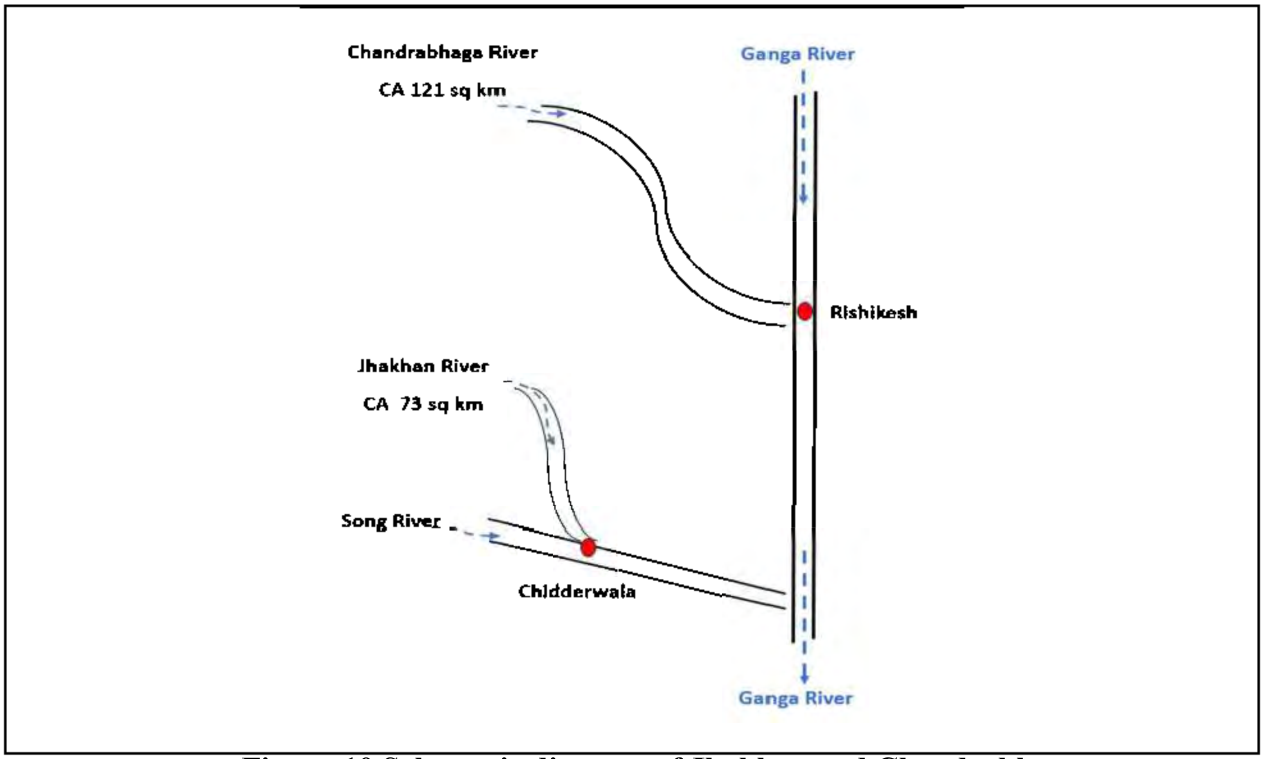


Figure-10 Schematic diagram of Jhakhan and Chandrabhaga

The watersheds receive rain under the influence of southwest monsoon. The northeast monsoon mainly contributes to the rainfall in the area. Most of the precipitation occurs in the monsoon season that causes flooding. Geomorphology of the study area is important for the assessment of floods because flooding is largely based on the topography. Low lying areas near to the channel are frequently flooded and such area is defined as an active floodplain. The floodplain covers channel belt and low-lying areas on either side of the river banks. Furthermore, the channel belt covers the active channel, secondary channel, chute channel and bars. Large floods often cause erosion and deposition in channel belt as well as in adjoining floodplain. Therefore, geomorphic processes (erosion or deposition) perverse footprints of large floods for many years in the virgin reaches of the river. The areas lying, between active floodplain and valley margins are called as older floodplain which gets inundated at high magnitude floods (e.g., 100-year return period floods). The start of the autumn season had a fairly good rainfall with relative humidity of 65 to 70%. At this time, the area was covered with mixed vegetation consisting of grassland, sugarcane, cherry, and rice. Crops were at their mature stage, which led to the variation in both surface roughness and the amount of moisture in the field. The end of the spring season had a meagre rainfall with a relative humidity of less than 50%. The beginning of the summer season had effectively no rainfall and humidity was less than 40%. The spring and summer seasons were dominated by three vegetation classes, namely, grassland, sugarcane, and wheat.

3. River Morphology

The river morphological study helped us to determine the transverse and longitudinal cross-sections for the HEC RAS modelling of the floodplain at 5, 25, 50, and 100-year return periods.

Yamuna River originates approximately at a height of 4,500 m (14,800 ft.) from the Yamunotri Glacier on the western faces of the Bandarpunchh peaks of the Lower Himalaya in Uttarakhand, and merges to Ganga River Basin.

The Tonnes, Yamuna's greatest tributary, has a length of 167 km and holds more water than Yamuna main stream. The longitudinal section for Yamuna River is presented in Fig.11.

Asan River is a tributary of the Yamuna River. It emerges from a Mussoorie ranges to nearby Bhatta falls. The longitudinal section is presented in Fig.11. The river runs approximately for 61 km between from origin to confluence with Yamuna River areas.

The longitudinal sections of rivers. Asan, Swarna, Sitla Rao, Nimi & Nun are shown in Fig.12-16 respectively.

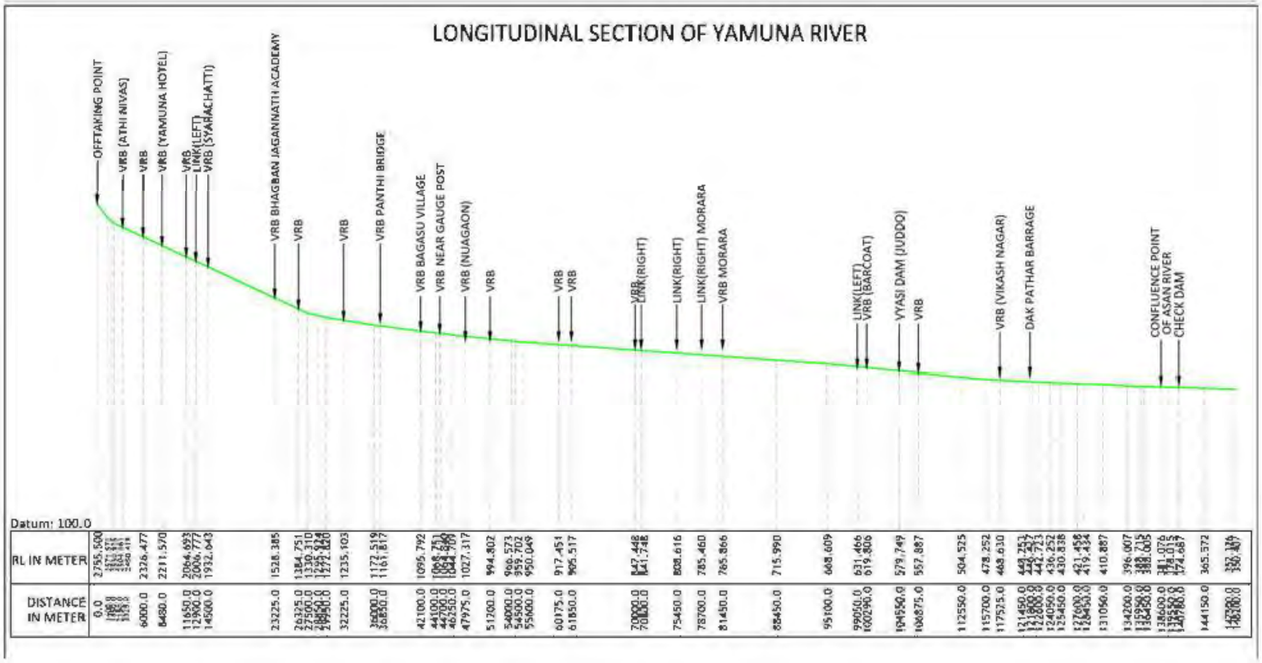


Figure 11: Longitudinal section of Yamuna River

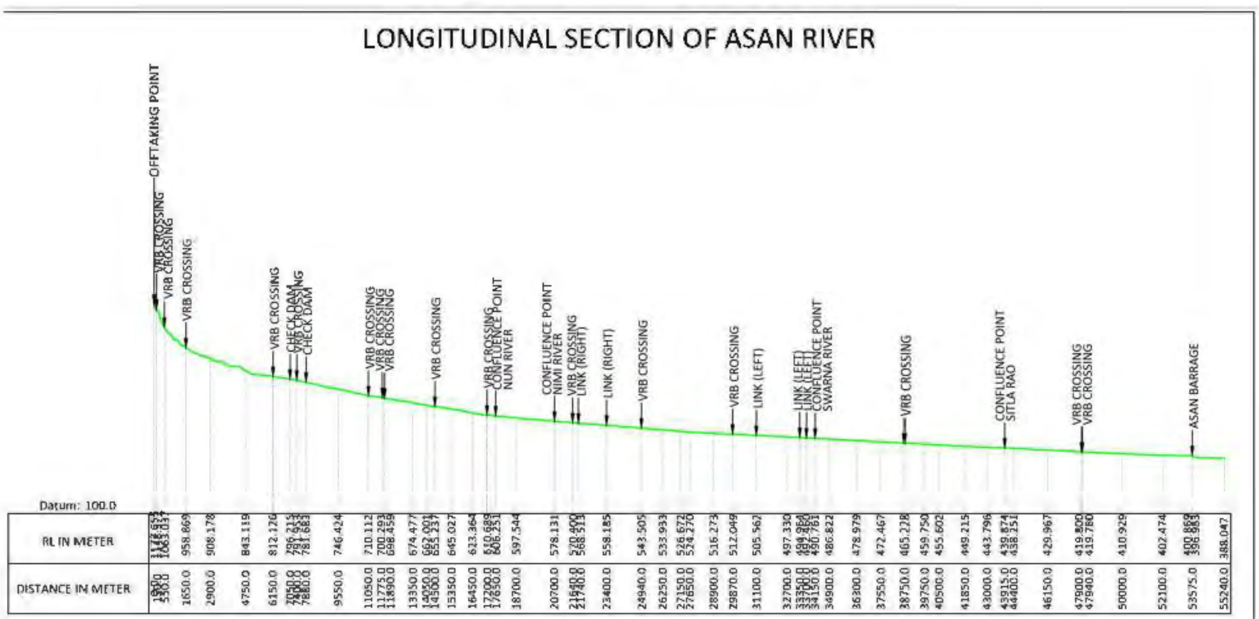


Figure 12: Longitudinal section of Asan River

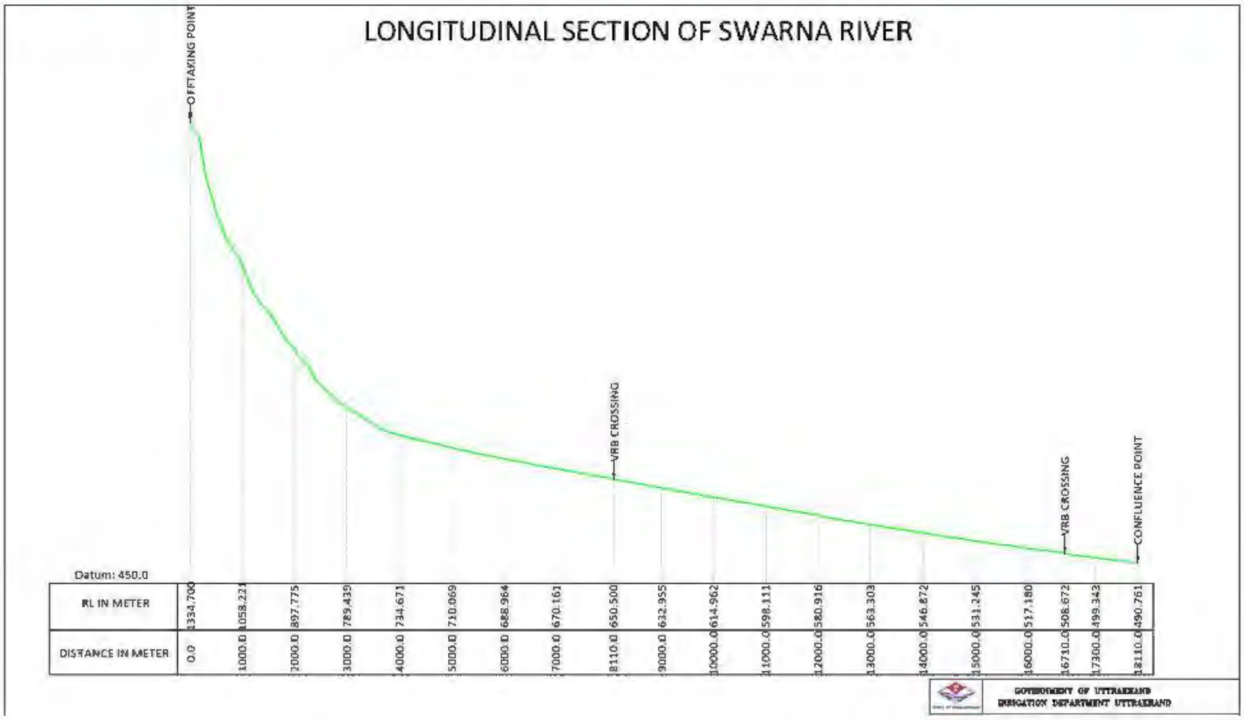


Figure 13: Longitudinal section of Swarna river

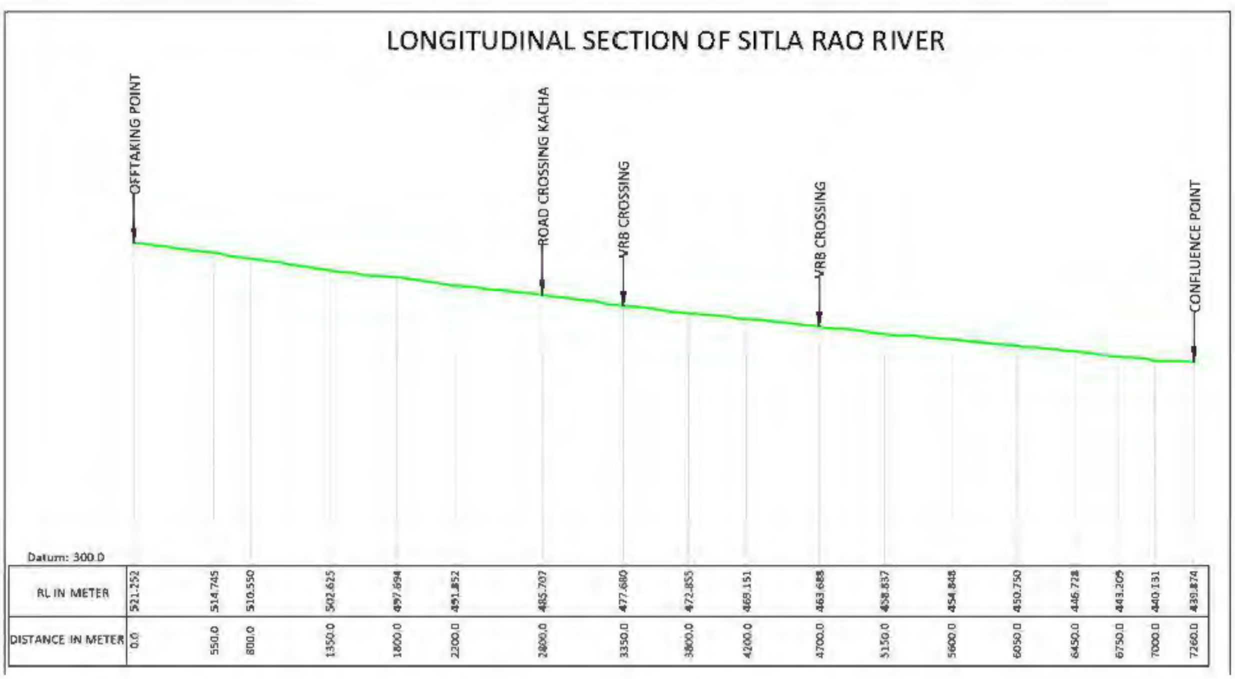


Figure 14: Longitudinal section of Sitala Rao River

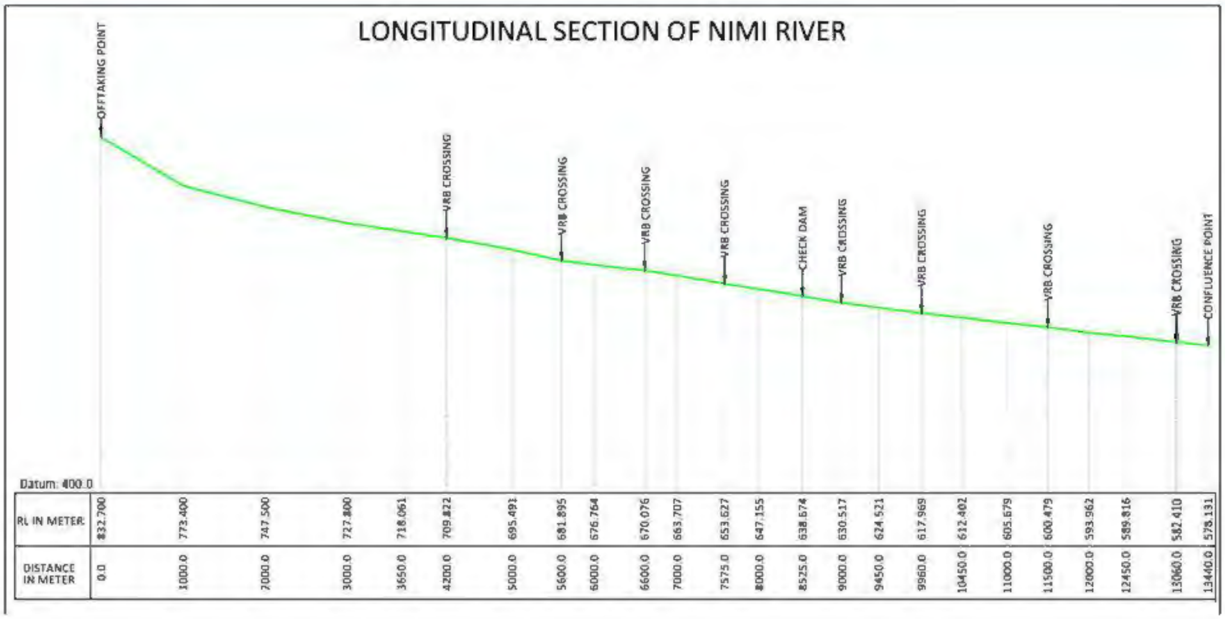


Figure 15: Longitudinal section of Nimi river

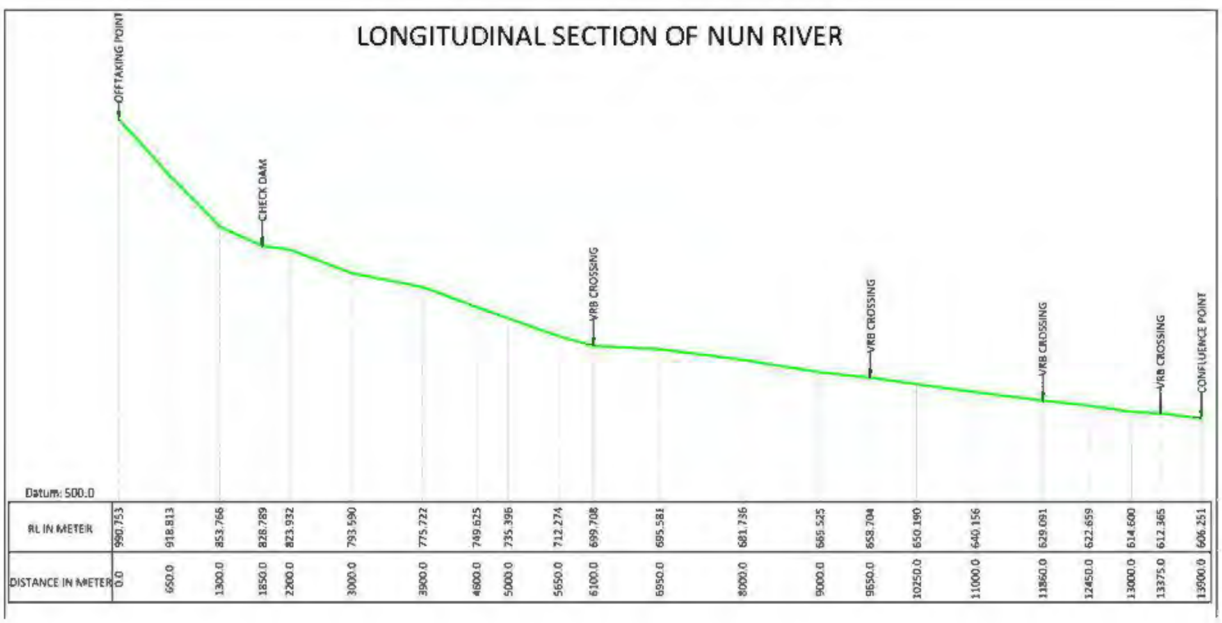


Figure 16: Longitudinal section of Nun River

Jhakhan River The drainage basin of the Jhakhan River is 121 km^2. The Delineated length of river approximately for 36km (28 km for FPZ) between from origin to confluence with Song River. The longitudinal section is presented in Fig.17.

Chandrabhagan River The drainage basin of the Chandrabhaga River is 73 km^2. The Delineated length of river approximately for 24 km (8 km for FPZ) between origin to confluence with Ganga River. The longitudinal section is presented in Fig.18.

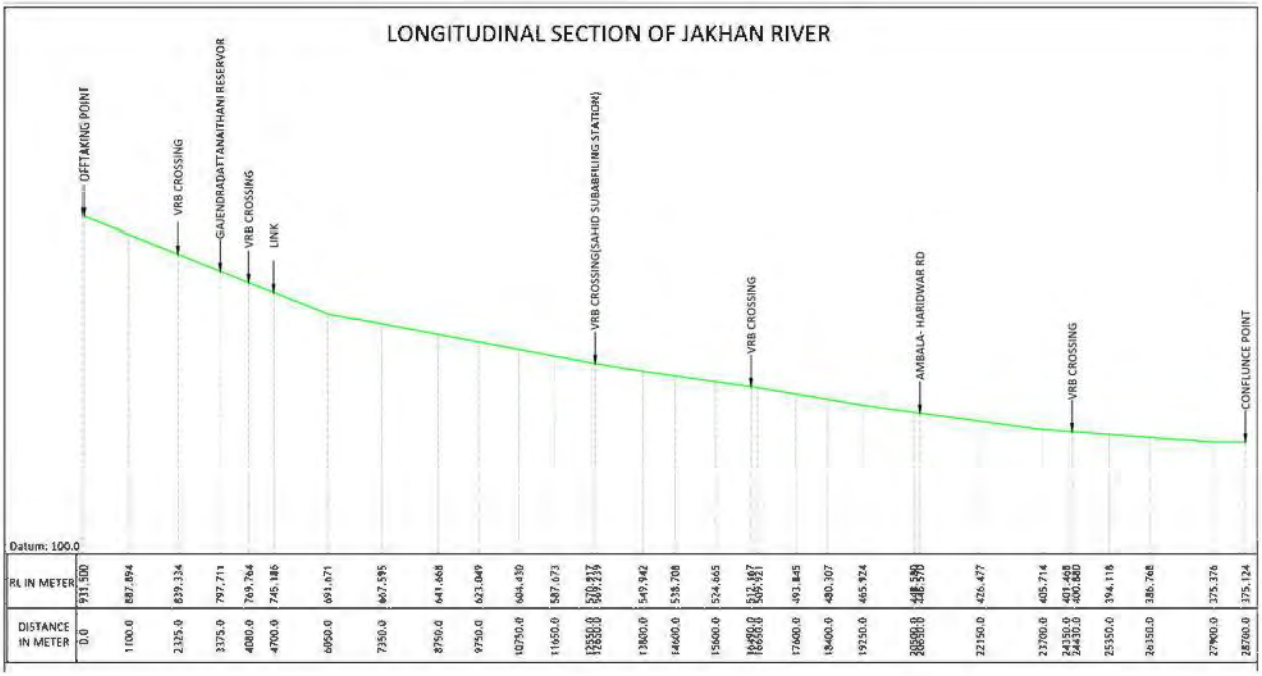


Figure 17: Longitudinal section of Jhakhan river

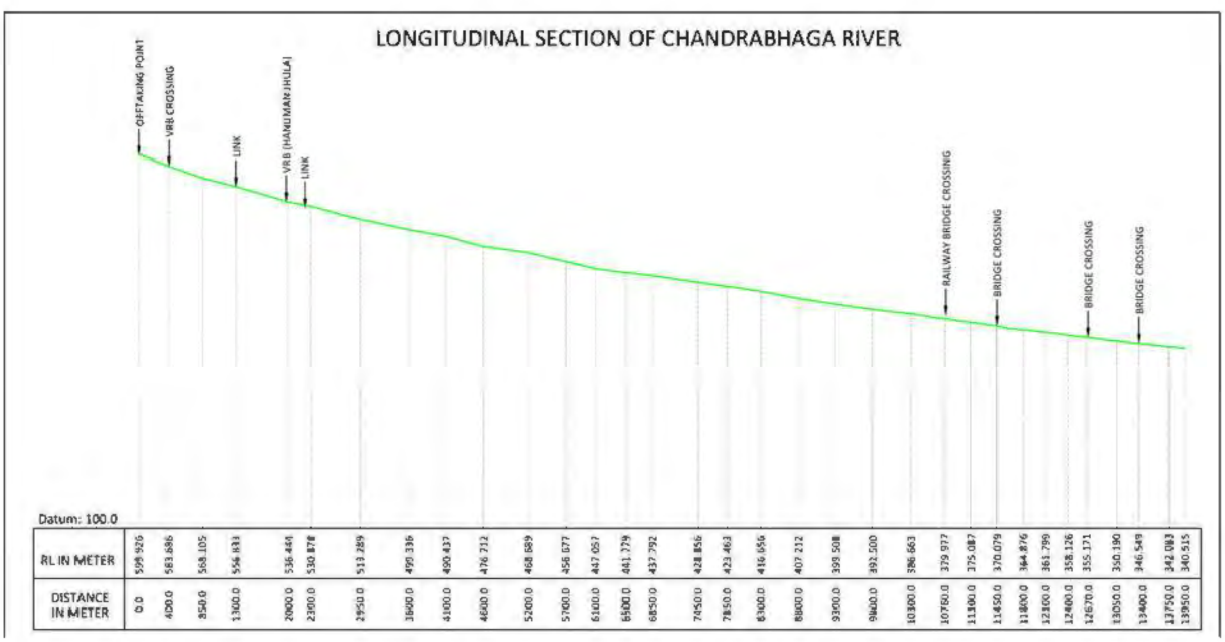


Figure 18: Longitudinal section of Chandrabhaga River

4. Input Data Base

The following data (Table 5) was procured and analyzed:

Table 5: List of input database in the present study.

Sl. No.	Input Data	Source	Remarks
1	Satellite Imagery	NRSC (National Remote Sensing Centre, Hyderabad)	
2	Rainfall Data	IMD (Indian Meteorological Department, Pune)	
3	Topographic Survey Sheet	SOI (Survey of India, Dehradun)	
4	Soil Map	NBSS-LUP (National Bureau of Soil Science & Land Use Planning, Nagpur)	One for Complete State
5	Annual Peak Flow & Associated Gauge Levels	Central Water Commission / Irrigation Department Uttarakhand	
6	Cross-Sections	Total Station, DGPS & Drone Survey	
7	Global Control Points	DGPS (Digital Global Positioning System)	
8	Field based Records	Interaction with Local Residents	For Recent Flood Events

5. Design Flood Estimation

5.1 Flood Frequency Analysis for Yamuna River

Flood frequency analyses are used to predict design floods for sites along a river. The technique involves using observed annual peak flow discharge data to calculate statistical information such as mean values, standard deviations, skewness and recurrence intervals. Subsequently those statistics are applied to the equations of different distributions in order to find the resultant estimated floods with respect to different return periods.

Before starting the hydrological and hydraulic modelling for discharge calculations, flood frequency analysis (FFA) has been carried out for four sites which are Haripur, Naugaon, Tons & Tons Pabar. All these four sites are located in Yamuna basin River stretch in Uttarakhand State; hence the results would give a good indication later for calibrating the H & H model. Daily discharge data is available for 44 years for Tons & Tons Pabar and 42 years data for Naugaon and 39 years data for Haripur and 31 years for Bausan and these data has been used for FFA. To get the instantaneous maximum discharge values from the daily discharge values, annual maximum daily discharge values have been multiplied by a factor of 1.2 i.e.,20% higher than the daily discharge values. The CWC in GUIDELINES FOR PREPARATION OF DPR FOR FLOOD MANAGEMENT WORKS - April 2018, prescribes a factor of 1.15. However, to be on safer side, a factor for 1.2 is considered.

For the purpose of flood estimation, the Normal distributions, Log normal distribution, Log Pearson type III and the Gumbel extreme value distribution seem to have found a wider applicability than many other distributions. Hence in this project, all four distributions have been used for carrying out the flood frequency analysis. The following section explains in brief about all the methodologies used for flood frequency analysis. An outlier analysis of the discharge values has also been carried out to ascertain the consistency of the discharge values using quartile deviation method and the discharge values are found to be within the lower limit and upper limit ranges.

There is a brief discussion of different distributions namely Normal, Log Normal, Log Pearson-III, Gumbel Extreme Value-I which are mentioned below:

5.1.1 Tuini (Tons) Site

The Tons site is located at downstream of Tuini (Pabar) on Tons River with a catchment area of 3362 sq. km. The flow data of this site is available from the year 1980-2023 and which was obtained. As per the frequency analysis conditions number of distributions namely Normal, LN, LPT-III & GEVT-I distribution are attempted respectively.

The tables presented below summaries the maximum discharge observed for 44 years from 1980 – 2023 and calculated discharges for different return period based on different distribution. A time series of the flow data at Tons site is prepared for better understanding of the year wise flow conditions.

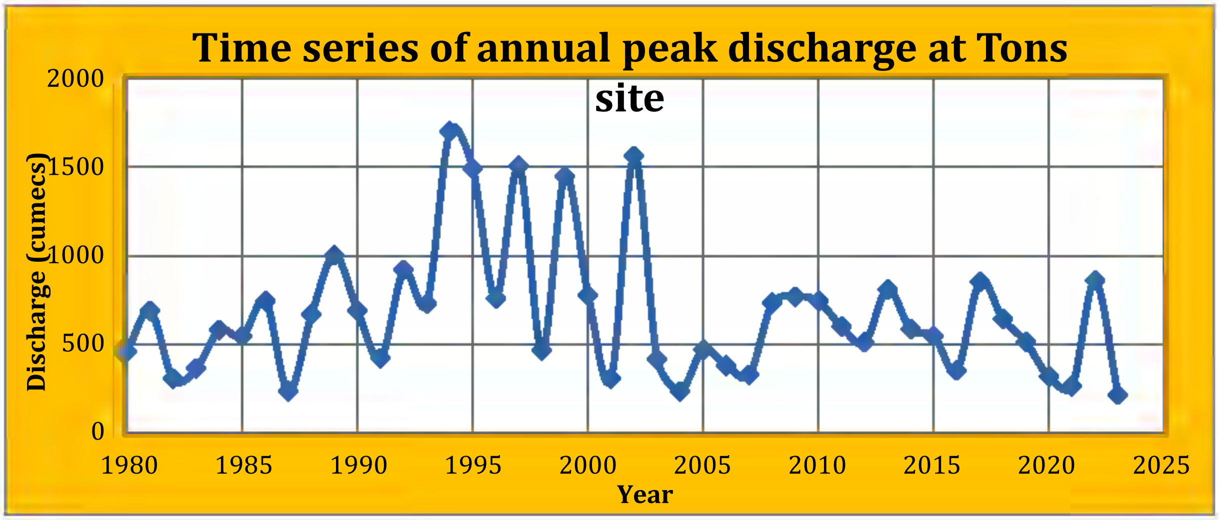


Figure 19: Time series of annual peak discharge at Tuini (Tons) site

It is seen from the time series that, the maximum flow at Tons site remains below 1000 cumecs since year 2003. Earlier during 1994-2002, four peaks have been occurred with magnitude close 1500 cumecs and above. The same data has been used subsequently for further analysis.

The observed data is first arranged in sequence of maximum to minimum and then multiplied with 1.2 (20% increase over the observed) in order to find the instantaneous values. Further the values are ranked as per their magnitude and their probability of exceedance is tested as per Weibull plotting position formula. The return periods of the existing values are also calculated and shown in Table

Table 6 Annual Maximum observed daily and instantaneous discharges at Tuini Tons Site

Year	Observed discharge	Year	Qmax (Cumec) arranged	Instantaneous Max. Q (Cumec)	Ranked values (m)	Probability of exceedance (P)	Return period (Years)
1980	464	1994	1701	2041	1	0.022	45.0
1981	689	2002	1563	1876	2	0.044	22.5
1982	306	1997	1506	1807	3	0.067	15.0
1983	365	1995	1492	1790	4	0.089	11.3
1984	580	1999	1449	1739	5	0.111	9.00
1985	546	1989	1003	1203	6	0.133	7.50
1986	746	1992	920	1104	7	0.156	6.43
1987	236	2022	859	1031	8	0.178	5.63
1988	670	2017	853	1024	9	0.200	5.00
1989	1003	2013	811	973	10	0.222	4.50
1990	692	2000	779	934	11	0.244	4.09
1991	422	2009	770	924	12	0.267	3.75
1992	920	1996	761	914	13	0.289	3.46
1993	731	1986	746	896	14	0.311	3.21
1994	1701	2010	745	894	15	0.333	3.00
1995	1492	2008	734	881	16	0.356	2.81
1996	761	1993	731	877	17	0.378	2.65
1997	1506	1990	692	830	18	0.400	2.50
1998	465	1981	689	826	19	0.422	2.37
1999	1449	1988	670	804	20	0.444	2.25
2000	779	2018	644	772	21	0.467	2.14
2001	308	2011	600	719	22	0.489	2.05
2002	1563	2014	587	704	23	0.511	1.96
2003	415	1984	580	696	24	0.533	1.88
2004	235	2015	548	658	25	0.556	1.80
2005	470	1985	546	655	26	0.578	1.73
2006	381	2019	514	617	27	0.600	1.67
2007	330	2012	512	614	28	0.622	1.61
2008	734	2005	470	564	29	0.644	1.55
2009	770	1998	465	558	30	0.667	1.50
2010	745	1980	464	556	31	0.689	1.45
2011	600	1991	422	507	32	0.711	1.41
2012	512	2003	415	498	33	0.733	1.36
2013	811	2006	381	458	34	0.756	1.32
2014	587	1983	365	438	35	0.778	1.29

2015	548	2016	354	425	36	0.800	1.25
2016	354	2007	330	396	37	0.822	1.22
2017	853	2020	318	382	38	0.844	1.18
2018	644	2001	308	370	39	0.867	1.15
2019	514	1982	306	367	40	0.889	1.13
2020	318	2021	265	318	41	0.911	1.10
2021	265	1987	236	284	42	0.933	1.07
2022	859	2004	235	282	43	0.956	1.05
2023	217	2023	217	261	44	0.978	1.02
			Mean	**806.08**			
			S. D	**449.27**			
			N	**44**			

The mean and standard deviations obtained from the series are 806.08 and 449.27 cumecs respectively basing on which the discharge values for different return periods are obtained and mentioned respectively.

A. Normal Distribution: The normal distribution is applied to the given data series. The frequency factor is obtained from the probability chart corresponding to coefficient of skewness = 0 and different return periods. The calculations of estimated peaks as per normal distributions are mentioned in Table.

Table 7: Discharges at Tons site for different return period from Normal distribution

T	KT	Qmean	S.D.	KT*SD	QT=Qmean+KT*SD
2.33	0	806.08	449.27	0.0	806
5	0.824	806.08	449.27	370.2	1176
10	1.282	806.08	449.27	576.0	1382
25	1.751	806.08	449.27	786.7	1593
50	2.054	806.08	449.27	922.8	1729
100	2.326	806.08	449.27	1045.0	1851
200	2.576	806.08	449.27	1157.3	1963

Note: The values of mean and standard deviation will remain same for all the distribution.

B. Log Normal Distribution:

The original data series is log transformed and its mean and standard deviations are obtained from that log transformed series.

Table 8: Logarithmic average and skewness calculations for Log Normal distribution

Year	Annual flood peak (Cumecs)	Year	Arranged Qmax series (Cumec)	Instantaneous max Q (1.2X Qmax)	Log transformed series Log(Q)
1980	464	1994	1701	2041	3.31
1981	689	2002	1563	1876	3.273
1982	306	1997	1506	1807	3.257
1983	365	1995	1492	1790	3.253
1984	580	1999	1449	1739	3.24
1985	546	1989	1003	1203	3.08
1986	746	1992	920	1104	3.043
1987	236	2022	859	1031	3.013
1988	670	2017	853	1024	3.01
1989	1003	2013	811	973	2.988
1990	692	2000	779	934	2.97
1991	422	2009	770	924	2.966
1992	920	1996	761	914	2.961
1993	731	1986	746	896	2.952
1994	1701	2010	745	894	2.951
1995	1492	2008	734	881	2.945
1996	761	1993	731	877	2.943
1997	1506	1990	692	830	2.919
1998	465	1981	689	826	2.917
1999	1449	1988	670	804	2.905
2000	779	2018	644	772	2.888
2001	308	2011	600	719	2.857
2002	1563	2014	587	704	2.848

2003	415	1984	580	696	2.843
2004	235	2015	548	658	2.818
2005	470	1985	546	655	2.816
2006	381	2019	514	617	2.79
2007	330	2012	512	614	2.788
2008	734	2005	470	564	2.752
2009	770	1998	465	558	2.747
2010	745	1980	464	556	2.745
2011	600	1991	422	507	2.705
2012	512	2003	415	498	2.697
2013	811	2006	381	458	2.661
2014	587	1983	365	438	2.642
2015	548	2016	354	425	2.628
2016	354	2007	330	396	2.598
2017	853	2020	318	382	2.582
2018	644	2001	308	370	2.568
2019	514	1982	306	367	2.565
2020	318	2021	265	318	2.503
2021	265	1987	236	284	2.453
2022	859	2004	235	282	2.45
2023	217	2023	217	261	2.417

Mean= 2.847

St. Dev= 0.229

Coefficient of skewness (Cs) = 0.119

The frequency factors remained same as that of Normal distributions considering coefficient of skewness= 0. The derived forecasted floods are mentioned in Table

Table 9: Discharges for different return periods from Log - Normal distribution

T	KT	Ϭ	KTϬ	Log(X)avg	log(x)avg+KTϬ	XT(Cumec)
2.33	0	0.229	0	2.847	2.847	703
5	0.824	0.229	0.189	2.847	3.036	1086
10	1.282	0.229	0.294	2.847	3.141	1382
25	1.751	0.229	0.401	2.847	3.248	1771
50	2.054	0.229	0.471	2.847	3.318	2078
100	2.326	0.229	0.533	2.847	3.380	2399
200	2.576	0.229	0.591	2.847	3.437	2737

C. Log PT-III Distribution:

The Log Pearson type-III distribution is applied to the data series corresponding to the mean and standard deviation obtained from the log transformed series. The frequency factors for different return periods are obtained as per the coefficient skewness values available in standard frequency factor tables.

The mean, standard deviations and coefficient of skewness obtained for the log transformed series are 2.847, 0.229 and 0.119 respectively basing on which the discharge values for different return periods are obtained and mentioned in Table after retrieving the normal values out of the log transformed series.

Table 10: Discharges at Tuini (Tons) Site at Tons River as per Log PT-III distribution

T (years)	KT	б	KTб	logX avg	log(x)avg+KT б	QT= XT(Cumec)
2.33	–0.017	0.229	-0.004	2.847	2.843	696
5	0.836	0.229	0.192	2.847	3.038	1092
10	1.292	0.229	0.296	2.847	3.143	1390
25	1.785	0.229	0.409	2.847	3.256	1803
50	2.107	0.229	0.483	2.847	3.330	2137
100	2.400	0.229	0.550	2.847	3.397	2494
200	2.670	0.229	0.612	2.847	3.459	2876

D. Gumbel Distribution:

The Gumbel distribution has been applied to the same data series and frequency factors are calculated from the equations. The forecasted floods for different return periods are estimated and mentioned in Table. **Table 11: Discharges at for different return period from GEVT-1**

S. No.	T years	Xavg	KT	S.D.	XT=Xavg+KT*S.D
1	2.33	806.08	0.03	449.27	819
2	5	806.08	0.83	449.27	1179
3	10	806.08	1.48	449.27	1472
4	25	806.08	2.31	449.27	1843
5	50	806.08	2.92	449.27	2117
6	100	806.08	3.53	449.27	2390
7	200	806.08	4.13	449.27	2662

5.1.2 Tuini Pabar Site

The Tuini Pabar site is located at upstream of Tons on Tuini River with a catchment area of 1406 sq. km. The flow data of this site is available from the year 1980-2023 and which was obtained. As per the frequency analysis conditions number of distributions namely Normal, LN, LPT-III & GEVT-I distribution are attempted respectively.

The tables presented below summaries the maximum discharge observed for 44 years from 1980 – 2023 and calculated discharges for different return period based on different distribution. A time series of the flow data at Tons site is prepared for better understanding of the year wise flow conditions.

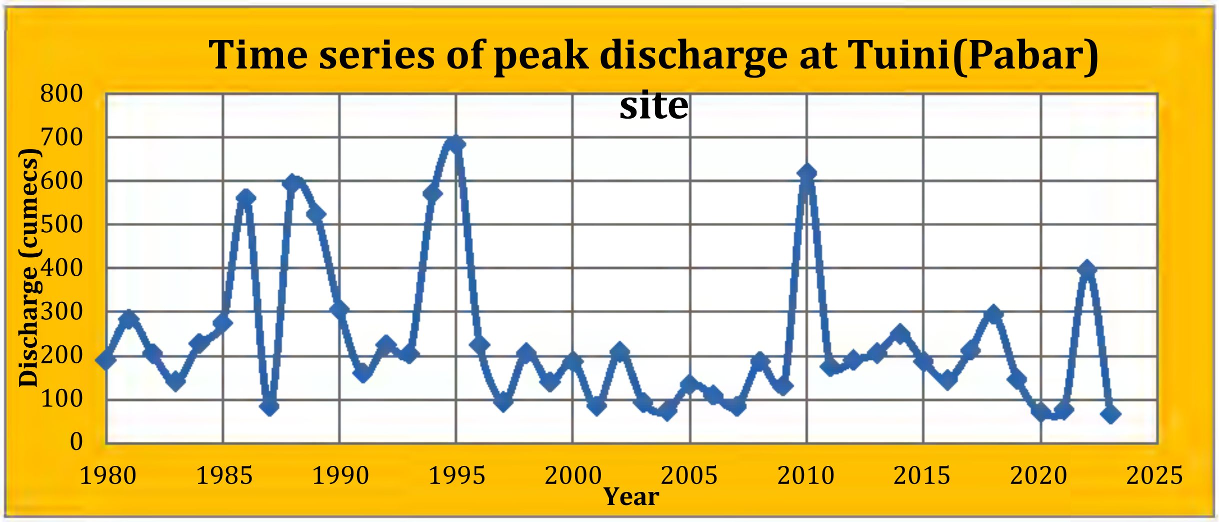


Fig. 20: Time series of annual peak discharge at Tuini Pabar site

It is seen from the time series that, the maximum flow at Tuini (Pabar) site remain below 300 cumecs in most of the time whereas four peaks have been occurred with magnitude more than 500 cumecs and above. The same data has been used subsequently for further analysis.

The observed data is first arranged in sequence of maximum to minimum and then multiplied with 1.2 (20% increase over the observed) in order to find the instantaneous values. Further the values are ranked as per their magnitude and their probability of exceedance is tested as per Weibull plotting position formula. The return periods of the existing values are also calculated and shown in Table.

The tables presented below summarize the maximum discharge observed for 44 years from 1980 – 2023 and calculated discharges for different return period based on different distribution. The observed data is first arranged in sequence of maximum to minimum and then multiplied with 1.2 (20% increase over the observed) in order to find the instantaneous values. Further the values are ranked as per their magnitude and their probability of exceedance is tested as per Weibull plotting position formula. The return periods of the existing values are also calculated and shown in **Table 12**

Table 12: AFS return period

Year	Observed discharge	Year	Qmax (Cumec) arranged	Instantaneous Max. Q (Cumec)	Ranked values (m)	Probability of exceedance (P)	Return period (Years)
1980	191	1995	685	821	1	0.02	45
1981	284	2010	618	742	2	0.04	22.5
1982	205	1988	593	711	3	0.07	15
1983	142	1994	571	685	4	0.09	11.25
1984	227	1986	560	672	5	0.11	9.00
1985	275	1989	525	630	6	0.13	7.50
1986	560	2022	397	476	7	0.16	6.43
1987	85	1990	306	367	8	0.18	5.63
1988	593	2018	295	354	9	0.20	5.00
1989	525	1981	284	341	10	0.22	4.50
1990	306	1985	275	330	11	0.24	4.09
1991	160	2014	250	300	12	0.27	3.75
1992	225	1984	227	273	13	0.29	3.46
1993	205	1996	226	271	14	0.31	3.21
1994	571	1992	225	271	15	0.33	3.00
1995	685	2017	213	255	16	0.36	2.81
1996	226	2002	209	251	17	0.38	2.65
1997	95	2013	206	247	18	0.40	2.50
1998	206	1998	206	247	19	0.42	2.37
1999	139	1993	205	246	20	0.44	2.25
2000	187	1982	205	246	21	0.47	2.14
2001	85	2012	191	229	22	0.49	2.05
2002	209	1980	191	229	23	0.51	1.96
2003	94	2015	187	224	24	0.53	1.88
2004	74	2008	187	224	25	0.56	1.80
2005	135	2000	187	224	26	0.58	1.73
2006	110	2011	176	211	27	0.60	1.67
2007	85	1991	160	192	28	0.62	1.61
2008	187	2019	147	177	29	0.64	1.55

2009	131	2016	145	174	30	0.67	1.50
2010	618	1983	142	170	31	0.69	1.45
2011	176	1999	139	167	32	0.71	1.41
2012	191	2005	135	161	33	0.73	1.36
2013	206	2009	131	158	34	0.76	1.32
2014	250	2006	110	132	35	0.78	1.29
2015	187	1997	95	114	36	0.80	1.25
2016	145	2003	94	112	37	0.82	1.22
2017	213	2007	85	102	38	0.84	1.18
2018	295	2001	85	102	39	0.87	1.15
2019	147	1987	85	102	40	0.89	1.13
2020	71	2021	77	93	41	0.91	1.10
2021	77	2004	74	89	42	0.93	1.07
2022	397	2020	71	85	43	0.96	1.05
2023	67	2023	67	80	44	0.98	1.02
			Avg	**279.27**			
			S. D	**194.16**			

The mean and standard deviations obtained from the series are 279.27 and 194.16 cumecs respectively basing on which the discharge values for different return periods are obtained and mentioned in Table.

A) **Normal Distribution:** The normal distribution is applied to the given data series. The frequency factor is obtained from the probability chart corresponding to coefficient of skewness = 0 and different return periods. The calculations of estimated peaks as per normal distributions are mentioned in Table.

Table 13: Discharges at Tons Pabar site for different return period from Normal distribution

T	KT	Qmean	S.D.	KT*SD	QT=Qmean+KT*SD
2.33	0	279.27	194.16	0	279
5	0.824	279.27	194.16	159.99	439
10	1.282	279.27	194.16	248.91	528
25	1.751	279.27	194.16	339.98	619
50	2.054	279.27	194.16	398.81	678
100	2.326	279.27	194.16	451.62	731
200	2.576	279.27	194.16	500.16	779

Note: The values of mean and standard deviation will remain same for all the distribution.

B. Log Normal Distribution: The original data series is log transformed and its mean and standard deviations are obtained from that log transformed series.

Table 14: Logarithmic average and skewness calculations for Log Normal distribution

Year	Qmax (Cumec)(X)	Instantaneous max Q(Multiplied by 1.2)	Z= Log(X)
1995	685	821	2.915
2010	618	742	2.870
1988	593	711	2.852
1994	571	685	2.836
1986	560	672	2.827
1989	525	630	2.799
2022	397	476	2.678
1990	306	367	2.565
2018	295	354	2.548
1981	284	341	2.533
1985	275	330	2.518
2014	250	300	2.477
1984	227	273	2.436
1996	226	271	2.433
1992	225	271	2.432
2017	213	255	2.407
2002	209	251	2.400
2013	206	247	2.393
1998	206	247	2.392
1993	205	246	2.391
1982	205	246	2.391
2012	191	229	2.361
1980	191	229	2.360
2015	187	224	2.351
2008	187	224	2.351
2000	187	224	2.350
2011	176	211	2.325
1991	160	192	2.283
2019	147	177	2.248
2016	145	174	2.241
1983	142	170	2.231
1999	139	167	2.224
2005	135	161	2.208
2009	131	158	2.198

2006	110	132	2.122
1997	95	114	2.057
2003	94	112	2.051
2007	85	102	2.009
2001	85	102	2.009
1987	85	102	2.007
2021	77	93	1.966
2004	74	89	1.950
2020	71	85	1.931
2023	67	80	1.902
		Log (Xavg)	**2.360**
		S.D.	**0.271**
		N	**44**

Mean= 2.36

St. Dev= 0.271

Coefficient of skewness (Cs) = 0.313

The frequency factors remained same as that of Normal distributions considering coefficient of skewness= 0. The derived forecasted floods are mentioned in Table.

Table 15: Discharges for different return periods from Log - Normal distribution

T	KT	б	KTб	Log(X)avg	log(x)avg+KTб	X_T(Cumec)
2.33	0	0.271	0	2.360	2.360	229
5	0.824	0.271	0.224	2.360	2.583	383
10	1.282	0.271	0.348	2.360	2.708	510
25	1.751	0.271	0.475	2.360	2.835	684
50	2.054	0.271	0.558	2.360	2.917	827
100	2.326	0.271	0.631	2.360	2.991	980
200	2.576	0.271	0.699	2.360	3.059	1146

C. Log PT-III Distribution:

The Log Pearson type-III distribution is applied to the data series corresponding to the mean and standard deviation obtained from the log transformed series. The frequency factors for different return periods are obtained as per the coefficient skewness values available in standard frequency factor tables.

The mean, standard deviations and coefficient of skewness obtained for the log transformed series are 2.36, 0.271 and 0.313 respectively basing on which the discharge values for different return periods are obtained and mentioned in Table after retrieving the normal values out of the log transformed series.

Table 16: Discharges at Tons Site at Tons Pabar River as per LPT-III

T (years)	K_T	б	K_Tб	Log(Xavg)	log(x)avg+K_T б	Q_T= X_T(Cumec)
2.33	–0.050	0.271	-0.014	2.360	2.346	222
5	0.824	0.271	0.224	2.360	2.583	383
10	1.309	0.271	0.355	2.360	2.715	519
25	1.849	0.271	0.502	2.360	2.862	727
50	2.211	0.271	0.600	2.360	2.960	912
100	2.544	0.271	0.691	2.360	3.050	1123
200	2.856	0.271	0.775	2.360	3.135	1365

D. Gumbel Distribution:

The Gumbel distribution has been applied to the same data series and frequency factors are calculated from the equations. The forecasted floods for different return periods are estimated and mentioned in Table.

Table 17: Discharges at for different return period from GEVT-1

T (years)	Xavg	KT	S.D.	XT=Xavg+KT*S.D.
2.33	279.27	0.03	194.16	285
5	279.27	0.83	194.16	440
10	279.27	1.48	194.16	567
25	279.27	2.31	194.16	727
50	279.27	2.92	194.16	846
100	279.27	3.53	194.16	964
200	279.27	4.13	194.16	1081

5.1.3 Haripur Site

The Haripur site is located at downstream of Tons on Tuini River with a catchment area of 5056 sq. Km just before its confluence with river Yamuna. The flow data of this site is available from the year 1985-2023 and which was obtained. As per the frequency analysis conditions number of distributions namely Normal, LN, LPT-III & GEVT-I distribution are attempted respectively.

The tables presented below summaries the maximum discharge observed for 39 years from 1985 – 2023 and calculated discharges for different return period based on different distribution. A time series of the flow data at Haripur site is prepared for better understanding of the year wise flow conditions.

It is seen from the time series that, the maximum flow at Haripur site remains below 2000 cumecs in most of the time where as it crossed thrice 2000 cumecs and above including this year. The same data has been used subsequently for further analysis.

The observed data is first arranged in sequence of maximum to minimum and then multiplied with 1.2 (20% increase over the observed) in order to find the instantaneous values. Further the values are ranked as per their magnitude and their probability of exceedance is tested as per Weibull plotting position formula. The return periods of the existing values are also calculated and shown in Table.

The Tables presented below summaries the maximum discharge observed for 39 years from 1985 – 2023 and calculated discharges for different return period based on different distribution. The observed data is first arranged in sequence of maximum to minimum and then multiplied with 1.2 (20% increase over the observed) in order to find the instantaneous values. Further the values are ranked as per their magnitude and their probability of exceedance is tested as per Weibull plotting position formula. The return periods of the existing values are also calculated and shown in Table.

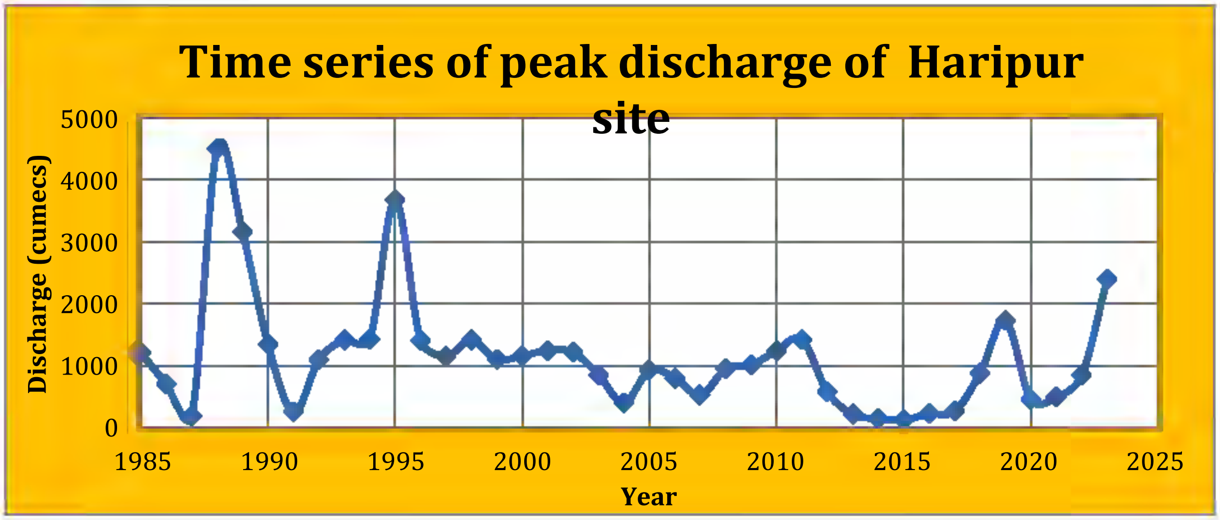


Figure 21. Time series of annual peak discharge at Haripur site

Table 18: Annual Maximum observed daily and instantaneous discharges at Haripur Site

Year	Observed discharge	Year	Qmax (Cumec) arranged	Instantaneous Max. Q (Cumec)	Ranked values (m)	Probability of exceedence (P)	Return period (Years)
1985	1206.01	1988	4497.88	5397.5	1	0.025	40.0
1986	703.91	1995	3676.53	4411.8	2	0.05	20.0
1987	188.2	1989	3153.54	3784.2	3	0.075	13.3
1988	4497.88	2023	2389.143	2867.0	4	0.1	10.0
1989	3153.54	2019	1726.716	2072.1	5	0.125	8.0
1990	1341.56	2011	1422.32	1706.8	6	0.15	6.7
1991	250.84	1994	1419.41	1703.3	7	0.175	5.7
1992	1091.91	1998	1414.9	1697.9	8	0.2	5.0
1993	1410.63	1993	1410.63	1692.8	9	0.225	4.4
1994	1419.41	1996	1408.13	1689.8	10	0.25	4.0
1995	3676.53	1990	1341.56	1609.9	11	0.275	3.6
1996	1408.13	2001	1241.84	1490.2	12	0.3	3.3
1997	1154.64	2010	1241.66	1490.0	13	0.325	3.1
1998	1414.9	2002	1218.52	1462.2	14	0.35	2.9

1999	1099.31	1985	1206.01	1447.2	15	0.375	2.7
2000	1162.62	2000	1162.62	1395.1	16	0.4	2.5
2001	1241.84	1997	1154.64	1385.6	17	0.425	2.4
2002	1218.52	1999	1099.31	1319.2	18	0.45	2.2
2003	847.66	1992	1091.91	1310.3	19	0.475	2.1
2004	398.68	2009	1013.41	1216.1	20	0.5	2.0
2005	923.09	2008	948.22	1137.9	21	0.525	1.9
2006	798.34	2005	923.09	1107.7	22	0.55	1.8
2007	525.73	2018	877.04	1052.4	23	0.575	1.7
2008	948.22	2022	848.42	1018.1	24	0.6	1.7
2009	1013.41	2003	847.66	1017.2	25	0.625	1.6
2010	1241.66	2006	798.34	958.0	26	0.65	1.5
2011	1422.32	1986	703.91	844.7	27	0.675	1.5
2012	579.16	2012	579.16	695.0	28	0.7	1.4
2013	216.83	2007	525.73	630.9	29	0.725	1.4
2014	144.04	2021	492.595	591.1	30	0.75	1.3
2015	126.6	2020	451.542	541.9	31	0.775	1.3
2016	225.67	2004	398.68	478.4	32	0.8	1.3
2017	266.83	2017	266.83	320.2	33	0.825	1.2
2018	877.04	1991	250.84	301.0	34	0.85	1.2
2019	1726.716	2016	225.67	270.8	35	0.875	1.1
2020	451.542	2013	216.83	260.2	36	0.9	1.1
2021	492.595	1987	188.2	225.8	37	0.925	1.1
2022	848.42	2014	144.04	172.8	38	0.95	1.1
2023	2389.143	2015	126.6	151.9	39	0.975	1.0
			Avg	**1357.0**			
			S. D	**1119.4**			
			N	**39**			

The mean and standard deviations obtained from the series are 1357.0 and 1119.4 cumecs respectively basing on which the discharge values for different return periods are obtained and mentioned in Table.

A) Normal Distribution: The normal distribution is applied to the given data series. The frequency factor is obtained from the probability chart corresponding to coefficient of skewness = 0 and different return periods. The calculations of estimated peaks as per normal distributions are mentioned in Table

Table 19: Return Period flood values at Haripur Site

T	KT	Qmean	S.D.	KT*SD	QT=Qmean+KT*SD
2.33	0	1357.05	1119.41	0	1357
5	0.824	1357.05	1119.41	922.39	2279
10	1.282	1357.05	1119.41	1435.08	2792
25	1.751	1357.05	1119.41	1960.08	3317
50	2.054	1357.05	1119.41	2299.26	3656
100	2.326	1357.05	1119.41	2603.74	3961
200	2.576	1357.05	1119.41	2883.59	4241

B. Log-Normal Distribution

Table 20: Discharges at Haripur Site at Yamuna River for different return period from Log - Normal distribution

T	KT	б	KTб	Log(X)avg	log(x)avg+KT б	XT(Cumec)
2.33	0	0.214	0	3.174	3.174	1494
5	0.824	0.214	0.177	3.174	3.351	2244
10	1.282	0.214	0.275	3.174	3.449	2813
25	1.751	0.214	0.375	3.174	3.550	3546
50	2.054	0.214	0.440	3.174	3.615	4118
100	2.326	0.214	0.499	3.174	3.673	4710
200	2.576	0.214	0.552	3.174	3.727	5329

C. Gumbel Extreme Value Type 1 Distribution (GEVT – 1)

The observed data is first arranged in sequence of maximum to minimum and then multiplied with 1.2 (20% increase over the observed) in order to find the instantaneous values. Further the values are ranked as per their magnitude and their probability of exceedance is tested as per Weibull plotting position formula. The return periods of the existing values are also calculated and shown in Table.

The mean and standard deviations obtained from the series are 1177.08 and 818.398 cumecs respectively basing on which the discharge values for different return periods are obtained and mentioned in Table

Table 21: Discharges at Haripur site for different return period from Gumbel distribution

T years	Xavg	KT	S.D.	XT=Xavg+KT*S.D.
2.33	1357.05	0.04	1119.41	1401
5	1357.05	0.87	1119.41	2331
10	1357.05	1.55	1119.41	3089
25	1357.05	2.40	1119.41	4046
50	1357.05	3.04	1119.41	4757
100	1357.05	3.67	1119.41	5462
200	1357.05	4.29	1119.41	6164

Note: Value of σ & $\bar{Q}$ will remain same for normal distribution and GEVT-I which is calculated by below mentioned formula.

$$\sigma = \sqrt{\frac{\sum (x-\bar{x})^2}{n}}$$

D. Log Pearson Type-III

The tables presented below summarize the maximum discharge observed for 39 years from 1985-2023 and calculated discharges for different return period based on the LPT-III distribution.

Table 22: Logarithmic average and skewness calculations for LPT-III distribution

Year	Qmax (Cumec)(X)	Instantaneous max Q (Multiplied by 1.2)	Z= Log(X)
1988	4498	5397	3.732189
1995	3677	4412	3.644619
1989	3154	3784	3.57798
2023	2389	2867	3.457423
2019	1727	2072	3.316402
2011	1422	1707	3.232179
1994	1419	1703	3.231289
1998	1415	1698	3.229907
1993	1411	1693	3.228594
1996	1408	1690	3.227824
1990	1342	1610	3.206791
2001	1242	1490	3.173247
2010	1242	1490	3.173184
2002	1219	1462	3.165014
1985	1206	1447	3.160532
2000	1163	1395	3.144619
1997	1155	1386	3.141628
1999	1099	1319	3.120301
1992	1092	1310	3.117368
2009	1013	1216	3.084966
2008	948	1138	3.05609
2005	923	1108	3.044425
2018	877	1052	3.022201
2022	848	1018	3.007792
2003	848	1017	3.007403
2006	798	958	2.981369

1986	704	845	2.926698
2012	579	695	2.84198
2007	526	631	2.799944
2021	493	591	2.771671
2020	452	542	2.733879
2004	399	478	2.679806
2017	267	320	2.505416
1991	251	301	2.478578
2016	226	271	2.432655
2013	217	260	2.415301
1987	188	226	2.353801
2014	144	173	2.237664
2015	127	152	2.181615
		Log(X)avg	**2.996**
		S.D.	**0.371**
		N	**39**

Mean= 2.996

St. Dev= 0.371

Coefficient of skewness (Cs) = -0.792

The mean, standard deviations and coefficient of skewness obtained for the log transformed series are 2.959, 0.351 and -0.792 respectively basing on which the discharge values for different return periods are obtained and mentioned in Table after retrieving the normal values out of the log transformed series.

Table 23: Discharges at Haripur Site at Tons River

T (years)	KT	σ	KTσ	logX avg	log(x)avg+KT σ	QT= XT(Cumec)
2.33	0.083	0.371	0.031	2.996	3.027	1064
5	0.856	0.371	0.318	2.996	3.314	2060
10	1.216	0.371	0.452	2.996	3.448	2803
25	1.567	0.371	0.582	2.996	3.578	3784
50	1.777	0.371	0.660	2.996	3.656	4529
100	1.955	0.371	0.726	2.996	3.722	5274
200	2.108	0.371	0.783	2.996	3.779	6011

5.1.4 Naugaon Site:

The Naugaon site is located at Yamuna River with a catchment area of 794 sq. km. The flow data of this site is available from the year 1982-2023 and which was obtained. As per the frequency analysis conditions number of distributions namely Normal, LN, LPT-III & GEVT-I distribution are attempted respectively.

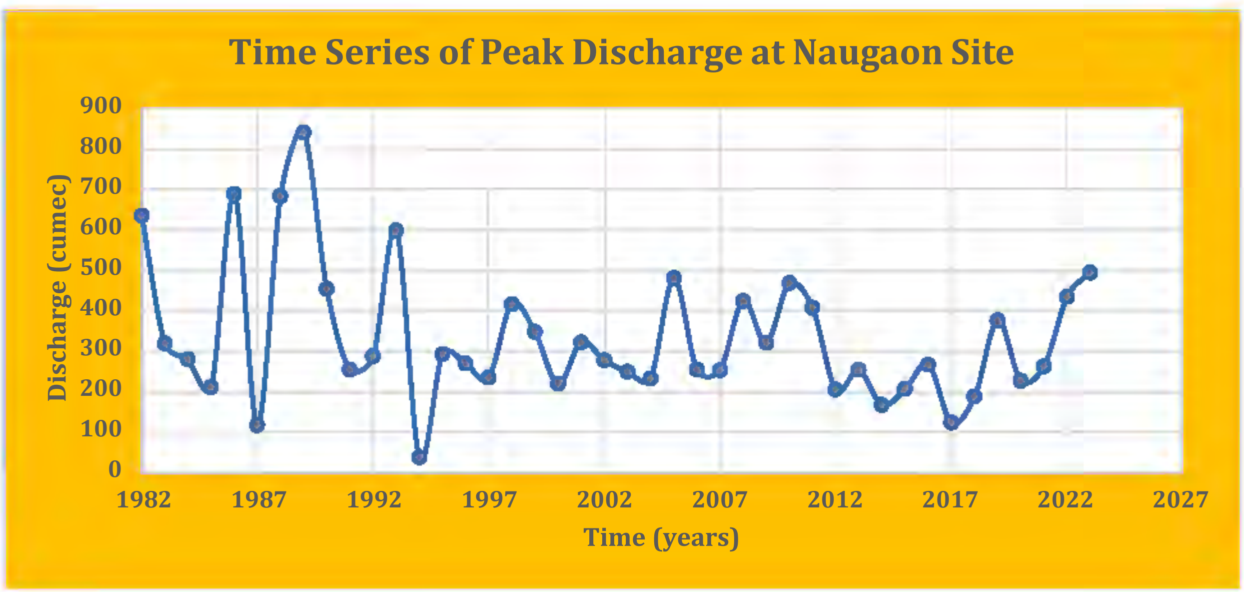


Figure 22. Time series of annual peak discharge at Naugaon site

Table 24: Annual Maximum observed daily and instantaneous discharges at Naugaon Site

Year	Observed Discharge	Year	Qmax (Cumec) Arranged	Instantaneous Max. Q (Cumec)	Rank(m)	PROBABILITY (P)	Tp (Years)
1982	635	1989	841	1009	1	0.02	43.0
1983	320	1986	689	827	2	0.05	21.5
1984	281	1988	684	820	3	0.07	14.3
1985	212	1982	635	762	4	0.09	10.8
1986	689	1993	599	719	5	0.12	8.60
1987	119	2023	495	594	6	0.14	7.17
1988	684	2005	481	577	7	0.16	6.14
1989	841	2010	469	563	8	0.19	5.38
1990	454	1990	454	545	9	0.21	4.78
1991	255	2022	435	522	10	0.23	4.30
1992	289	2008	425	510	11	0.26	3.91
1993	599	1998	417	500	12	0.28	3.58
1994	39	2011	408	489	13	0.30	3.31
1995	294	2019	377	453	14	0.33	3.07
1996	271	1999	349	419	15	0.35	2.87
1997	236	2001	323	388	16	0.37	2.69
1998	417	2009	322	386	17	0.40	2.53
1999	349	1983	320	384	18	0.42	2.39
2000	221	1995	294	353	19	0.44	2.26
2001	323	1992	289	347	20	0.47	2.15
2002	279	1984	281	337	21	0.49	2.05
2003	250	2002	279	335	22	0.51	1.95
2004	234	1996	271	326	23	0.53	1.87
2005	481	2016	268	322	24	0.56	1.79
2006	256	2021	264	317	25	0.58	1.72
2007	254	2006	256	307	26	0.60	1.65
2008	425	1991	255	306	27	0.63	1.59
2009	322	2013	255	306	28	0.65	1.54
2010	469	2007	254	305	29	0.67	1.48
2011	408	2003	250	300	30	0.70	1.43
2012	207	1997	236	284	31	0.72	1.39
2013	255	2004	234	281	32	0.74	1.34
2014	169	2020	228	273	33	0.77	1.30
2015	208	2000	221	265	34	0.79	1.26
2016	268	1985	212	255	35	0.81	1.23
2017	125	2015	208	250	36	0.84	1.19

2018	189	2012	207	249	37	0.86	1.16
2019	377	2018	189	227	38	0.88	1.13
2020	228	2014	169	203	39	0.91	1.10
2021	264	2017	125	149	40	0.93	1.08
2022	435	1987	119	143	41	0.95	1.05
2023	495	1994	39	46	42	0.98	1.02
			Avg	**403.68**			
			S. D	**201.03**			
			N	**42**			

A. Normal Distribution

Table 25: Discharges at Naugaon Site in Yamuna River for different return period from Normal distribution.

T	KT	Qmean	S.D.	KT*SD	QT=Qmean+KT*SD
2.33	0	403.68	201.03	0	404
5	0.824	403.68	201.03	165.65	569
10	1.282	403.68	201.03	257.73	661
25	1.751	403.68	201.03	352.01	756
50	2.054	403.68	201.03	412.93	817
100	2.326	403.68	201.03	467.61	871
200	2.576	403.68	201.03	517.87	922

B. Log-Normal Distribution

Table 26: Discharges at Naugaon Site at Yamuna River for different return period from Log - Normal distribution

T	KT	б	KTб	Log(X)avg	log(x)avg+KTб	XT(Cumec)
2.33	0	0.236	0	2.551	2.551	356
5	0.824	0.236	0.195	2.551	2.746	557
10	1.282	0.236	0.303	2.551	2.854	714
25	1.751	0.236	0.413	2.551	2.965	922
50	2.054	0.236	0.485	2.551	3.036	1087
100	2.326	0.236	0.549	2.551	3.100	1260
200	2.576	0.236	0.608	2.551	3.159	1443

C. Gumbel Extreme Value Type 1 Distribution (GEVT – 1)

The tables presented below summarize the maximum discharge observed for 42 years from 1982 2023 and calculated discharges for different return period based on the GEVT – 1 distribution.

Table 27: Annual Maximum observed daily and instantaneous discharges at Naugaon Site

Year	Qmax (Cumec)	Instantaneous Max. Q (Cumec)	Rank(m)	PROBABILITY (P)	Tp (Years)
1989	841	1009	1	0.024	42.000
1986	689	827	2	0.048	21.000
1988	684	820	3	0.071	14.000
1982	635	762	4	0.095	10.500
1993	599	719	5	0.119	8.400
2023	495	594	6	0.143	7.000
2005	481	577	7	0.167	6.000
2010	469	563	8	0.190	5.250
1990	454	545	9	0.214	4.667
2022	435	522	10	0.238	4.200
2008	425	510	11	0.262	3.818
1998	417	500	12	0.286	3.500
2011	408	489	13	0.310	3.231
2019	377	453	14	0.333	3.000
1999	349	419	15	0.357	2.800
2001	323	388	16	0.381	2.625
2009	322	386	17	0.405	2.471
1983	320	384	18	0.429	2.333
1995	294	353	19	0.452	2.211
1992	289	347	20	0.476	2.100
1984	281	337	21	0.500	2.000
2002	279	335	22	0.524	1.909
1996	271	326	23	0.548	1.826
2016	268	322	24	0.571	1.750
2021	264	317	25	0.595	1.680
2006	256	307	26	0.619	1.615
1991	255	306	27	0.643	1.556
2013	255	306	28	0.667	1.500
2007	254	305	29	0.690	1.448
2003	250	300	30	0.714	1.400

1997	236	284	31	0.738	1.355
2004	234	281	32	0.762	1.313
2020	228	273	33	0.786	1.273
2000	221	265	34	0.810	1.235
1985	212	255	35	0.833	1.200
2015	208	250	36	0.857	1.167
2012	207	249	37	0.881	1.135
2018	189	227	38	0.905	1.105
2014	169	203	39	0.929	1.077
2017	125	149	40	0.952	1.050
1987	119	143	41	0.976	1.024
1994	39	46	42	1.000	1.000
	Avg	**403.68**			
	S. D	**201.03**			
	N	**42**			

Table 28: Discharges Naugaon site for different return period from GEVT-1

T years	Xavg	KT	S.D.	XT=Xavg+KT*S.D .
5	403.68	0.83	201.03	571
10	403.68	1.49	201.03	703
25	403.68	2.32	201.03	869
50	403.68	2.93	201.03	993
100	403.68	3.54	201.03	1115
200	403.68	4.15	201.03	1237

Note: Value of σ **&** $\bar{Q}$ will remain same for all the distributions.

D. Log Pearson Type III Distribution:

The tables presented below summarize the maximum discharge observed for 42 years from 1982-2023 and calculated discharges for different return period based on the LPT-III distribution.

Table 29: Logarithmic average and skewness calculations for LPT-III discharge distribution.

Year	Qmax (Cumec)(X)	Instantaneous max Q (Multiplied by 1.2)	Z= Log(X)	A=Sum of (Z-Zavg)^3	Cs-Coefficient of Skewness(n*A/(n-1)*(n-2)*s.d.^3
1989	841	1009	3.004	0.09	-1.063
1986	689	827	2.918	0.05	-1.063
1988	684	820	2.914	0.05	-1.063
1982	635	762	2.882	0.04	-1.063
1993	599	719	2.857	0.03	-1.063
2023	495	594	2.774	0.01	-1.063
2005	481	577	2.762	0.01	-1.063
2010	469	563	2.751	0.01	-1.063
1990	454	545	2.737	0.01	-1.063
2022	435	522	2.718	0.00	-1.063
2008	425	510	2.708	0.00	-1.063
1998	417	500	2.699	0.00	-1.063
2011	408	489	2.689	0.00	-1.063
2019	377	453	2.656	0.00	-1.063
1999	349	419	2.623	0.00	-1.063
2001	323	388	2.589	0.00	-1.063
2009	322	386	2.587	0.00	-1.063
1983	320	384	2.585	0.00	-1.063
1995	294	353	2.547	0.00	-1.063
1992	289	347	2.541	0.00	-1.063
1984	281	337	2.528	0.00	-1.063
2002	279	335	2.524	0.00	-1.063
1996	271	326	2.513	0.00	-1.063
2016	268	322	2.508	0.00	-1.063
2021	264	317	2.501	0.00	-1.063
2006	256	307	2.487	0.00	-1.063
1991	255	306	2.486	0.00	-1.063
2013	255	306	2.486	0.00	-1.063
2007	254	305	2.485	0.00	-1.063
2003	250	300	2.477	0.00	-1.063
1997	236	284	2.453	0.00	-1.063
2004	234	281	2.449	0.00	-1.063

2020	228	273	2.437	0.00	-1.063
2000	221	265	2.423	0.00	-1.063
1985	212	255	2.406	0.00	-1.063
2015	208	250	2.397	0.00	-1.063
2012	207	249	2.396	0.00	-1.063
2018	189	227	2.356	-0.01	-1.063
2014	169	203	2.307	-0.01	-1.063
2017	125	149	2.174	-0.05	-1.063
1987	119	143	2.156	-0.06	-1.063
1994	39	46	1.665	-0.70	-1.063
		LogXavg	**2.551**		
		S.D.	**0.236**		
		N	**42**		

Table 30: Discharges at Naugaon site for different return period

T (years)	KT	б	KTб	logX avg	log(x)avg+KTб	LPTQT= XT(Cumec)
2.33	0.164	0.23606 8	0.0387	2.551	2.590	389
5	0.852	0.23606 8	0.2011	2.551	2.752	565
10	1.128	0.23606 8	0.2663	2.551	2.817	657
25	1.366	0.23606 8	0.3225	2.551	2.874	748
50	1.492	0.23606 8	0.3522	2.551	2.903	801
100	1.588	0.23606 8	0.3749	2.551	2.926	843
200	1.664	0.23606 8	0.3928	2.551	2.944	879

5.1.5 Bausan Site:

The Bausan site is located at downstream of Naugaon on Yamuna River with a catchment area of 2075 sq. km. The flow data of this site is available from the year 1985-2015 and which was obtained. As per the frequency analysis conditions the distributions namely Normal, LN, LPT-III & GEVT-I distribution are attempted respectively on the flow data of the site.

The tables presented below summarize the maximum discharge observed for 31 years from 1985 – 2015 and calculated discharges for different return period based on different distribution. A time series of the flow data at Bausan site (Fig.23) is prepared for better understanding of the year wise flow conditions.

It is seen from the time series that, the maximum flow at Bausan site remain below 1850 cumecs in most of the time where as it crossed thrice 1600 cumecs and above. In the year 2012 to 2015 the flows are very low and between 450 to 800 cumecs nearly. The flow data beyond year 2015 of this station is not available for analysis. The available data has been used subsequently for further analysis.

The observed data is first arranged in sequence of maximum to minimum and then multiplied with 1.2 (20% increase over the observed) in order to find the instantaneous values. Further the values are ranked as per their magnitude and their probability of exceedance is tested as per Weibull plotting position formula. The return periods of the existing values are also calculated and shown in Table.

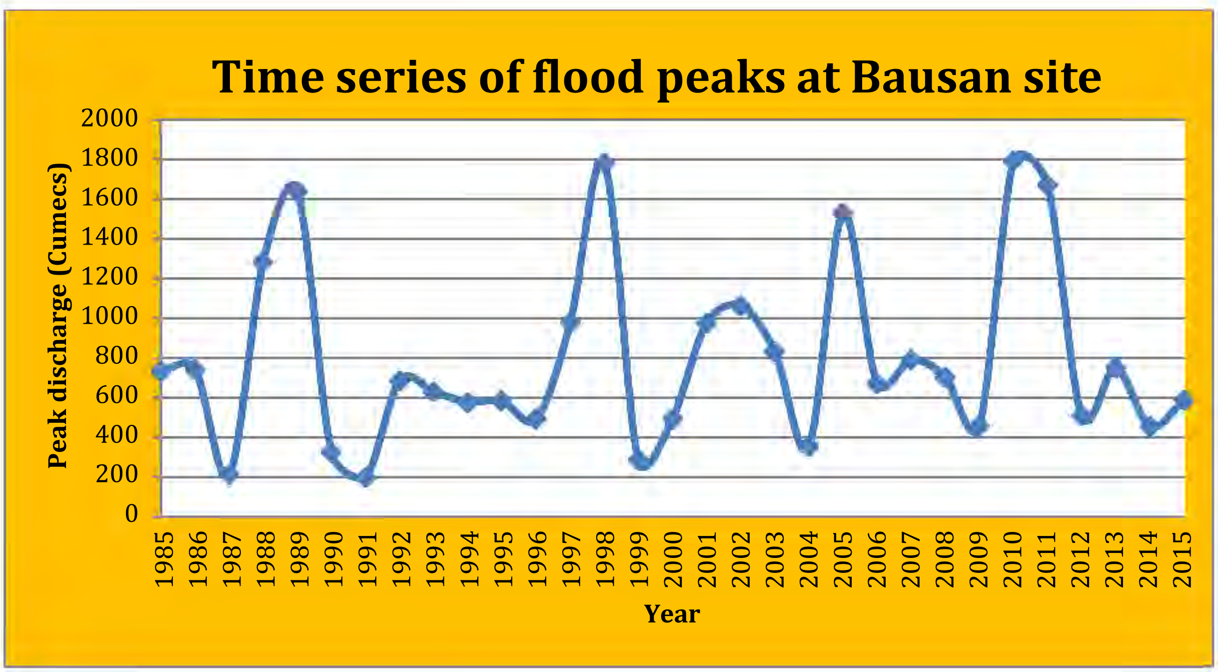


Figure 23. Time series of annual peak discharge at Bausan site)

The Tables presented below summarize the maximum discharge observed for 31 years from 1985 – 2015 and calculated discharges for different return period based on different distribution. The observed data is first arranged in sequence of maximum to minimum and then multiplied with 1.2 (20% increase over the observed) in order to find the instantaneous values. Further the values are ranked as per their magnitude and their probability of exceedance is tested as per Weibull plotting position formula. The return periods of the existing values are also calculated and shown in Table.

Table 31: Annual Maximum observed daily and instantaneous discharges at Bausan Site

Year	Observed discharge	Year	Qmax (Cumec) arranged	Instantaneous Max. Q (Cumec)	Ranked values (m)	Probability of exceedence (P)	Return period (Years)
1985	738	2010	1794	2153.3	1	0.031	32
1986	746	1998	1784	2140.5	2	0.063	16
1987	216	2011	1673	2008	3	0.094	10.7
1988	1287	1989	1641	1969.8	4	0.125	8
1989	1641	2005	1532	1838.7	5	0.156	6.4
1990	330	1988	1287	1544.4	6	0.188	5.3
1991	202	2002	1065	1278.5	7	0.219	4.6
1992	689	1997	979	1174.9	8	0.250	4
1993	634	2001	977	1172.2	9	0.281	3.6
1994	580	2003	835	1002.2	10	0.313	3.2
1995	588	2007	794	952.6	11	0.344	2.9
1996	498	2013	754	904.5	12	0.375	2.7
1997	979	1986	746	894.8	13	0.406	2.5
1998	1784	1985	738	885.6	14	0.438	2.3
1999	288	2008	705	845.9	15	0.469	2.1
2000	498	1992	689	826.4	16	0.500	2
2001	977	2006	677	812.3	17	0.531	1.9
2002	1065	1993	634	761.2	18	0.563	1.8
2003	835	2015	589	707.1	19	0.594	1.7
2004	359	1995	588	705.3	20	0.625	1.6
2005	1532	1994	580	695.8	21	0.656	1.5
2006	677	2012	515	617.7	22	0.688	1.5
2007	794	1996	498	597.2	23	0.719	1.4
2008	705	2000	498	597.2	24	0.750	1.3
2009	463	2009	463	556.2	25	0.781	1.3
2010	1794	2014	458	549.8	26	0.813	1.2

2011	1673	2004	359	431.4	27	0.844	1.2
2012	515	1990	330	396	28	0.875	1.1
2013	754	1999	288	345.2	29	0.906	1.1
2014	458	1987	216	259.4	30	0.938	1.1
2015	589	1991	202	242.9	31	0.969	1
			Avg	**963**	**Cs=0.990 2**		
			S. D	**554.95**			

The mean and standard deviations obtained from the series are 963 and 554.95 cumecs respectively basing on which the discharge values for different return periods are obtained and mentioned respectively.

A) Normal Distribution: The normal distribution is applied to the given data series. The frequency factor is obtained from the probability chart corresponding to coefficient of skewness = 0 and different return periods. The calculations of estimated peaks as per normal distributions are mentioned in Table.

Table 32: Discharges at Bausan site for different return period from Normal distribution

T	KT	Qmean	S.D.	KT*SD	QT=Qmean+KT*SD
2.33	0	963.46	554.95	0	963
5	0.824	963.46	554.95	457.28	1421
10	1.282	963.46	554.95	711.45	1675
25	1.751	963.46	554.95	971.72	1935
50	2.054	963.46	554.95	1139.88	2103
100	2.326	963.46	554.95	1290.82	2254
200	2.576	963.46	554.95	1429.56	2393

Note: The values of mean and standard deviation will remain same for all the distribution.

B. Log Normal Distribution: The original data series is log transformed and its mean and standard deviations are obtained from that log transformed series.

Table 33: Logarithmic average and skewness calculations for Log Normal distribution

Year	Annual flood peak (Cumecs)	Year	Arranged Qmax series (Cumec)	Instantaneous max Q (1.2X Qmax)	Log transformed series Log(Q)
1985	738	2010	1794	2153.3	3.3331
1986	746	1998	1784	2140.5	3.3305
1987	216	2011	1673	2008.0	3.3028
1988	1287	1989	1641	1969.8	3.2944
1989	1641	2005	1532	1838.7	3.2645
1990	330	1988	1287	1544.4	3.1888
1991	202	2002	1065	1278.5	3.1067
1992	689	1997	979	1174.9	3.0700
1993	634	2001	977	1172.2	3.0690
1994	580	2003	835	1002.2	3.0010
1995	588	2007	794	952.6	2.9789
1996	498	2013	754	904.5	2.9564
1997	979	1986	746	894.8	2.9517
1998	1784	1985	738	885.6	2.9472
1999	288	2008	705	845.9	2.9273
2000	498	1992	689	826.4	2.9172
2001	977	2006	677	812.3	2.9097
2002	1065	1993	634	761.2	2.8815
2003	835	2015	589	707.1	2.8495
2004	359	1995	588	705.3	2.8484
2005	1532	1994	580	695.8	2.8425
2006	677	2012	515	617.7	2.7908
2007	794	1996	498	597.2	2.7761
2008	705	2000	498	597.2	2.7761
2009	463	2009	463	556.2	2.7452
2010	1794	2014	458	549.8	2.7402
2011	1673	2004	359	431.4	2.6349
2012	515	1990	330	396.0	2.5977
2013	754	1999	288	345.2	2.5381
2014	458	1987	216	259.4	2.4140
2015	589	1991	202	242.9	2.3855

Mean= 2.915

St. Dev= 0.2529

Coefficient of skewness (Cs) = -0.1422

The frequency factors remained same as that of Normal distributions considering coefficient of skewness= 0. The derived forecasted floods are mentioned in Table.

Table 34: Discharges for different return periods from Log - Normal distribution

T	KT	б	KTб	Log(X)avg	log(x)avg+KTб	XT(Cumec)
2.33	0	0.25299771	0	2.9152	2.915	823
5	0.824	0.25299771	0.208	2.9152	3.124	1329
10	1.282	0.25299771	0.324	2.9152	3.239	1736
25	1.751	0.25299771	0.443	2.9152	3.358	2281
50	2.054	0.25299771	0.520	2.9152	3.435	2722
100	2.326	0.25299771	0.588	2.9152	3.504	3189
200	2.576	0.25299771	0.652	2.9152	3.567	3689

C. Log PT-III Distribution:

The Log Pearson type-III distribution is applied to the data series corresponding to the mean and standard deviation obtained from the log transformed series. The frequency factors for different return periods are obtained as per the coefficient skewness values available in standard frequency factor tables.

The mean, standard deviations and coefficient of skewness obtained for the log transformed series are 2.915, 0.2529 and -0.1422 respectively basing on which the discharge values for different return periods are obtained and mentioned in Table after retrieving the normal values out of the log transformed series.

Table 35: Discharges at Bausan Site at Yamuna River as per Log PT-III distribution

T (years)	KT	б	KTб	logX avg	log(x)avg+KT б	LPTQT= XT(Cumec)
2.33	0.024	0.252998	0.0060 1	2.915	2.9212	833.99
5	0.848	0.252998	0.2145	2.915	3.1296	1347.77
10	1.265	0.252998	0.3200	2.915	3.2352	1718.61
25	1.701	0.252998	0.4303	2.915	3.3455	2215.40

50	1.977	0.252998	0.5001	2.915	3.4153	2601.81
100	2.221	0.252998	0.5619	2.915	3.4770	2999.18
200	2.442	0.252998	0.6179	2.915	3.5331	3412.37

D. Gumbel Distribution: The Gumbel distribution has been applied to the same data series and frequency factors are calculated from the equations. The forecasted floods for different return periods are estimated and mentioned in Table

Table 36: Discharges at for different return period from GEVT-1

T years	Xavg	KT	S.D.	XT=Xavg+KT*S.D.
2.33	963.46	0.04	554.95	984
5	963.46	0.86	554.95	1442
10	963.46	1.54	554.95	1815
25	963.46	2.39	554.95	2287
50	963.46	3.02	554.95	2637
100	963.46	3.64	554.95	2984
200	963.46	4.26	554.95	3330

5.1.6 Flood values for other key locations:

In order to calculate the discharges at different interim points/ ungauged sites the flow values as well as the statistics obtained from the gauged sites namely, Tuini (Tons River), Tuini (Pabar River), Haripur (Tons River), Naugaon (Yamuna River) and Bausan (Yamuna River) were considered as the bench mark/ datum. The catchment areas of the ungauged locations (Fig.25) are found from GIS and the corresponding discharges have been obtained from the equation developed with respect to the Area-Discharge (A-Q) relationship. For these four sites, the discharge at 5, 25, 50 and 100-year return period were determined using Log Pearson type-III and Gumbel Extreme Value Type-I methods.

Table 37: Return Period Analysis:

Site	River Name	Catchment Area	LPT-III					GEVT-I				
			5	10	25	50	100	5	10	25	50	100
Tuini (P)	Pabar	1406	383	519	727	912	1123	440	567	727	846	964
Tuini (Tons)	Tons	3362	1086	1382	1771	2078	2399	1179	1472	1843	2117	2390
Naugaon	Yamuna	794	565	657	748	801	843	571	703	869	993	1115
Haripur	Tons	5056	1815	2331	2928	3326	3685	1889	2443	3143	3662	4178
Bausan	Yamuna	2075	1348	1719	2215	2602	2999	1329	1736	2281	2722	3189

By using maximum daily discharge data flood frequency analysis is carried out for 5 gauging sites for 5,10-,25-,50- & 100-year return period. The proportionate discharges for few significant locations are also mentioned in Table 38.

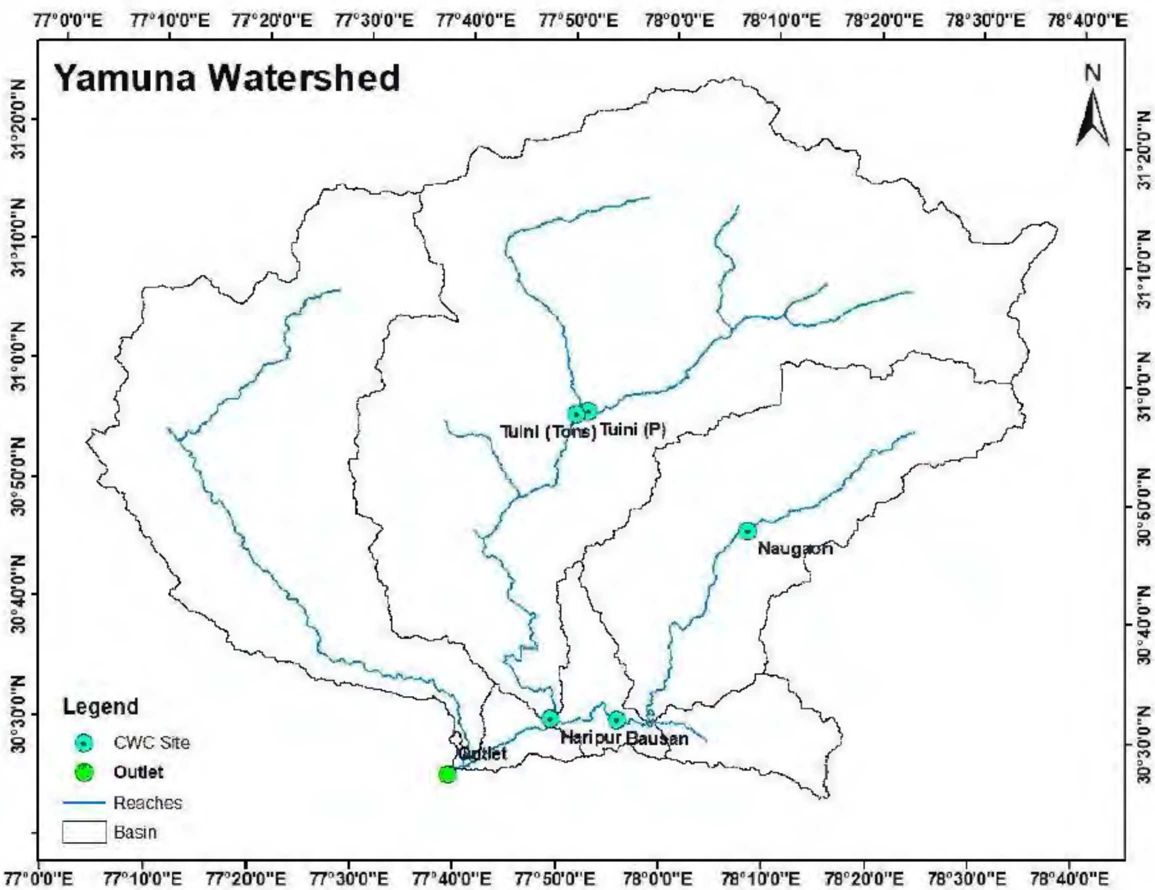


Fig. 24: CWC gauge locations in Yamuna Basin

power-function equations for 5-, 25-, 50- and 100-year return period has been used to estimate the discharges of ungauged rivers or watersheds (e.g. Jain et al. 2006). The power function equations for different return periods (LPT-III and GEVT-I) are as follows:

LPT-III Method

$Q_5 = 3.8811A^{0.7119}$……… *(1),* $R^2 = 0.7477$

$Q_{25} = 3.8712A^{0.7747}$……… *(2),* $R^2 = 0.7763$

$Q_{50} = 3.981A^{0.7905}$……… *(3),* $R^2 = 0.7727$

$Q_{100} = 4.1A^{0.8036}$……… *(4),* $R^2 = 0.7618$

GEVT-I Method

$Q_5 = 3.9416A^{0.8247}$……… *(5),* $R^2 = 0.8123$

$Q_{25} = 5.160A^{0.7447}$……… *(6),* $R^2 = 0.7806$

$Q_{50} = 5.7358A^{0.7506}$……… *(7),* $R^2 = 0.7609$

$Q_{100} = 6.2919x^{0.7557}$……… *(8),* $R^2 = 0.7394$

Where A denotes area of the watershed in km2 and Q5, 25, 50 &100 shows discharges (in cumec) at 5-25-, 50- and 100-year return period. Flood frequency of Seventeen ungauged watersheds (Label ID 1-17) has been computed using above power function equations

Furthermore, area-discharge power function relationship has been established at each return period. In this study the Log Pearson type-III method was found to be the most suitable for the computation of different flood frequencies. The calculated values have high R^2 values (closer to 1) in comparison to the Gumbel Extreme Value Type-I.

Table 38: Discharge for different Ungauged watershed joining to Yamuna River

Watershed Id	Area (Sq km)	LPT-III				GEVT-I			
		Q5	Q25	Q50	Q100	Q5	Q25	Q50	Q 100
1	160	144	197	220	242	259	226	258	291
2	56	69	88	97	105	110	104	118	133
3	161	145	199	222	244	261	228	261	293
4	59	71	92	100	109	114	108	123	138
5	218	179	251	281	311	334	285	327	368
6	99	102	136	151	165	175	158	181	203
7	89	95	125	138	151	160	146	167	187
8	169	149	206	229	253	271	235	269	303
9	101	103	138	152	167	177	160	183	205
10	309	230	328	370	410	445	369	424	479
11	130	124	168	187	205	219	194	222	249
12	5141	1702	2903	3417	3935	4531	2994	3500	4011
13	2630	1056	1727	2011	2296	2607	1818	2116	2417
14	693.8121	409	615	701	787	869	674	778	883
15	277.3052	213	302	340	377	408	340	391	441

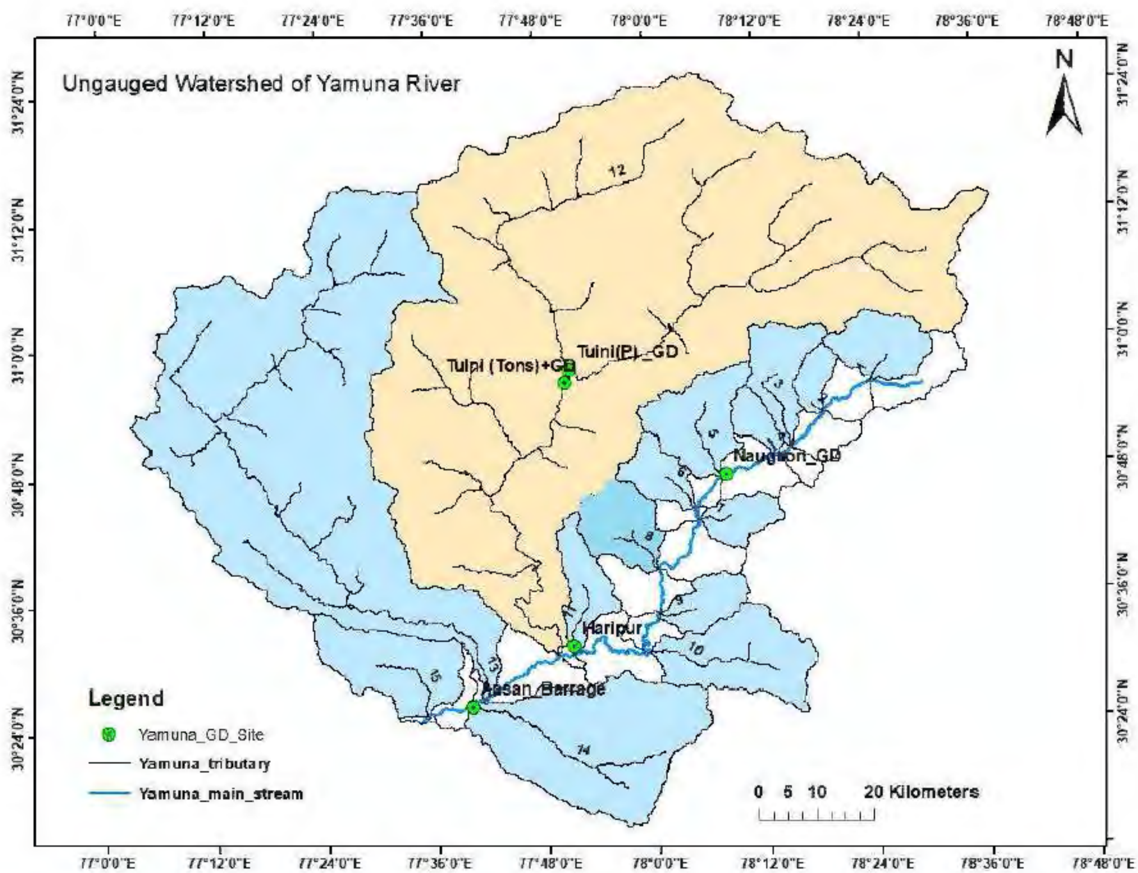


Fig. 25 Ungauged Watershed of Yamuna River Basin

Table 39: Discharge values at key locations for different return period

Identification Name	Area (Sq km)	LPT-III				GEVT-I			
		Q5	Q25	Q50	Q100	Q5	Q25	Q50	Q 100
Janki Chatti	65	76	98	108	117	79	116	132	148
Hanuman Chatti	258	202	286	321	355	211	323	370	418
Syanchatti	293	221	315	355	394	231	355	408	460
Kuthnaur	384	268	389	439	489	280	434	499	565
Kharadi	450	300	440	498	556	314	488	562	637
Nandgaon	614	375	560	637	713	393	615	710	805
Tilari Shaheed Sthal	705	414	623	710	797	433	682	788	894
Barkote	745	430	650	742	833	451	711	821	932
Bagasu	781	445	674	770	866	466	736	851	966
Naugaon	810	457	694	793	891	479	756	874	992
Pankhet	941	508	779	893	1005	533	846	979	1112
Lakha Mandal	1055	551	851	977	1102	579	921	1066	1212
Damta	1161	590	917	1054	1190	620	989	1146	1303
Nainbagh	1363	661	1038	1196	1354	695	1114	1292	1471
Yamuna Bridge	1714	778	1239	1434	1628	819	1321	1535	1749
Juddo bridge	1774	798	1273	1473	1674	840	1356	1575	1795
Jikala	1958	856	1374	1593	1812	901	1459	1696	1934
Dakpathar (Before Confluence)	1974	861	1383	1603	1824	907	1468	1706	1946
Dakpathar (After Confluence)	7152	2152	3749	4435	5131	2281	3829	4485	5147
Before Confluence with Giri	7282	2180	3801	4499	5206	2311	3881	4546	5218
After Confluence with Giri	9912	2715	4827	5741	6670	2882	4882	5729	6587
After Confluence with Asan	10611	2850	5089	6058	7045	3026	5136	6030	6935
At Outlet (State Border	11274	2976	5333	6356	7397	3161	5374	6311	7260

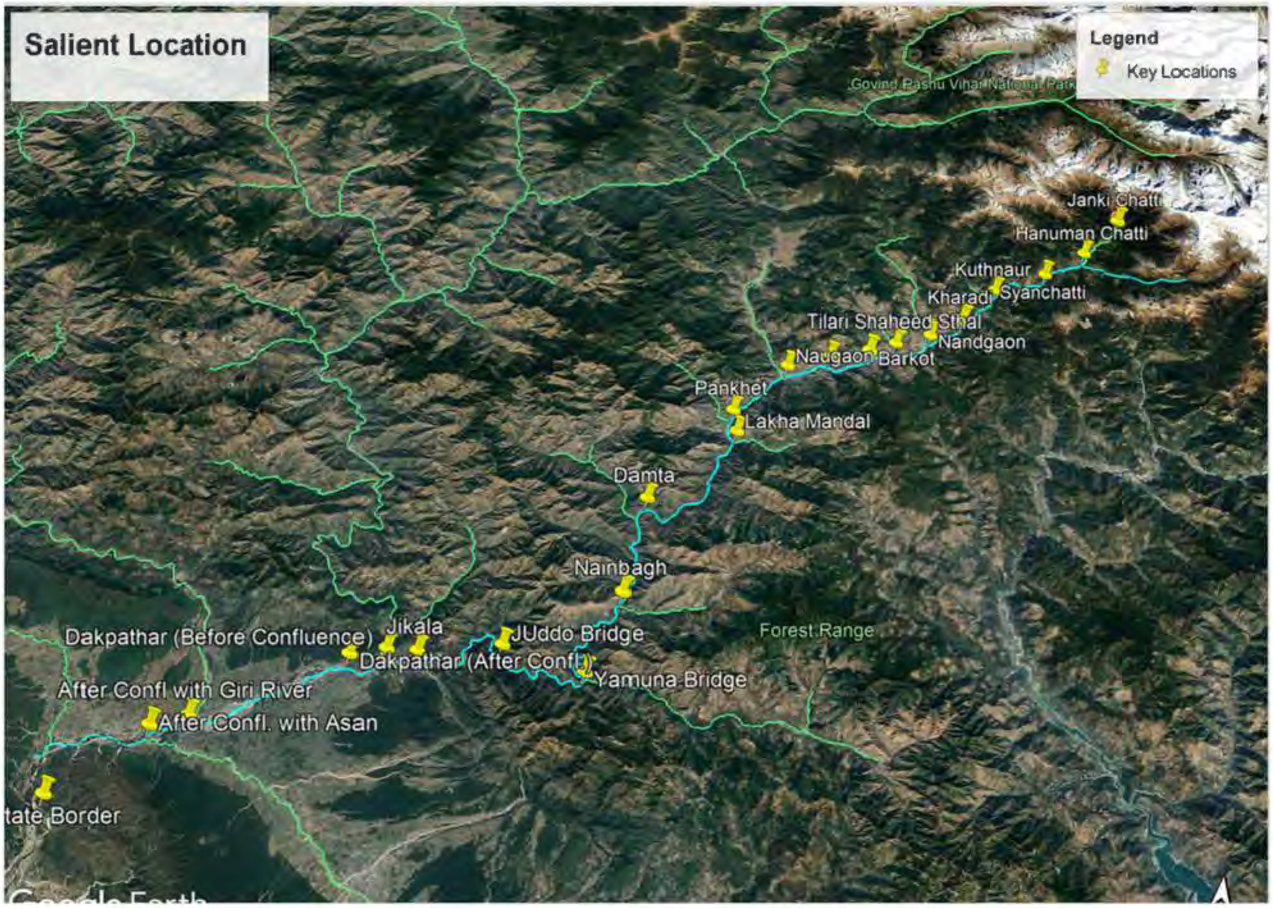


Fig.26 Different Key Locations in Yamuna River

5.1.7 Goodness of Fit Test:

The validity of a probability distribution function proposed to fit the empirical frequency of a given sample may be tested graphical and analytical methods. Often, graphical approaches for judging, how good a model is, are quite subjective. A number of analytical tests have been proposed for testing the goodness of fit of proposed distribution. Some of the commonly used tests are i) Chi-square tests ii) Kolmogorov-Smirnov (K-S) test and iii) D-index tests. The Chi- square and K-S tests are not very powerful in the sense that the probability of accepting the hypothesis when it is fact false is very high when these tests are used. In this light, the D-index test is better.

5.1.7.1 D-Index test:

The D-index for the comparison of the fit of various distributions in upper tail is given as:

D index= $= \left(\frac{1}{\underline{X}}\right) \sum_{i=1}^{6} \quad Abs(X_i - \hat{X}_i)$

Where, X_i and $\hat{X}_i$ are the ith highest observed and computed values for the distributions. The distribution giving the least D-index is considered to be the best fit distribution.

Tuini Tons site

40(a) Normal Distribution

Mean= 671.74, St. Dev= 374

Rank	X_i	$P(x \geq X)$	K_T	$\hat{X}_i = \underline{X} + K_T\sigma$	Abs$\lvert X_i - \hat{X}\rvert$
1	1701	0.023	1.99747	1419.832	281.17
2	1563	0.045	1.69777	1307.586	255.41
3	1506	0.068	1.51406	1238.781	267.22
4	1492	0.091	1.34964	1177.201	314.80
5	1449	0.114	1.21996	1128.632	320.37
6	1003	0.136	1.12317	1092.381	89.38
					1528.35
				D-Index	**=2.2753**

40(b) Log Normal Distribution

Mean= 6.372, St. Dev= 0.528, Cs= 0.118

Rank	X_i	$P(x \geq X)$	K_T	$\hat{X}_i = e^{(\mu+K_T\sigma)}$	Abs$\lvert X_i - \hat{X}\rvert$
1	1701	0.023	1.99747	1680.193	20.80664
2	1563	0.045	1.69777	1434.286	128.7138
3	1506	0.068	1.51406	1301.696	204.3035
4	1492	0.091	1.34964	1193.458	298.5424
5	1449	0.114	1.21996	1114.475	334.5248
6	1003	0.136	1.12317	1058.951	55.95067
					1042.842
				D-Index	**=1.5524**

40(c) Log PT-III Distribution

Mean= 6.372, St. Dev= 0.528 Cs= 0.118

Rank	X_i	$P(x \geq X)$	K_T	$\hat{X}_i = e^{(\mu+K_T\sigma)}$	Abs$\lvert X_i - \hat{X}\rvert$
1	1701	0.023	2.05565	1732.61	31.61
2	1563	0.045	1.734088	1462.06	100.94
3	1506	0.068	1.53933	1319.18	186.82
4	1492	0.091	1.3626	1201.65	290.35
5	1449	0.114	1.2293	1119.98	329.02
6	1003	0.136	1.12852	1061.95	58.95
					997.681
				D-Index	**=1.485**

40(d) Gumbel Distribution

Mean= 6.372, St. Dev= 0.528 Cs= 0.118, α=, u=

Rank	X_i	K_T	$\hat{X}_i = \alpha + K_T.u$	Abs$\lvert X_i - \hat{X}\rvert$
1	1701	3.772717	1605.359	95.641
2	1563	3.067873	1399.425	163.575
3	1506	2.6505	1277.482	228.518
4	1492	2.350619	1189.866	302.134
5	1449	2.115044	1121.038	327.962
6	1003	1.919975	1064.045	61.045
				1178.875
			D-Index	**=1.755**

40(e) D-index Comparison

Distribution	D-Index	Remark
Normal	2.2753	
Log Normal	1.5524	
Log PT-III	1.485	Lowest D-index value is Log PT-III. So Robust distribution
Gumbel	1.755	

41(a) Tuini-Pabar site

Normal Distribution

Mean= 232.72, St. Dev= 161.8

Rank	X_i	$P(x \geq X)$	K_T	$\widehat{X}_i = \underline{X} + K_T\sigma$	Abs$\lvert X_i - \widehat{X}\rvert$
1	684.53	0.023	1.99747	555.9106	128.62
2	618.3	0.045	1.69777	507.4192	110.88
3	592.62	0.068	1.51406	477.6949	114.93
4	570.77	0.091	1.34964	451.0918	119.68
5	560	0.114	1.21996	430.1095	129.89
6	524.61	0.136	1.12317	414.4489	110.16
					714.16
				D-Index	**=3.068**

41(b) Log Normal Distribution

Mean= 5.25, St. Dev= 0.625, Cs= 0.313

Rank	X_i	$P(x \geq X)$	K_T	$\widehat{X}_i = e^{(\mu + K_T\sigma)}$	Abs$\lvert X_i - \widehat{X}\rvert$
1	684.53	0.023	1.99747	664.09	20.44
2	618.3	0.045	1.69777	550.65	67.65
3	592.62	0.068	1.51406	490.92	101.70
4	570.77	0.091	1.34964	442.98	127.79
5	560	0.114	1.21996	408.49	151.51
6	524.61	0.136	1.12317	384.51	140.10
					609.175
				D-Index	**=2.618**

41(c)Log PT-III Distribution

Mean= 5.25, St. Dev= 0.625 Cs= 0.313

Rank	X_i	$P(x \geq X)$	K_T	$\widehat{X}_i = e^{(\mu+K_T\sigma)}$	Abs$\lvert X_i - \widehat{X} \rvert$
1	684.53	0.023	2.14915	730.13	45.60
2	618.3	0.045	1.79117	583.75	34.55
3	592.62	0.068	1.57817	510.99	81.63
4	570.77	0.091	1.38565	453.06	117.71
5	560	0.114	1.24206	414.17	145.83
6	524.61	0.136	1.13482	387.32	137.29
					562.587
				D-Index	**=2.417**

41(d) Gumbel Distribution

Mean= 232.72, St. Dev= 161.8, α= 126.219, u= 159.87

Rank	X_i	K_T	$\widehat{X}_i = \alpha + K_T.u$	Abs$\lvert X_i - \widehat{X} \rvert$
1	684.53	3.772717	636.0641	48.47
2	618.3	3.067873	547.0988	71.20
3	592.62	2.6505	494.4181	98.20
4	570.77	2.350619	456.5671	114.20
5	560	2.115044	426.8329	133.17
6	524.61	1.919975	402.2114	122.40
				587.64
			D-Index	**=2.53**

41(e) D-index Comparison

Distribution	D-Index	Remark
Normal	3.068	
Log Normal	2.618	
Log PT-III	2.417	Lowest D-index value is Log PT-III. So Robust distribution
Gumbel	2.53	

42(a) Haripur site

Normal Distribution

Mean= 1130.8, St. Dev= 932.84

Rank	X_i	$P(x \geq X)$	K_T	$\tilde{X}_i = \underline{X} + K_T\sigma$	Abs$\lvert X_i - \tilde{X}\rvert$
1	4497.88	0.025	1.95996	2959.199	1538.68
2	3676.53	0.05	1.64485	2665.252	1011.28
3	3153.54	0.075	1.4632	2495.801	657.74
4	2389.143	0.1	1.28155	2326.351	62.79
5	1726.716	0.125	1.17159	2223.776	497.06
6	1422.32	0.15	1.06159	2121.164	698.84
					4466.39
				D-Index	**=3.95**

42(b) Log Normal Distribution

Mean= 6.72, St. Dev= 0.855, Cs= -0.454

Rank	X_i	$P(x \geq X)$	K_T	$\tilde{X}_i = e^{(\mu + K_T\sigma)}$	Abs$\lvert X_i - \tilde{X}\rvert$
1	4497.88	0.025	1.95996	4428.28	69.60
2	3676.53	0.05	1.64485	3382.42	294.11
3	3153.54	0.075	1.4632	2895.86	257.68
4	2389.143	0.1	1.28155	2479.28	90.14
5	1726.716	0.125	1.17159	2256.81	530.10
6	1422.32	0.15	1.06159	2054.24	631.92
					1873.553
				D-Index	**=1.657**

42(c) Log PT-III Distribution

Mean= 6.72, St. Dev= 0.855 Cs= -0.454

Rank	X_i	$P(x \geq X)$	K_T	$\tilde{X}_i = e^{(\mu + K_T\sigma)}$	Abs$\lvert X_i - \tilde{X}\rvert$
1	4497.88	0.025	1.73644	3657.94	839.94
2	3676.53	0.05	1.50566	3002.92	673.61
3	3153.54	0.075	1.36429	2661.03	492.51
4	2389.143	0.1	1.22291	2358.04	31.10
5	1726.716	0.125	1.13115	2180.12	453.40
6	1422.32	0.15	1.03939	2015.61	593.29
					3083.853
				D-Index	**=2.727**

42 (d) Gumbel Distribution

Mean= 1130.8, St. Dev= 932.84, α= 727.7, u= 710.84

Rank	X_i	K_T	$\hat{X}_i = \alpha + K_T.u$	Abs$\lvert X_i - \hat{X} \rvert$
1	4497.88	3.676247	3386.05	1111.83
2	3676.53	2.970195	2872.256	804.27
3	3153.54	2.548936	2565.706	587.83
4	2389.143	2.250367	2348.437	40.71
5	1726.716	2.013419	2176.01	449.29
6	1422.32	1.822375	2036.987	614.67
				3608.61
			D-Index	**=3.19**

42(e) D-index Comparison

Distribution	D-Index	Remark
Normal	3.90	
Log Normal	1.713	Lowest D-index value is Log Normal. So Robust distribution
Log PT-III	2.727	
Gumbel	3.19	

43(a) Naugaon site

Normal Distribution

Mean= 336.33, St. Dev= 167.48

Rank	X_i	$P(x \geq X)$	K_T	$\hat{X}_i = \underline{X} + K_T\sigma$	Abs$\lvert X_i - \hat{X} \rvert$
1	841	0.023	1.99747	670.8663	170.13
2	689	0.047	1.6766	617.127	71.87
3	684	0.070	1.49953	587.4713	96.53
4	635	0.093	1.33241	559.482	75.52
5	599	0.116	1.21116	539.1751	59.82
6	495	0.140	1.10558	521.4925	26.49
					500.37
				D-Index	**=1.487**

43(b) Log Normal Distribution

Mean= 5.692, St. Dev= 0.542, Cs= -1.04

Rank	X_i	$P(x \geq X)$	K_T	$\widehat{X}_i = e^{(\mu + K_T \sigma)}$	Abs$\lvert X_i - \widehat{X} \rvert$
1	841	0.023	1.99747	875.35	34.35
2	689	0.047	1.6766	735.62	46.62
3	684	0.070	1.49953	668.31	15.69
4	635	0.093	1.33241	610.43	24.57
5	599	0.116	1.21116	571.61	27.39
6	495	0.140	1.10558	539.81	44.81
					193.448
				D-Index	**=0.575**

43(c) Log PT-III Distribution

Mean=5.692, St. Dev= 0.542 Cs= -1.04

Rank	X_i	$P(x \geq X)$	K_T	$\widehat{X}_i = e^{(\mu + K_T \sigma)}$	Abs$\lvert X_i - \widehat{X} \rvert$
1	841	0.023	1.44827	649.99	191.01
2	689	0.047	1.31627	605.11	83.89
3	684	0.070	1.22909	577.19	106.81
4	635	0.093	1.21834	573.83	61.17
5	599	0.116	1.07639	531.34	67.66
6	495	0.140	1.01177	513.05	18.05
					528.583
				D-Index	**=1.572**

43(d) Gumbel Distribution

Mean=336.33, St. Dev= 167.48, α= 130.65, u= 260.92

Rank	X_i	K_T	$\widehat{X}_i = \alpha + K_T . u$	Abs$\lvert X_i - \widehat{X} \rvert$
1	841	3.749458	750.80	90.20
2	689	3.044333	658.67	30.33
3	684	2.626645	604.10	79.90
4	635	2.326484	564.88	70.12
5	599	2.090592	534.06	64.94
6	495	1.89524	508.54	13.54
				349.02
			D-Index	**=1.04**

Distribution	D-Index	Remark
Normal	1.487	
Log Normal	0.575	Lowest D-index value is Log Normal. So Robust distribution
Log PT-III	1.572	
Gumbel	1.04	

44(a) Bausan Site

Normal Distribution

Mean= 802.83, St. Dev= 462.4

Rank	X_i	$P(x \geq X)$	K_T	$\hat{X}_i = \underline{X} + K_T\sigma$	Abs$\lvert X_i - \hat{X} \rvert$
1	1794	0.03125	1.87276	1668.794	125.21
2	1784	0.0625	1.55403	1521.413	262.59
3	1673	0.09375	1.32696	1416.416	256.58
4	1641	0.125	1.17157	1344.564	296.44
5	1532	0.15625	1.03409	1280.993	251.01
6	1287	0.1875	0.89661	1217.422	69.58
					1261.40
				D-Index	**=1.571**

44(b) Log Normal Distribution

Mean= 6.53, St. Dev= 0.583, Cs= -0.144

Rank	X_i	$P(x \geq X)$	K_T	$\hat{X}_i = e^{(\mu + K_T\sigma)}$	Abs$\lvert X_i - \hat{X} \rvert$
1	1794	0.03125	1.87276	2042.27	248.27
2	1784	0.0625	1.55403	1695.95	88.05
3	1673	0.09375	1.32696	1485.66	187.34
4	1641	0.125	1.17157	1356.99	284.01
5	1532	0.15625	1.03409	1252.47	279.53
6	1287	0.1875	0.89661	1156.00	131.00
					1218.191
				D-Index	**=1.517**

44(c) Log PT-III Distribution

Mean= 6.53, St. Dev= 0.583 Cs= -0.144

Rank	X_i	$P(x \geq X)$	K_T	$X^{\frown}{}_i = e^{(\mu + K_T\sigma)}$	Abs$\lvert X_i - X^{\frown} \rvert$
1	1794	0.03125	1.81132	1970.42	176.42
2	1784	0.0625	1.51836	1661.05	122.95
3	1673	0.09375	1.30726	1468.70	204.30
4	1641	0.125	1.16071	1348.43	292.57
5	1532	0.15625	1.03032	1249.72	282.28
6	1287	0.1875	0.98167	1214.77	72.23
					1150.745
				D-Index	**=1.433**

44(d) Gumbel Distribution

Mean= 802.83, St. Dev= 462.4, α= 360.715, u= 594.634

Rank	X_i	K_T	$X^{\frown}{}_i = \alpha + K_T.u$	Abs$\lvert X_i - X^{\frown} \rvert$
1	1794	3.449904	1839.066	45.07
2	1784	2.740493	1583.171	200.83
3	1673	2.321586	1432.065	240.94
4	1641	2.013419	1320.904	320.10
5	1532	1.772551	1234.02	297.98
6	1287	1.564982	1159.146	127.85
				1232.76
			D-Index	**=1.09**

Distribution	D-Index	Remark
Normal	1.571	
Log Normal	1.517	
Log PT-III	1.433	
Gumbel	1.09	Lowest D-index value is Gumbel. So Robust distribution

5.2 Flood Frequency Analysis for Asan Barrage

A. Gumbel Extreme Value Type 1 Distribution (GEVT – 1)

The formula used for estimation of discharges for any return period in the method is written as:

$$Q_T = \bar{Q} + K_T\sigma$$

Where:

Q_T = the probable discharge with a return period of T years

$\bar{Q}$ = mean flood (i.e., of 13 years in this project, n=13)

K_T= frequency factor = $(Y_T - Y_n)/ \sigma_n$

σ_n = Standard deviation of data

Y_T= - Ln (Ln (T/T- 1))

Yn, σ_n = expected mean and standard deviations of reduced extremes to be found from Gumbel's table based on number of year of data available.

The tables presented below summarize the maximum discharge observed for 13 years from 2010 – 2022 and calculated discharges for different return period based on the GEVT – 1 distribution.

Table 45: Annual Maximum observed daily and instantaneous discharges at Asan Barrage

Year	Qmax (Cumec)	Instantaneous Max. Q (Cumec)	Rank(m)	PROBABILITY (P)	Tp(Years)
2010	2028	2433	1	0.071	14.000
2014	1877	2253	2	0.143	7.000
2015	1832	2199	3	0.214	4.667
2012	1794	2153	4	0.286	3.500
2018	1657	1988	5	0.357	2.800
2021	1656	1987	6	0.429	2.333
2016	1656	1987	7	0.500	2.000
2013	1570	1884	8	0.571	1.750
2017	1570	1884	9	0.643	1.556
2022	1427	1713	10	0.714	1.400
2020	1333	1600	11	0.786	1.273
2019	1271	1525	12	0.857	1.167
2011	898	1078	13	0.929	1.077
Avg		**1898.62**			
S. D		**356.72**			

Table 46: Discharges at for different return period from GEVT-1

T years	Xavg	KT	S.D.	XT=Xavg+KT*S.D.
2.33	1898.62	0.07	356.73	1924
5	1898.62	1.00	356.73	2254
10	1898.62	1.75	356.73	2522
25	1898.62	2.70	356.73	2862
50	1898.62	3.40	356.73	3113
100	1898.62	4.11	356.73	3363
200	1898.62	4.80	356.73	3612

Note: Value of σ & Q̄ will remain same for normal distribution and GEVT-I which is calculated by below mentioned formula.

$$\sigma = \sqrt{\frac{\sum (x-\bar{x})^2}{n}}$$

B. Log Pearson Type III Distribution

The formula used for estimation of discharges for any return period in the method is written as:

$\log X_T = \log(x)_{avg} + K_T \sigma$

Where:

Q_T or X_T = the probable discharge with a return period of T years

log(x)avg. = average of the log X discharge values

K_T= frequency factor (referred from standard table based on skewness coefficient Cs and return period)

σ = the standard deviation of the log X values

The tables presented below summarize the maximum discharge observed for 13 years from 2010-2022 and calculated discharges for different return period based on the LPT-III distribution.

Table 47: Logarithmic average and skewness calculations for LPT-III discharge distribution.

Year	Qmax (Cumec)(X)	Instantaneous max Q(Multiplied by 1.2)	Z= Log(X)	A=Sum of (Z-Zavg)^3	Cs-Coefficient of Skewness(n*A/(n-1)*(n-2)*s.d.^3
2010	2028	2433	3.386147	0.00	-1.469700575
2014	1877	2253	3.352748	0.00	-1.469700575
2015	1832	2199	3.342139	0.00	-1.469700575
2012	1794	2153	3.33305	0.00	-1.469700575
2018	1657	1988	3.29839	0.00	-1.469700575
2021	1656	1987	3.29813	0.00	-1.469700575
2016	1656	1987	3.298123	0.00	-1.469700575
2013	1570	1884	3.275081	0.00	-1.469700575
2017	1570	1884	3.275058	0.00	-1.469700575
2022	1427	1713	3.233665	0.00	-1.469700575
2020	1333	1600	3.204145	0.00	-1.469700575
2019	1271	1525	3.183287	0.00	-1.469700575
2011	898	1078	3.032458	-0.01	-1.469700575
Log(X) avg	**3.270**				
S.D.	**0.091**				
N	**13**				

Table 48 Discharges at Asan River Barrage

T (years)	KT	б	K_Tб	logX avg	log(x)avg+KT б	LPTQT= XT(Cumec)
2.33	0.235	0.09199 6	0.0216 1	3.270	3.291798865	1958
5	0.826	0.09199 6	0.0760	3.270	3.346197515	2219
10	1.024	0.09199 6	0.0942	3.270	3.3644147	2314
25	1.170	0.09199 6	0.1076	3.270	3.377783988	2387
50	1.235	0.09199 6	0.1136	3.270	3.383798523	2420
100	1.278	0.09199 6	0.1175	3.270	3.387733404	2442
200	1.307	0.09199 6	0.1202	3.270	3.390400563	2457

C. Normal Distribution

Analysis by using the Normal distribution uses the formula as below:

$$QT = \bar{Q} + K_T Sn$$

Where:

Q_T = the probable discharge with a return period of T years

$\bar{Q}$ =mean flood (i.e. of 13 years in this project, n=13) K_T= frequency factor

S n = Standard deviation of data

The tables presented below summarize calculated discharges for different return period based on the Normal distribution.

Table 49: Discharges at Asan River Barrage for different return period from Normal distribution.

T	K_T	Qmean	S.D.	K_T*SD	QT=Q_{mean}+KT*SD
2.33	0	1898.62	356.73	0	1899
5	0.824	1898.62	356.73	293.94	2193
10	1.282	1898.62	356.73	457.32	2356
25	1.751	1898.62	356.73	624.63	2523
50	2.054	1898.62	356.73	732.72	2631
100	2.326	1898.62	356.73	829.75	2728
200	2.576	1898.62	356.73	918.93	2818

D. Log-Normal Distribution

The formula used for estimation of discharges for any return period in the method is written as:

$$\log X_T = \log(x)_{avg} + K_T\sigma$$

Where:

Q_T or X_T = Probable discharge with a return period of T years

log(x)avg. = Average of the log X discharge values

K_T= Frequency factor (referred from for return period)

σ = Standard deviation of the log X values

Table 50: Discharges at just for different return period from Log - Normal distribution

T	K_T	σ	$K_T\sigma$	Log(X)avg	log(x)avg+$K_T\sigma$	X_T(Cumec)
2.33	0	0.092	0	3.270	3.270	1863
5	0.824	0.092	0.076	3.270	3.346	2218
10	1.282	0.092	0.118	3.270	3.388	2444
25	1.751	0.092	0.161	3.270	3.431	2699
50	2.054	0.092	0.189	3.270	3.459	2878
100	2.326	0.092	0.214	3.270	3.484	3049
200	2.576	0.092	0.237	3.270	3.507	3215

By using Flood Frequency Analysis for Asan barrage LPT-III value has been adopted based on Goodness of Fit criteria which will be further used for calculation of discharges at different key locations.

Table 51 Discharge at salient locations of Asan barrage

Identification Name	Catchment Area of Drain(km^2)	Catchment Area (km^2)	Return Period (Year) Flow (cumec)			
			5	25	50	100
Raja Dhunga	41.1	41.1	134	170	185	199
Birpur Barrage	2.6	43.7	142	180	196	212
Tapkeshwar Mahadev	6.3	50	163	206	225	243
Bajawala	43	93	302	384	418	451
Tons Bridge School	68.06	161.06	524	665	723	782
Regional Science Centre	44.94	206	670	851	925	1000
Shishambara Plant	51.09	257.09	836	1062	1155	1248
Sabharwal Bridge	84.21	341.3	1110	1410	1533	1656
Vikas Nagar	50.7	392	1275	1619	1761	1902
Asan Bridge	94	486	1581	2007	2183	2358

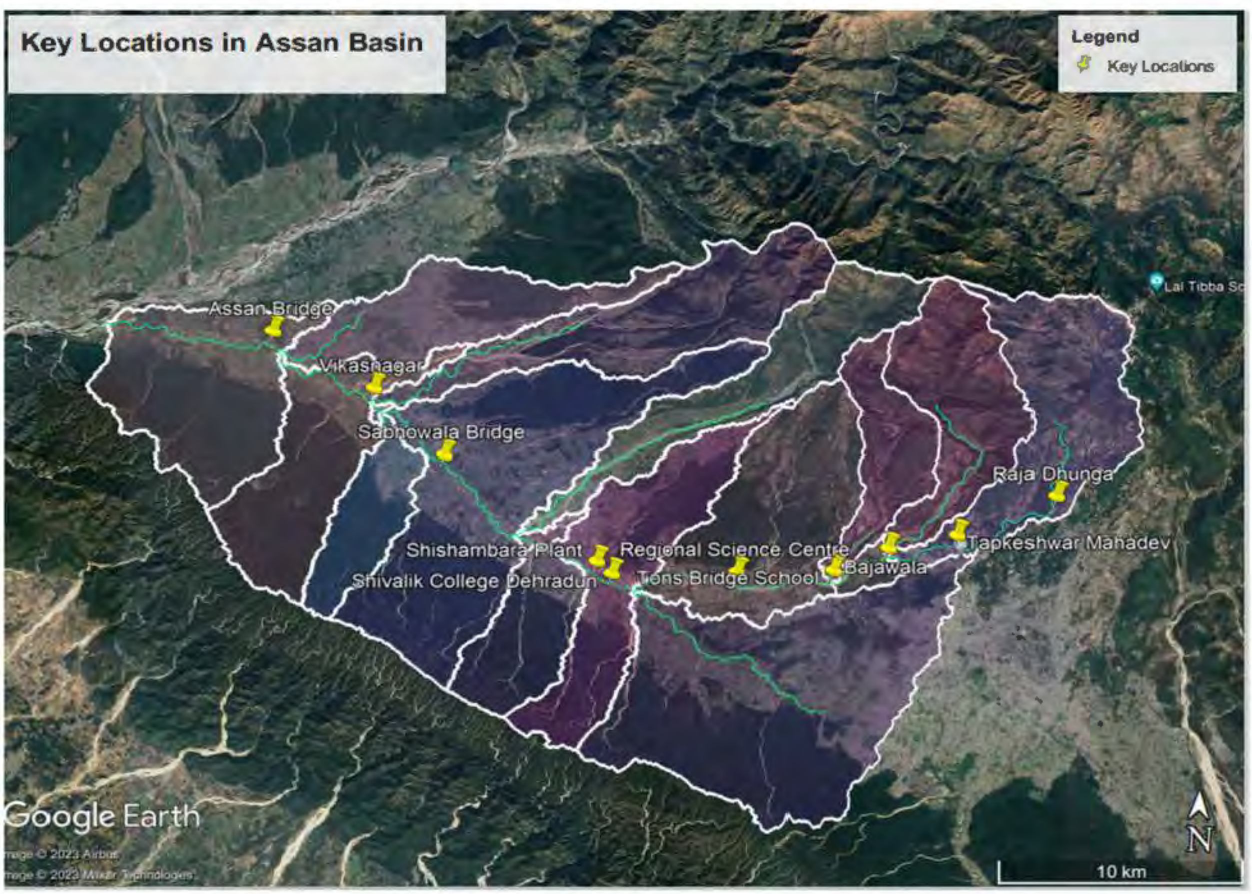


Fig. 27 Key Location for Asan Basin

Table 52: Discharge for Ungauged tributaries of Asan Rivers

Tributataries	Area (Sq km)	LPT-III				GEVT-I			
		Q5	Q25	Q50	Q100	Q5	Q25	Q50	Q 100
Nun	41	45	47	48	48	42	57	64	70
Nimi	24	30	29	29	29	27	36	40	44
Swarna	41	45	47	48	48	42	57	64	70
Sitla Rao	56	54	57	58	59	50	68	77	85

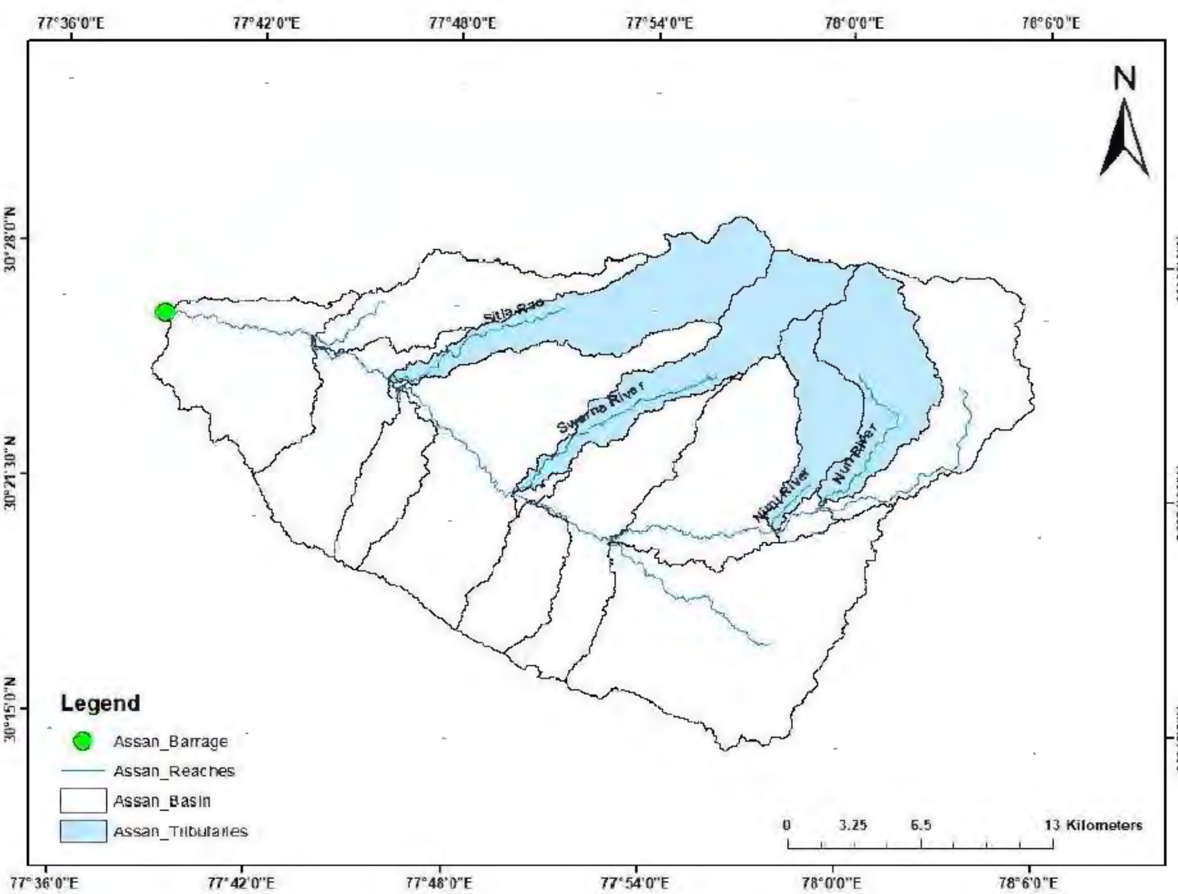


Fig. 28 Ungauged tributaries of Asan River

Table 53: Discharge at Asan barrage corresponding to different return periods

Discharge in cumecs at Asan barrage				
Return period (Yr.)	**Log Normal**	**Normal**	**LPT-III**	**GEVT-I**
2.33	1863	1899	1958	1924
5	2218	2193	2219	2254
10	2444	2356	2314	2522
25	2699	2523	2387	2862
50	2878	2631	2420	3113
100	3049	2728	2442	3363
200	3215	2818	2457	3612

The Jhakhan and Chandrabhaga rivers are not covered by GD sites hence treated as per the methodology followed for ungauged catchments. Hence Synthetic Unit Hydrograph (SUH) approach has been applied for both the sites and discharges have been calculated the design storm kept for different return periods. The same has also been compared with L-Moment chart.

5.3 Flood Estimation for Jhakhan River

Physiographic parameters: The physiographic parameters of the river catchment at project site have been estimated by GIS processing. The elevation along the longest flow path of the river varies from about 1017 to 387 m. The estimated parameters of the river catchment at project site are given in

Table 54. Physiographic Parameters

Catchment Area (km^2)	L (km)	Lc (km)	Equivalent stream slope (m/km)
121	41.09	27	4.25

Assessment of Unit Hydrograph

In absence of short interval observed discharge and concurrent rainfall data; the unit hydrograph of one hour duration has been derived using Flood Estimation Report for Western Himalay zone-7 The estimated UH parameters are given at Table-55. The unit hydrograph ordinates as assessed for the unit hydrograph of catchment are given at Table-54.

Table-55: Unit Hydrograph Parameters:

Parameter	Unit	Value
Time from the center of effective rainfall duration to the UH peak $tp = 2.498*(L*Lc/S)^{0.156}$	hr	5.95
Peak discharge of unit hydrograph per unit area $qp = 1.048*(tp)^{-0.178}$	m 3 /sec/sq. km	0.76
Width of the UH measured at 50% of peak discharge ordinate $W50 = 1.954*(L*Lc/S)^{0.099}$	hr	3.39
Width of the UH measured at 75% of peak discharge ordinate $W75 = 0.972*(L*Lc/S)^{0.124}$	hr	1.94
Width of the rising limb of UH measured at 50% of peak discharge ordinate $WR50 = 0.189(W50)^{1.769}$	hr	1.64
Width of the rising limb of UH measured at 75% of peak discharge ordinate $WR75 = 0.419(W75)^{1.246}$	hr	0.96
Base width of UH $TB = 7.845*(tp)^{0.453}$	hr	17.60
Peak Discharge of UH Qp = qp x A	m 3 /sec	92.31
Unit duration of unit hydrograph tr	hr	1.00
Time from the start of rise to the peak of the UH Tm=tp+tr /2	hr	6.45
Q theoretical = A*d/0.36*tr here d= 1 cm depth and tr = 1 hr	m 3 /sec	336.11

Raingauge station rainfall are obtained by PMP Atlas for required return period the weighted average rainfall is calculated for the basin. Once the station rainfall is derived, the various reduction factor (0.725), areal reduction factor (0.932) and appropriate distribution coefficients are used to get effective rainfall, based on Td,TB & catchment area. (Annexure 5)

Table-56: Rainfall for Different Return Period

Return Period	5	10	25	50	100
Rainfall (mm)	178	219	272	311	350
Rainfall (cm)	17.8	21.9	27.2	31.1	35

e.g. Effective rainfall= 35*0.725*0.932= **23.65cm**

Table-57: Unit Hydrograph Ordinates

Unit Hydrograph	
Time (hrs)	**UH Ord.(m3/sec)**
0	0
1	4.5
2	9
3	17
4	26.5
5	40
6	69
7	92
8	69
9	42
10	32
11	24
12	18
13	13
14	9
15	6.5
16	4
17	1
18	0

Below mentioned figure shows the plot of smoothened Unit Hydrograph after designing it into the graph paper.

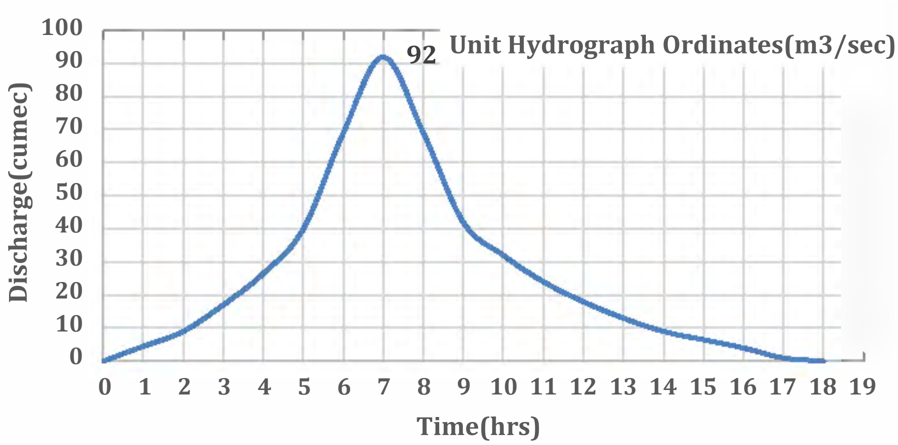


Fig. 29: Synthetic Unit Hydrograph for Jhakhan River

A. 100 Year Return Period Flood Estimation

A design loss rate of 0 to 0 .6 cm /hr as recommended in CWC FER of Western Himalayan zone-7 report for has been adopted for design flood computation.

As recommended by CWC Western Himalayan zone-7 report following base flow rate has been adopted:

Base flow / km2 of drainage area = 0.10 (max)

Using the above formula, the computed base flow for the catchment area is 0.61 m^3 /sec.

Table 58: Effective Rainfall Calculation:

Duration (hr)	Distributed Coefficient	Storm Rainfall (cm)	Rainfall Increments (cm)	Loss Per Hr (cm)	Effective Rainfall Increments (cm)
1	2	3	4	5	6
1	0.23	5.44	5.44	0.6	4.84
2	0.37	8.75	3.31	0.6	2.71
3	0.46	10.88	2.13	0.6	1.53
4	0.54	12.77	1.89	0.6	1.29
5	0.6	14.19	1.42	0.6	0.82
6	0.66	15.61	1.42	0.6	0.82

Table 59: Computation of Flood Peak (100yr RP)

Time (hrs) 1	U.G. Ordinate (cumecs) 2	1 Hr Effective rainfall 3	Direct Runoff (cumec) 4
5	40	0.82	32.76
6	69	2.71	187.05
7	92	4.84	445.22
8	69	1.53	105.46
9	42	1.29	54.26
10	32	0.82	26.21
		Total	850.97
		Base flow	0.61
		100-yr flood Peak	**851.57**

Table 60: Computation of Design Flood Hydrograph for 100year RP

Time Hrs	SUH ordinates	Rainfall Excess in cms						Total D.S.R.O. in cumecs	Base Flow in cumecs	Total Flow in cumecs
		0.82	1.29	1.53	4.84	2.71	0.82			
		Direct Runoff Hydrograph (cumecs)								
1	2	3	4	5	6	7	8	9	10	11
1	0	0.00						0.00	0.61	0.61
2	4.5	3.69	0.00					3.69	0.61	4.29
3	9	7.37	5.81	0.00				13.18	0.61	13.79
4	17	13.92	11.63	6.88	0.00			32.43	0.61	33.03
5	26.5	21.70	21.96	13.76	21.78	0.0		79.20	0.61	79.80
6	40	32.76	34.24	25.98	43.55	12.2	0.0	148.73	0.61	149.34
7	69	56.51	51.68	40.50	82.27	24.4	3.7	259.04	0.61	259.65
8	92	75.35	89.15	61.14	128.24	46.1	7.4	407.33	0.61	407.93
9	69	56.51	118.86	105.46	193.58	71.8	13.9	560.17	0.61	560.78
10	42	34.40	89.15	140.62	333.92	108.4	21.7	728.22	0.61	728.82
11	32	26.21	54.26	105.46	445.22	187.1	32.8	850.97	0.61	851.57
12	24	19.66	41.34	64.20	333.92	249.4	56.5	765.03	0.61	765.63
13	18	14.74	31.01	48.91	203.25	187.1	75.3	560.31	0.61	560.92
14	13	10.65	23.26	36.68	154.86	113.9	56.5	395.81	0.61	396.42
15	9	7.37	16.80	27.51	116.15	86.7	34.4	288.97	0.61	289.58
16	6.5	5.32	11.63	19.87	87.11	65.1	26.2	215.20	0.61	215.80
17	4	3.28	8.40	13.76	62.91	48.8	19.7	156.79	0.61	157.40
18	1	0.82	5.17	9.93	43.55	35.2	14.7	109.46	0.61	110.06
19	0	0.00	1.29	6.11	31.46	24.4	10.6	73.91	0.61	74.51
20			0.00	1.53	19.36	17.6	7.4	45.88	0.61	46.48
21				0.00	4.84	10.8	5.3	21.01	0.61	21.61
23					0	2.7	3.3	5.99	0.61	6.59
23						0.0	0.8	0.82	0.61	1.42
							0.0	0.00	0.61	0.61

B. 50 Year Return Flood Estimation

Table 61: Effective Rainfall Calculation

Duration	Distributed Coefficient	Storm Rainfall	Rainfall Increments	Loss Per Hr	Effective Rainfall Increments
1	**2**	**3**	**4**	**5**	**6**
hr		**cm**	**cm**	**cm**	**cm**
1	0.23	4.83	4.83	0.6	4.23
2	0.37	7.78	2.94	0.6	2.34
3	0.46	9.67	1.89	0.6	1.29
4	0.54	11.35	1.68	0.6	1.08
5	0.6	12.61	1.26	0.6	0.66
6	0.66	13.87	1.26	0.6	0.66

Table 62: Flood Peak Computation (50yr RP)

Time (hrs) 1	U.G. Ordinate (cumecs) 2	1 Hr Effective rainfall 3	Direct Runoff (cumec) 4
5	40	0.66	26.43
6	69	2.34	161.60
7	92	4.23	389.46
8	**69**	**1.29**	89.10
9	**42**	**1.08**	45.41
10	**32**	**0.66**	21.15
		Total	733.15
		Base flow	0.61
		50-yr flood Peak	**733.75**

Table 63: Computation of design Flood Hydrograph for 50 year return period

Time Hrs	SUH ordinates	Rainfall Excess in cms						Total D.S.R.O. in cumecs	Base Flow in cumecs	Total Flow in cumecs
		0.66	1.08	1.29	4.23	2.34	0.66			
		Direct Runoff Hydrograph (cumecs)								
1	2	3	4	5	6	7	8	9	10	11
1	0	0.00						0.00	0.61	0.61
2	4.5	2.97	0.00					2.97	0.61	3.58
3	9	5.95	4.87	0.00				10.81	0.61	11.42
4	17	11.23	9.73	5.81	0.00			26.78	0.61	27.38
5	26.5	17.51	18.38	11.62	19.05	0.0		66.56	0.61	67.17
6	40	26.43	28.65	21.95	38.10	10.5	0.0	125.67	0.61	126.28
7	69	45.60	43.25	34.22	71.97	21.1	3.0	219.08	0.61	219.69
8	92	60.80	74.60	51.65	112.18	39.8	5.9	344.99	0.61	345.60
9	69	45.60	99.47	89.10	169.33	62.1	11.2	476.79	0.61	477.40
10	42	27.76	74.60	118.80	292.10	93.7	17.5	624.44	0.61	625.05
11	32	21.15	45.41	89.10	389.46	161.6	26.4	733.15	0.61	733.75
12	24	15.86	34.60	54.23	292.10	215.5	45.6	657.85	0.61	658.46
13	18	11.90	25.95	41.32	177.80	161.6	60.8	479.36	0.61	479.96
14	13	8.59	19.46	30.99	135.47	98.4	45.6	338.47	0.61	339.08
15	9	5.95	14.05	23.24	101.60	74.9	27.8	247.54	0.61	248.15
16	6.5	4.30	9.73	16.79	76.20	56.2	21.1	184.37	0.61	184.97
17	4	2.64	7.03	11.62	55.03	42.2	15.9	134.34	0.61	134.95
18	1	0.66	4.32	8.39	38.10	30.4	11.9	93.82	0.61	94.42
19	0	0.00	1.08	5.17	27.52	21.1	8.6	63.43	0.61	64.04
20			0.00	1.29	16.93	15.2	5.9	39.40	0.61	40.00
21				0.00	4.23	9.4	4.3	17.90	0.61	18.50
23					0	2.3	2.6	4.99	0.61	5.59
23						0.0	0.7	0.66	0.61	1.27
							0.0	0.00	0.61	0.61

C. 25 Year Return Period Flood Estimation

Table 64: Effective Rainfall Calculation

Duration (hr)	Distributed Coefficient	Storm Rainfall (cm)	Rainfall Increments (cm)	Loss Per Hr (cm)	Effective Rainfall Increments (cm)
1	**2**	**3**	**4**	**5**	**6**
1	0.23	4.23	4.23	0.6	3.63
2	0.37	6.80	2.57	0.6	1.97
3	0.46	8.45	1.65	0.6	1.05
4	0.54	9.92	1.47	0.6	0.87
5	0.6	11.03	1.10	0.6	0.50
6	0.66	12.13	1.10	0.6	0.50

Table 65: Flood Peak Computation (25yr RP)

Time (hrs) 1	U.G. Ordinate (cumecs) 2	1 Hr Effective rainfall 3	Direct Runoff (cumec) 4
5	40	0.50	20.11
6	69	1.97	136.14
7	92	3.63	333.70
8	69	1.05	72.73
9	42	0.87	36.55
10	32	0.50	16.09
		Total	615.33
		Base flow	0.61
		25-yr flood Peak	**615.93**

Table 66: Computation of design Flood Hydrograph for 25year return period

Time Hrs	SUH ordinates	Rainfall Excess in cms						Total D.S.R.O. in cumecs	Base Flow in cumecs	Total Flow in cumecs
		0.50	0.87	1.05	3.63	1.97	0.50			
		Direct Runoff Hydrograph (cumecs)								
1	2	3	4	5	6	7	8	9	10	11
1	0	0.00						0.00	0.61	0.61
2	4.5	2.26	0.00					2.26	0.61	2.87
3	9	4.52	3.92	0.00				8.44	0.61	9.05
4	17	8.55	7.83	4.74	0.00			21.12	0.61	21.73
5	26.5	13.32	14.80	9.49	16.32	0.0		53.93	0.61	54.53
6	40	20.11	23.06	17.92	32.64	8.9	0.0	102.62	0.61	103.22
7	69	34.69	34.81	27.93	61.66	17.8	2.3	179.12	0.61	179.72
8	92	46.25	60.05	42.16	96.12	33.5	4.5	282.66	0.61	283.26
9	69	34.69	80.07	72.73	145.09	52.3	8.5	393.41	0.61	394.02
10	42	21.12	60.05	96.98	250.28	78.9	13.3	520.67	0.61	521.27
11	32	16.09	36.55	72.73	333.70	136.1	20.1	615.33	0.61	615.93
12	24	12.07	27.85	44.27	250.28	181.5	34.7	550.68	0.61	551.28
13	18	9.05	20.89	33.73	152.34	136.1	46.3	398.40	0.61	399.01
14	13	6.54	15.67	25.30	116.07	82.9	34.7	281.13	0.61	281.73
15	9	4.52	11.31	18.97	87.05	63.1	21.1	206.12	0.61	206.72
16	6.5	3.27	7.83	13.70	65.29	47.4	16.1	153.53	0.61	154.14
17	4	2.01	5.66	9.49	47.15	35.5	12.1	111.89	0.61	112.49
18	1	0.50	3.48	6.85	32.64	25.6	9.0	78.18	0.61	78.78
19	0	0.00	0.87	4.22	23.58	17.8	6.5	52.96	0.61	53.56
20			0.00	1.05	14.51	12.8	4.5	32.91	0.61	33.52
21				0.00	3.63	7.9	3.3	14.79	0.61	15.39
23					0	2.0	2.0	3.98	0.61	4.59
23						0.0	0.5	0.50	0.61	1.11
							0.0	0.00	0.61	0.61

C. 5 Year Return Period Flood Estimation

Table 67: Effective Rainfall Calculation

Duration (hr)	Distributed Coefficient	Storm Rainfall (cm)	Rainfall Increments (cm)	Loss Per Hr (cm)	Effective Rainfall Increments (cm)
1	**2**	**3**	**4**	**5**	**6**
1	0.23	3.40	3.40	0.6	2.80
2	0.37	5.48	2.07	0.6	1.47
3	0.46	6.81	1.33	0.6	0.73
4	0.54	7.99	1.18	0.6	0.58
5	0.6	8.88	0.89	0.6	0.29
6	0.66	9.77	0.89	0.6	0.29

Table 68: Computation of Flood Peak (5yr RP)

Time (hrs) 1	U.G. Ordinate (cumecs) 2	1 Hr Effective rainfall 3	Direct Runoff (cumec) 4
5	40	0.29	11.51
6	69	1.47	101.55
7	92	2.80	257.92
8	**69**	**0.73**	50.49
9	**42**	**0.58**	24.52
10	**32**	**0.29**	9.21
		Total	455.21
		Base Flow	0.61
		5-yr Flood Peak	**455.82**

Table 69: Computation of design Flood Hydrograph for 5 year return period

Time Hrs	SUH ordinates	Rainfall Excess in cms						Total D.S.R.O. in cumecs	Base Flow in cumecs	Total Flow in cumecs
		0.50	0.87	1.05	3.63	1.97	0.50			
		Direct Runoff Hydrograph (cumecs)								
1	2	3	4	5	6	7	8	9	10	11
1	0	0.00						0.00	0.61	0.61
2	4.5	2.26	0.00					2.26	0.61	2.87
3	9	4.52	3.92	0.00				8.44	0.61	9.05
4	17	8.55	7.83	4.74	0.00			21.12	0.61	21.73
5	26.5	13.32	14.80	9.49	16.32	0.0		53.93	0.61	54.53
6	40	20.11	23.06	17.92	32.64	8.9	0.0	102.62	0.61	103.22
7	69	34.69	34.81	27.93	61.66	17.8	2.3	179.12	0.61	179.72
8	92	46.25	60.05	42.16	96.12	33.5	4.5	282.66	0.61	283.26
9	69	34.69	80.07	72.73	145.09	52.3	8.5	393.41	0.61	394.02
10	42	21.12	60.05	96.98	250.28	78.9	13.3	520.67	0.61	521.27
11	32	16.09	36.55	72.73	333.70	136.1	20.1	615.33	0.61	615.93
12	24	12.07	27.85	44.27	250.28	181.5	34.7	550.68	0.61	551.28
13	18	9.05	20.89	33.73	152.34	136.1	46.3	398.40	0.61	399.01
14	13	6.54	15.67	25.30	116.07	82.9	34.7	281.13	0.61	281.73
15	9	4.52	11.31	18.97	87.05	63.1	21.1	206.12	0.61	206.72
16	6.5	3.27	7.83	13.70	65.29	47.4	16.1	153.53	0.61	154.14
17	4	2.01	5.66	9.49	47.15	35.5	12.1	111.89	0.61	112.49
18	1	0.50	3.48	6.85	32.64	25.6	9.0	78.18	0.61	78.78
19	0	0.00	0.87	4.22	23.58	17.8	6.5	52.96	0.61	53.56
20			0.00	1.05	14.51	12.8	4.5	32.91	0.61	33.52
21				0.00	3.63	7.9	3.3	14.79	0.61	15.39
23					0	2.0	2.0	3.98	0.61	4.59
23						0.0	0.5	0.50	0.61	1.11
							0.0	0.00	0.61	0.61

Design Flood Hydrograph

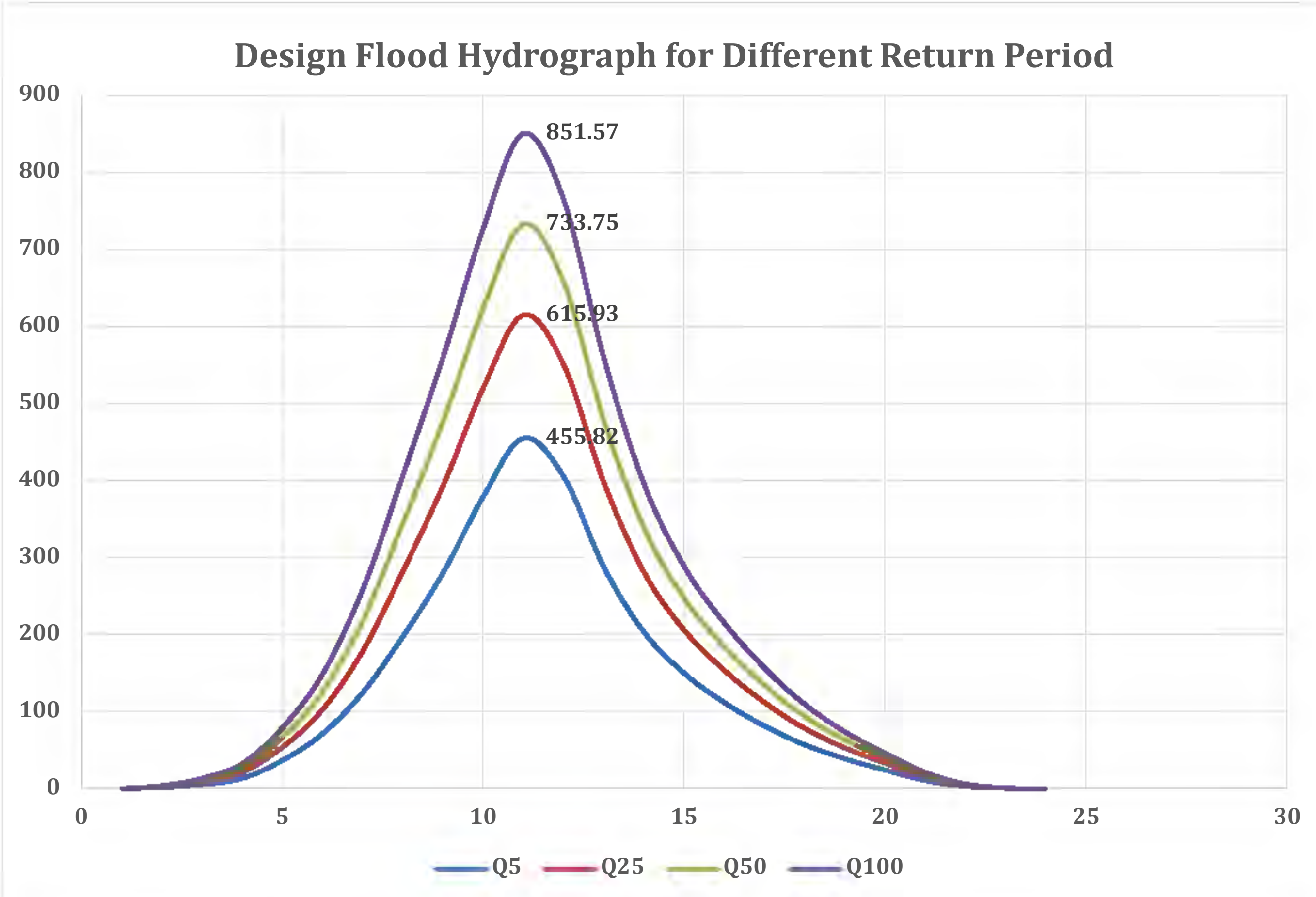


Fig. 30 Design Flood Hydrograph for different Return Period

Table 70: Discharges Values at different key locations for Jhakhan River

Identification Name	Catchment Area	Return Period (Year)			
		5	25	50	100
Silla Chowki	40.89	154	208	248	288
Golden Gate Bridge	55.16	208	281	334	388
Bangai Ghat Bridge	61.05	230	311	370	430
Jauligrant	93.99	354	478	570	661
Jhakhan River Crossing	97.11	366	494	589	683
Jeevan Wala	98.3	370	500	596	692
Majari Grant	101.43	382	516	615	714
Naturoville	114.29	431	582	693	804
At Confluence	121	456	616	734	852

Figure. 31 Key Locations at Jhakhan River

Table 71: Discharge values for Ungauged watershed of Jhakhan River:

Watershed Id	Catchment Area (Sq. km.	Return Period (Year)			
		5	25	50	100
1	19.4	73	99	118	137
2	10.04	38	51	61	71
4	10.29	39	52	62	72
3	11.95	45	61	72	84
5	42.31	159	215	257	298
6	20.31	77	103	123	143
7	6.59	25	34	40	46

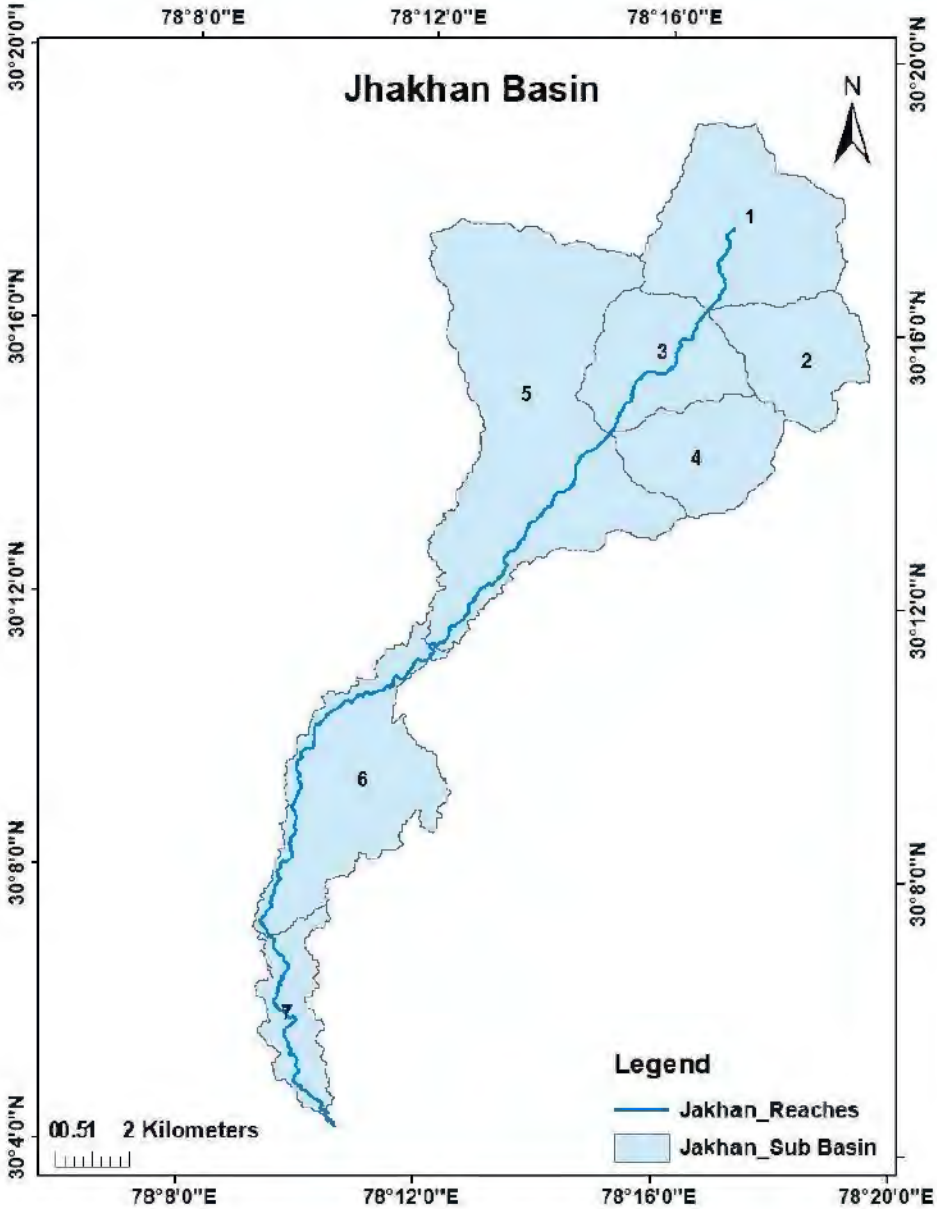


Figure 32: Ungauged watersheds of Jhakhan River. The Label ID denotes the numbering of watersheds.

5.3.1 Development of Regional Flood Frequency Relationship Using L-Moments Approach For Ungauged Catchments:

For development of regional flood frequency relationships for ungauged catchments, the regional flood frequency relationships developed for gauged catchments have been coupled with the regional relationships between mean annual peak floods and catchment areas of the respective Zones. In this manner the following form of regional flood frequency relationships have been developed for ungauged catchments.

For estimation of floods of commonly used returns periods for an ungauged catchment for a given catchment area the value of flood estimates may be directly obtained from the fig. mentioned below for western Zone-7 which is adopted from Regional Flood Frequency Estimation in India (Rakesh Kumar, 2011).

5.3.2 Design Flood Peak from Different Method:

Based on the above-mentioned envelope derived by L-moments return period flood peak values are compared with the design values obtained by SUH (synthetic unit hydrograph).

Table 72: Discharge Calculation by different approach

Return Period	Jhakhan River	
	SUH	L Moments
5	456	330
25	616	450
50	734	1000
100	852	1200

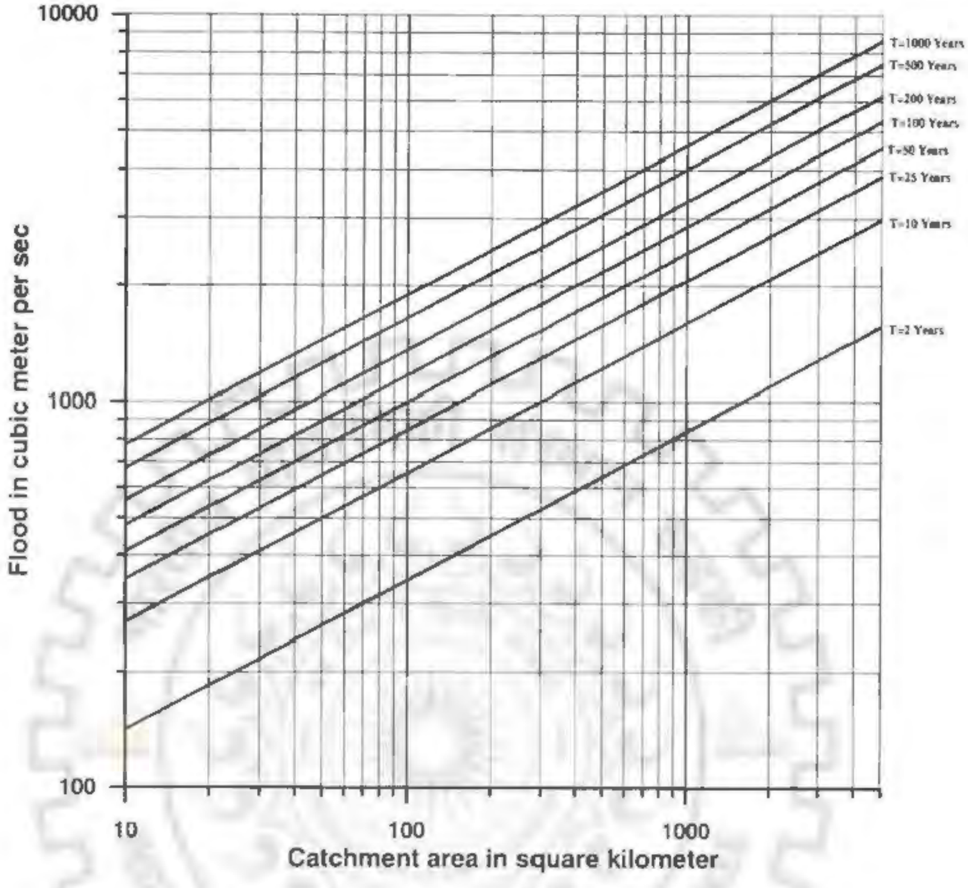


Figure 33: Variation of floods of Various return periods with catchment area based on L-moments for Sub-Himalayan region Zone-7

5.4 Flood Estimation for Chandrabhaga River

Physiographic parameters:

The physiographic parameters of the river catchment at project site have been estimated by GIS processing. The elevation along the longest flow path of the river varies from about 599 to 337 m. The estimated parameters of the river catchment at project site are given in Table.

Table-73: Catchment parameters for Chandrabhaga River:

Catchment Area (km^2)	L (km)	Lc (km)	Equivalent stream slope (m/km)
74	23	12	18.5

Assessment of Unit Hydrograph

In absence of short interval observed discharge and concurrent rainfall data; the unit hydrograph of one hour duration has been derived using Flood Estimation Report for Western Himalay zone-7 The estimated UH parameters are given at Table. The unit hydrograph ordinates as assessed for the unit hydrograph of catchment are given at Table.

Table-74: Unit Hydrograph Parameters:

Parameter	Unit	Value
Time from the centre of effective rainfall duration to the UH peak tp = 2.498*(L*Lc/S)0.156	hr	3.81
Peak discharge of unit hydrograph per unit area qp =1.048*(tp)-0.178	m 3 /sec/sq. km	0.83
Width of the UH measured at 50% of peak discharge ordinate W50 =1.954*(L*Lc/S)0.099	hr	2.55
Width of the UH measured at 75% of peak discharge ordinate W75 = 0.972*(L*Lc/S)0.124	hr	1.36
Width of the rising limb of UH measured at 50% of peak discharge ordinate WR50 = 0.189(W50)1.769	hr	0.99
Width of the rising limb of UH measured at 75% of peak discharge ordinate WR75 = 0.419(W75)1.246	hr	0.61
Base width of UH TB = 7.845*(tp)0.453	hr	14.38
Peak Discharge of UH Qp = qp x A	m 3 /sec	61.13
Unit duration of unit hydrograph tr	hr	1.00
Time from the start of rise to the peak of the UH Tm=tp+tr /2	hr	4.31
Q theoretical = A*d/0.36*tr here d= 1 cm depth and tr = 1 hr	m 3 /sec	205.56

Table-75: Return Period Rainfall

Return Period	5	10	25	50	100
Rainfall (mm)	178	219	272	311	350
Rainfall (cm)	17.8	21.9	27.2	31.1	35

Raingauge station rainfall are obtained by PMP Atlas for required return period the weighted average rainfall is calculated for the basin. Once the station rainfall is derived, the variou reduction factor, areal reduction factotr and appropriate distribution coefficients are applied to get effective rainfall, based on Td,TB & catchment area. (Annexure 5)

Table 76: Unit Hydrograph Ordinates

Unit Hydrograph	
Time (hrs)	**UH Ord.(m3/sec)**
0	0.0
1	2.6
2	7.8
3	15.5
4	36.2
5	62.0
6	37.2
7	28.4
8	21.2
9	15.5
10	11.4
11	8.3
12	5.2
13	3.1
14	1.0
15	0.0

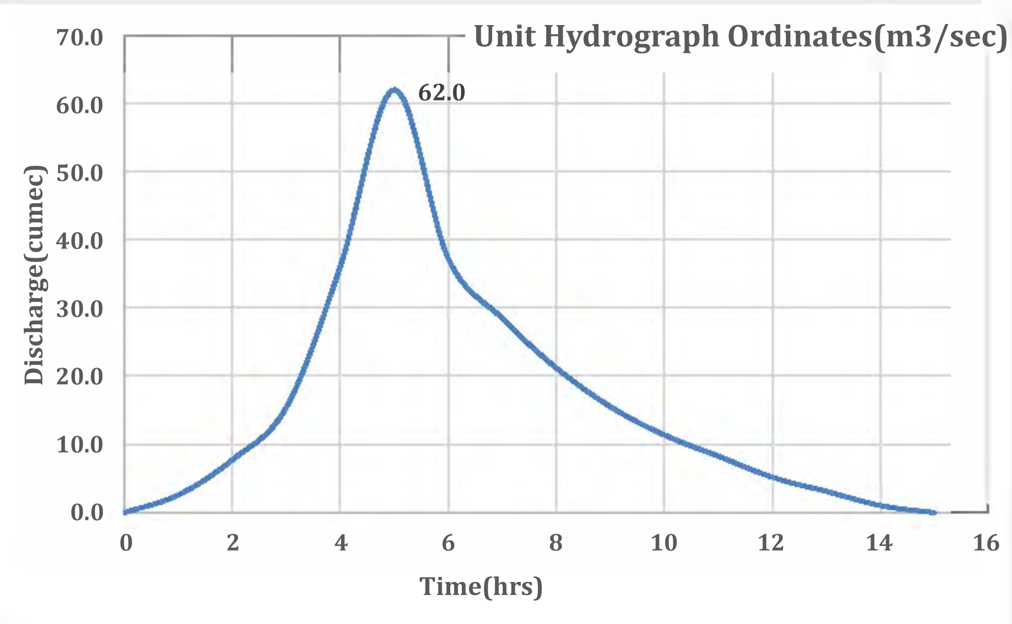


Figure 34: Synthetic UH for Chandrabhaga River Basin

A. 100 Year Return Flood Estimation

A design loss rate of 0to 0 .6 cm /hr as recommended in CWC FER of Western Himalayan zone-7 report for has been adopted for design flood computation.

As recommended by CWC Western Himalayan zone-7 report following base flow rate has been adopted:

Base flow / km^2 of drainage area = 0.10 (max)

Using the above formula, the computed base flow for the catchment area is 1.0 m^3 /sec.

Table 77: Effective Rainfall Calculation:

Duration (hr)	Distributed Coefficient	Storm Rainfall (cm)	Rainfall Increments (cm)	Loss Per Hr	Effective Rainfall Increments (cm)
1	0.56	12.70	12.70	0.6	12.10
2	0.75	17.00	4.31	0.6	3.71
3	0.87	19.72	2.72	0.6	2.12
4	0.96	21.76	2.04	0.6	1.44
5	1	22.67	0.91	0.6	0.31

Table 78: Computation of Flood Peak

Time (hrs)	U.G. Ordinate (cumec)	1-Hr Effective rainfall	Direct Runoff (cumec)
1	**2**	**3**	**4**
4	36.17	2.12	76.71
5	62.01	12.10	750.16
6	37.21	3.71	137.96
7	28.42	1.44	40.94
8	21.18	0.31	6.50
		Total	1012.28
		Base flow	1.00
		100yr- Flood Peak	**1013.28**

Table 79: Computation of Design Flood Hydrograph for 100year RP

Time Hrs	SUH ordinates	Rainfall Excess in cms					Total D.S.R.O. in cumecs	Base Flow in cumecs	Total Flow in cumecs
		0.31	**1.44**	**3.71**	**12.10**	**2.12**			
		Direct Runoff Hydrograph (cumecs)							
1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
1	0.0	0.00					0.00	1.00	1.00
2	2.6	0.79	0.00				0.79	1.00	1.79
3	7.8	2.38	3.72	0.00			6.10	1.00	7.10
4	15.5	4.76	11.17	9.58	0.00		25.50	1.00	26.50
5	36.2	11.10	22.33	28.74	31.26	0.00	93.43	1.00	94.43
6	62.0	19.03	52.11	57.48	93.77	5.48	227.87	1.00	228.87
7	37.2	11.42	89.33	134.13	187.54	16.44	438.85	1.00	439.85
8	28.4	8.72	53.60	229.93	437.59	32.88	762.72	1.00	763.72
9	21.2	6.50	40.94	137.96	750.16	76.71	1012.28	1.00	**1013.28**
10	15.5	4.76	30.52	105.39	450.10	131.51	722.27	1.00	723.27
11	11.4	3.49	22.33	78.56	343.82	78.91	527.11	1.00	528.11
12	8.3	2.54	16.38	57.48	256.30	60.28	392.98	1.00	393.98
13	5.2	1.59	11.91	42.15	187.54	44.93	288.12	1.00	289.12
14	3.1	0.95	7.44	30.66	137.53	32.88	209.46	1.00	210.46
15	1.0	0.32	4.47	19.16	100.02	24.11	148.08	1.00	149.08
16	0.0	0.00	1.49	11.50	62.51	17.53	93.03	1.00	94.03
17			0.00	3.83	37.51	10.96	52.30	1.00	53.30
18				0.00	12.50	6.58	19.08	1.00	20.08
19					0.00	2.19	2.19	1.00	3.19
20						0.00	0.00	1.00	1.00

50 Year Return Period Flood

Table 80: Effective Rainfall Calculation

Duration (hr)	Distributed Coefficient	Storm Rainfall (cm)	Rainfall Increments (cm)	Loss Per Hr (cm)	Effective Rainfall Increments (cm)
1	**2**	**3**	**4**	**5**	**6**
1	0.56	11.28	11.28	0.6	10.68
2	0.75	15.11	3.83	0.6	3.23
3	0.87	17.53	2.42	0.6	1.82
4	0.96	19.34	1.81	0.6	1.21
5	1	20.14	0.81	0.6	0.21

Table 81: Flood Peak Computation

Time (hrs)	U.G. Ordinate (cumec)	1 Hr Effective rainfall	Direct Runoff (cumec)
1	**2**	**3**	**4**
4	35	1.82	63.61
5	60	10.68	640.86
6	36	3.23	116.19
7	27.5	1.21	33.36
8	20.5	0.21	4.22
		Total	858.24
		Base flow	1.00
		50yr- Flood Peak	**859.24**

Table 82: Design Flood Hydrograph

Time Hrs	SUH ordinates	Rainfall Excess in cms					Total D.S.R.O. in cumecs	Base Flow in cumecs	Total Flow in cumecs
		0.21	1.21	3.23	10.68	1.82			
		Direct Runoff Hydrograph (cumecs)							
1	2	3	4	5	6	7	8	9	10
1	0	0.00					0.00	1.00	1.00
2	2.5	0.51	0.00				0.51	1.00	1.51
3	7.5	1.54	3.03	0.00			4.58	1.00	5.58
4	15	3.09	9.10	8.07	0.00		20.25	1.00	21.25
5	35	7.20	18.20	24.21	26.70	0.00	76.31	1.00	77.31
6	60	12.35	42.46	48.41	80.11	4.54	187.87	1.00	188.87
7	36	7.41	72.78	112.96	160.22	13.63	367.00	1.00	368.00
8	27.5	5.66	43.67	193.65	373.84	27.26	644.07	1.00	645.07
9	20.5	4.22	33.36	116.19	640.86	63.61	858.24	1.00	**859.24**
10	15	3.09	24.87	88.76	384.52	109.04	610.27	1.00	611.27
11	11	2.26	18.20	66.16	293.73	65.43	445.78	1.00	446.78
12	8	1.65	13.34	48.41	218.96	49.98	332.34	1.00	333.34
13	5	1.03	9.70	35.50	160.22	37.26	243.71	1.00	244.71
14	3	0.62	6.07	25.82	117.49	27.26	177.25	1.00	178.25
15	1	0.21	3.64	16.14	85.45	19.99	125.42	1.00	126.42
16	0	0.00	1.21	9.68	53.41	14.54	78.84	1.00	79.84
17			0.00	3.23	32.04	9.09	44.36	1.00	45.36
18				0.00	10.68	5.45	16.13	1.00	17.13
19					0.00	1.82	1.82	1.00	2.82
20						0.00	0.00	1.00	1.00

C. 25 Year Return Period Flood Estimation:

Table 83: Effective Rainfall Calculation

Duration (hr)	Distributed Coefficient	Storm Rainfall (cm)	Rainfall Increments (cm)	Loss Per Hr (cm)	Effective Rainfall Increments (cm)
1	**2**	**3**	**4**	**5**	**6**
1	0.56	9.87	9.87	0.6	9.27
2	0.75	13.21	3.35	0.6	2.75
3	0.87	15.33	2.11	0.6	1.51
4	0.96	16.91	1.59	0.6	0.99
5	1	17.62	0.70	0.6	0.10

Table 84: Flood Peak Estimation

Time (hrs)	U.G. Ordinate (cumec)	1-Hr Effective rainfall	Direct Runoff (cumec)
1	**2**	**3**	**4**
4	35	1.51	53.00
5	60	9.27	555.98
6	36	2.75	98.91
7	27.5	0.99	27.11
8	20.5	0.10	2.15
		Total	737.14
		Base flow	1.00
		25yr- Flood Peak	**738.14**

Table 85: Design Flood Hydrograph

Time Hrs	SUH ordinates	Rainfall Excess in cms					Total D.S.R.O. in cumecs	Base Flow in cumecs	Total Flow in cumecs
		0.10	0.99	2.75	9.27	1.51			
		Direct Runoff Hydrograph (cumecs)							
1	2	3	4	5	6	7	8	9	10
1	0	0.00					0.00	1.00	1.00
2	2.5	0.26	0.00				0.26	1.00	1.26
3	7.5	0.79	2.46	0.00			3.25	1.00	4.25
4	15	1.57	7.39	6.87	0.00		15.83	1.00	16.83
5	35	3.67	14.79	20.61	23.17	0.00	62.22	1.00	63.22
6	60	6.28	34.50	41.21	69.50	3.79	155.28	1.00	156.28
7	36	3.77	59.14	96.16	139.00	11.36	309.43	1.00	310.43
8	27.5	2.88	35.48	164.85	324.32	22.71	550.25	1.00	551.25
9	20.5	2.15	27.11	98.91	555.98	53.00	737.14	1.00	**738.14**
10	15	1.57	20.21	75.56	333.59	90.85	521.78	1.00	522.78
11	11	1.15	14.79	56.32	254.83	54.51	381.60	1.00	382.60
12	8	0.84	10.84	41.21	189.96	41.64	284.49	1.00	285.49
13	5	0.52	7.89	30.22	139.00	31.04	208.67	1.00	209.67
14	3	0.31	4.93	21.98	101.93	22.71	151.87	1.00	152.87
15	1	0.10	2.96	13.74	74.13	16.66	107.59	1.00	108.59
16	0	0.00	0.99	8.24	46.33	12.11	67.67	1.00	68.67
17			0.00	2.75	27.80	7.57	38.12	1.00	39.12
18				0.00	9.27	4.54	13.81	1.00	14.81
19					0.00	1.51	1.51	1.00	2.51
20						0.00	0.00	1.00	1.00

D. 5 Year Return Period Flood Estimation:

Table 86: Effective Rainfall Calculation

Duration (hr)	Distributed Coefficient	Storm Rainfall (cm)	Rainfall Increments (cm)	Loss Per Hr (cm)	Effective Rainfall Increments (cm)
1	**2**	**3**	**4**	**5**	**6**
1	0.56	6.46	6.46	0.6	5.86
2	0.75	8.65	2.19	0.6	1.59
3	0.87	10.03	1.38	0.6	0.78
4	0.96	11.07	1.04	0.6	0.44
5	1	11.53	0.46	0.4	0.06

Table 87: Flood Peak Estimation

Time (hrs)	U.G. Ordinate (cumec)	1-Hr Effective rainfall	Direct Runoff (cumec)
1	**2**	**3**	**4**
4	35	0.78	27.43
5	60	5.86	351.40
6	36	1.59	57.26
7	27.5	0.44	12.04
8	20.5	0.06	1.25
		Total	449.38
		Base flow	1.00
		5yr- Flood Peak	**450.38**

Table 88: Design Flood Hydrograph

Time Hrs	SUH ordinates	Rainfall Excess in cms					Total D.S.R.O. in cumecs	Base Flow in cumecs	Total Flow in cumecs
		0.06	0.44	1.59	5.86	0.78			
		Direct Runoff Hydrograph (cumecs)							
1	2	3	4	5	6	7	8	9	10
1	0	0.00					0.00	1.00	1.00
2	2.5	0.15	0.00				0.15	1.00	1.15
3	7.5	0.46	1.09	0.00			1.55	1.00	2.55
4	15	0.92	3.28	3.98	0.00		8.18	1.00	9.18
5	35	2.14	6.57	11.93	14.64	0.00	35.28	1.00	36.28
6	60	3.67	15.32	23.86	43.93	1.96	88.73	1.00	89.73
7	36	2.20	26.26	55.67	87.85	5.88	177.86	1.00	178.86
8	27.5	1.68	15.76	95.44	204.98	11.75	329.62	1.00	330.62
9	20.5	1.25	12.04	57.26	351.40	27.43	449.38	1.00	**450.38**
10	15	0.92	8.97	43.74	210.84	47.01	311.49	1.00	312.49
11	11	0.67	6.57	32.61	161.06	28.21	229.11	1.00	230.11
12	8	0.49	4.81	23.86	120.06	21.55	170.77	1.00	171.77
13	5	0.31	3.50	17.50	87.85	16.06	125.22	1.00	126.22
14	3	0.18	2.19	12.73	64.42	11.75	91.27	1.00	92.27
15	1	0.06	1.31	7.95	46.85	8.62	64.80	1.00	65.80
16	0	0.00	0.44	4.77	29.28	6.27	40.76	1.00	41.76

17			0.00	1.59	17.57	3.92	23.08	1.00	24.08
18				0.00	5.86	2.35	8.21	1.00	9.21
19					0.00	0.78	0.78	1.00	1.78
20						0.00	0.00	1.00	1.00

Discharges at Different Return Period

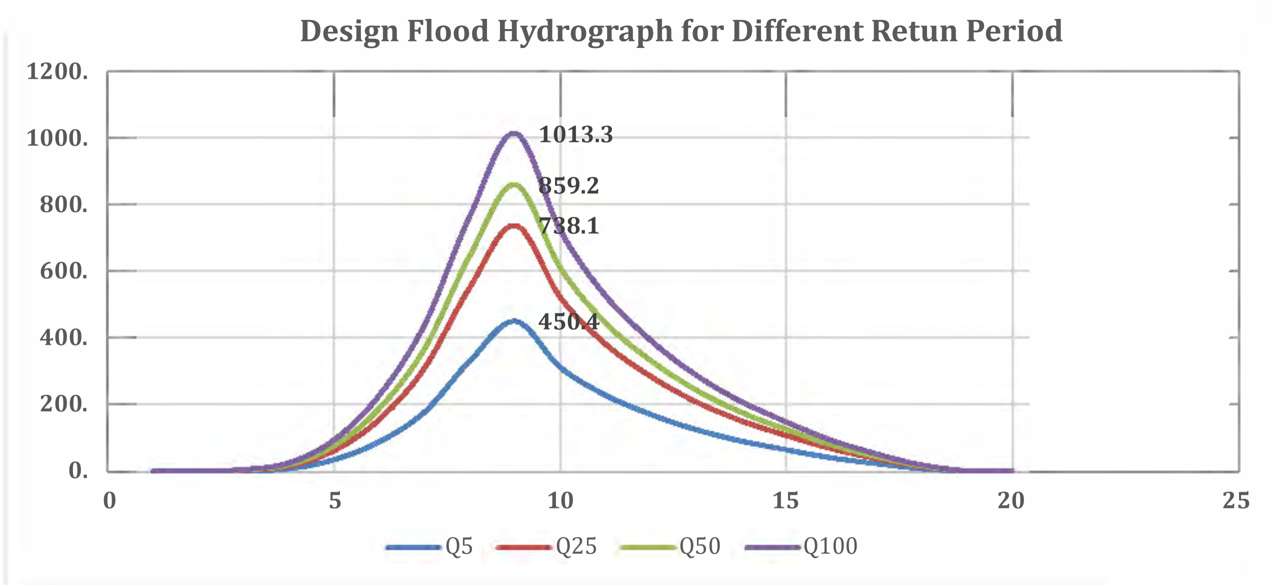


Figure 35: Design Flood Hydrograph for different Return Period

Table 89: Discharges Values at different key locations for Chandrabhaga River:

Identification Name	Catchment Area	Return Period (Year)			
		5	25	50	100
Kandari Gaon	22	134	220	256	302
Iron Bridge Narendra Nagar	31	189	310	361	426
Hanuman Jhula	39	236	387	450	531
Chandrabhaga Bridge	70	426	698	813	959
At Confluence with Ganga	74	450	738	859	1013

Table 90: Discharge values for Ungauged watershed of Chandrabhaga River:

Watershed Id	Catchment Area (Sq. km.	Return Period (Year)			
		5	25	50	100
1	13.62	83	136	158	187
2	8.43	51	84	98	115
4	5.57	34	56	65	76
3	16.75	102	167	194	229
5	28.72	175	286	333	393

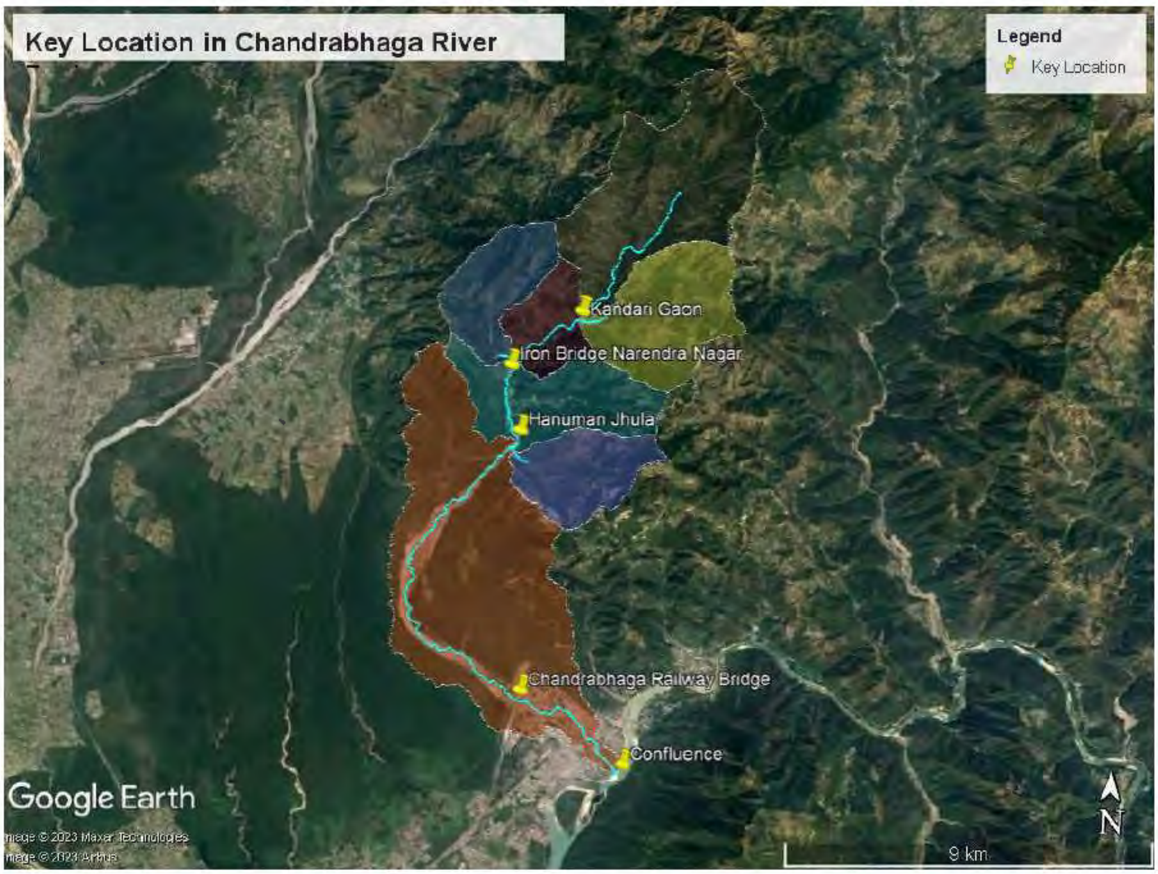


Figure 36: Key Locations at Chandrabhaga River

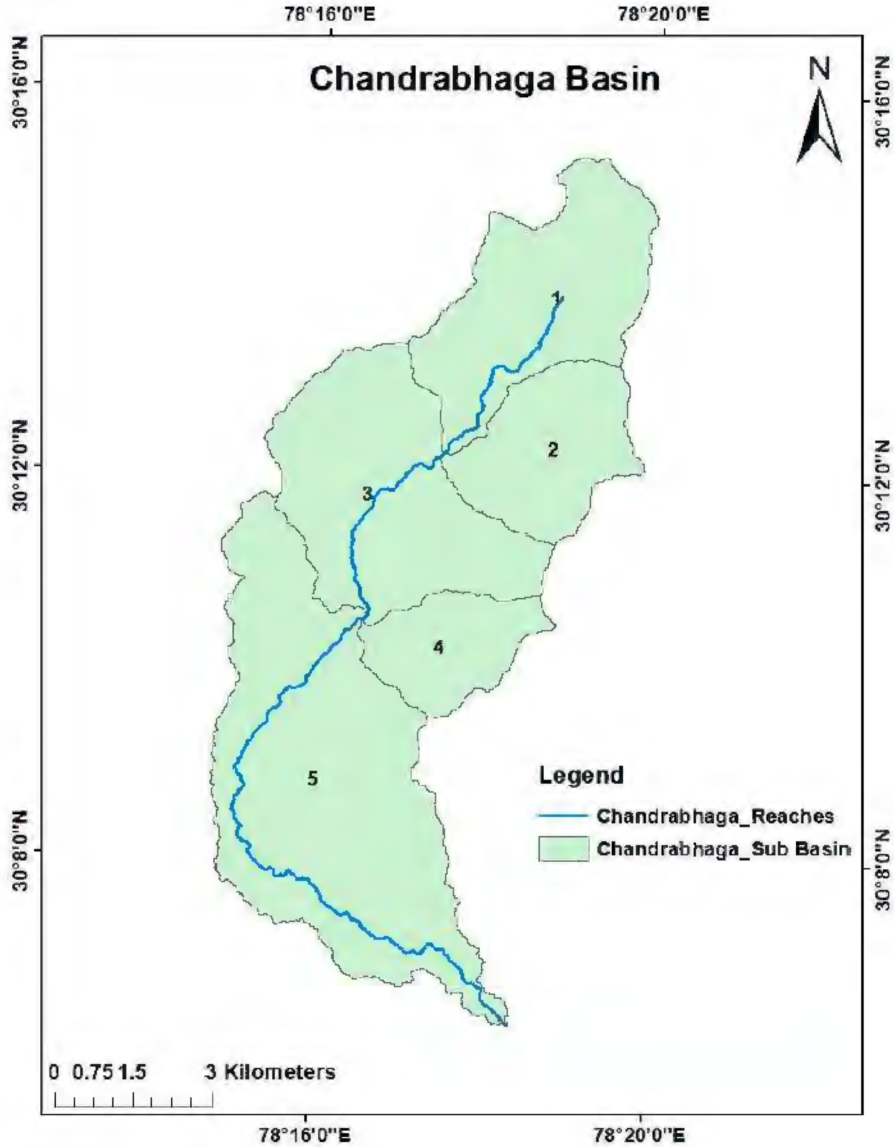


Figure 37: Ungauged watersheds contributing water to the Chandrabhaga River. The Label ID denotes the numbering of watersheds

5.4.1 Development of Regional Flood Frequency Relationship Using L-Moments Approach For Ungauged Catchments:

For development of regional flood frequency relationships for ungauged catchments, the regional flood frequency relationships developed for gauged catchments have been coupled with the regional relationships between mean annual peak floods and catchment areas of the respective Zones. In this manner the following form of regional flood frequency relationships have been developed for ungauged catchments.

For estimation of floods of commonly used returns periods for an ungauged catchment for a given catchment area the value of flood estimates may be directly obtained from the fig. mentioned below for western Zone-7 which is adopted from Regional Flood Frequency Estimation in India (Rakesh Kumar, 2011).

5.4.2Design Flood Peak from Different Method:

Based on the above-mentioned envelope derived by L-moments return period flood peak values are compared with the design values obtained by SUH (synthetic unit hydrograph).

Table 91 Discharges from Different approach

Return Period	Chandrabhaga River	
	SUH	L Moments
5	450	300
25	738	850
50	859	950
100	1013	1100

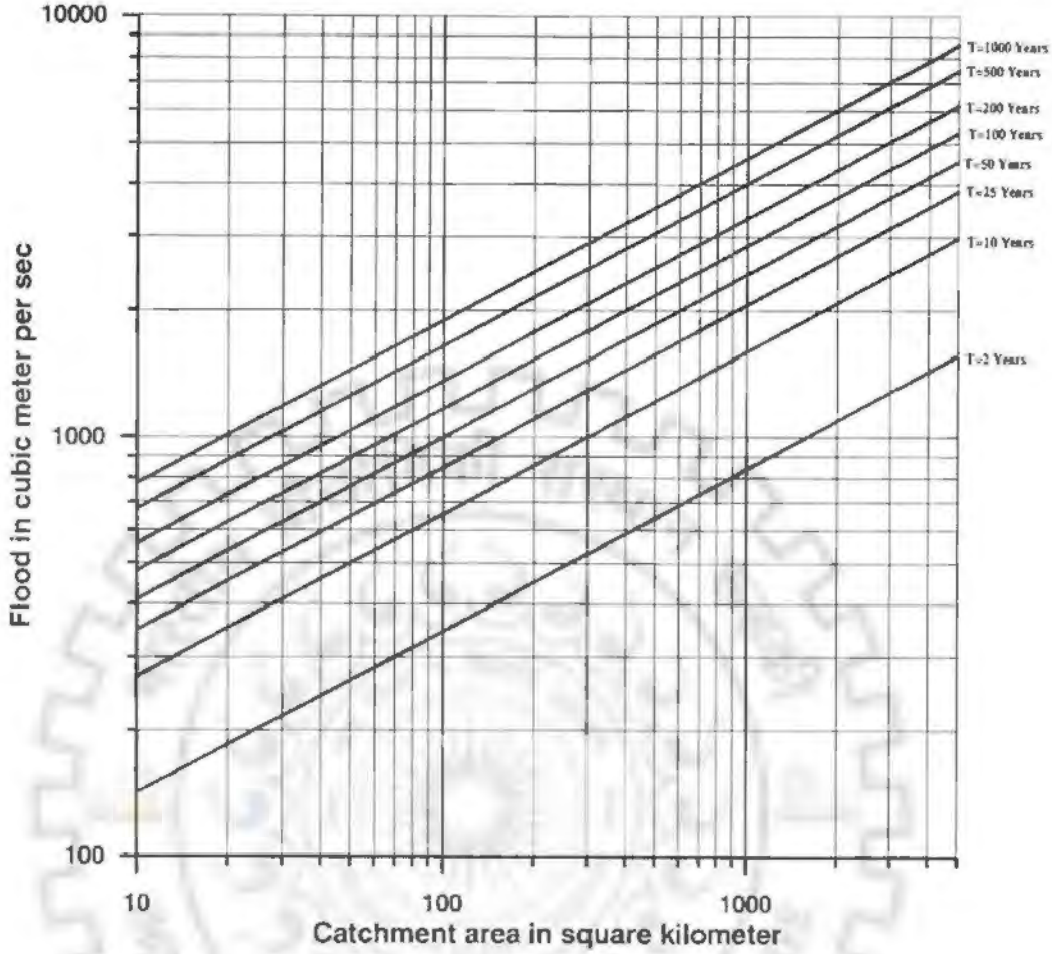


Figure 38: Variation of floods of Various return periods with catchment area based on L-moments for Sub-Himalayan region Zone-7

6. Parametric Analysis

6.1 Integration of Multiple DEMs for Enhanced Terrain Modeling

Introduction:

In this section, we delve into the integration of multiple Digital Elevation Models (DEMs) to create a detailed and accurate representation of terrain features. We focus on the process of integrating DEMs derived from different satellite sensors, namely the Shuttle Radar Topography Mission (SRTM), Advanced Land Observing Satellite (ALOS) Phased Array L-band Synthetic Aperture Radar (PALSAR), and FAB DEM data. The integration of these datasets, each with varying resolutions ranging from 30 meters to 10 meters, presents challenges and opportunities for enhancing terrain modelling capabilities.

Data Integration and Processing:

The integration process commenced by selecting the ALOS PALSAR data as the master file, owing to its finer 10-meter resolution. Geometric correction techniques were then applied to the SRTM and FAB DEM data, treating them as slave files, to ensure spatial alignment with the master dataset. This correction involved rigorous transformations such as affine and polynomial transformations to minimize distortions and achieve precise registration between datasets. The successful alignment of slave datasets with the master dataset was critical for maintaining spatial accuracy and coherence across the composite DEM.

Process Flow:

1. Data Acquisition:

- Obtain DEM datasets from different sources, including SRTM, ALOS PALSAR, and FAB DEM data.
- Ensure availability of metadata describing resolution, spatial coverage, and acquisition dates for each dataset.

2. Selection of Master Dataset:

- Choose the ALOS PALSAR dataset as the master file due to its finer 10 meters resolution, which serves as the reference for spatial accuracy.

3. Geometric Correction:

- Apply geometric correction to align slave datasets (SRTM and FAB DEM) with the master dataset (ALOS PALSAR).
- Utilize techniques such as affine and polynomial transformations to minimize distortions and achieve precise registration between datasets.

Field Survey Data Incorporation:

To augment the accuracy and reliability of the composite DEM, ground-truth measurements obtained from field surveys were incorporated into the GIS environment. These field data served as reference points for validating and refining the DEM, thereby enhancing its spatial accuracy. Spatial interpolation techniques, including kriging or inverse distance weighting, were employed to interpolate elevation values between survey points, further improving the fidelity of the DEM. Moreover, temporal considerations were addressed by accounting for temporal changes in terrain features, ensuring the temporal coherence of the final DEM

4. Field Survey Data Collection:

- Conduct field surveys to collect ground-truth measurements of elevation.
- Record GPS coordinates and elevation values at representative locations across the study area.

5. Field Survey Data Incorporation:

- Import field survey data into the GIS environment.
- Use field data as reference points for validating and refining the DEM.

6. Spatial Interpolation:

- Employ spatial interpolation techniques (e.g., kriging, inverse distance weighting) to interpolate elevation values between survey points.
- Enhance spatial accuracy by filling gaps and smoothing irregularities in the DEM surface.

Resolution Enhancement and Grid Development:

To capture finer-scale terrain details, daughter grids were generated from the field survey data, typically at a resolution of 1 meter. These daughter grids provided a higher resolution representation of terrain features, such as ridges, valleys, and micro-topographic variations. Subsequently, the composite DEM was resampled to match the resolution of the daughter grids, thereby enhancing the level of detail and precision in terrain representation.

7. Resolution Enhancement:

- Generate daughter grids from field survey data at a finer resolution (e.g., 1 meter) to capture detailed terrain features.
- Resample the composite DEM to match the resolution of daughter grids, increasing the level of detail and precision in terrain representation.

Conclusion:

The integration of multiple DEMs, coupled with meticulous data processing and field survey incorporation, resulted in the generation of a comprehensive and high-resolution terrain model. This model provides valuable insights into the complex terrain dynamics of the study area, supporting various geospatial analyses and applications. The methodology outlined in this section offers a systematic approach for leveraging diverse remote sensing datasets and field observations to enhance terrain modelling capabilities, thereby advancing our understanding of landscape dynamics and informing decision-making processes.

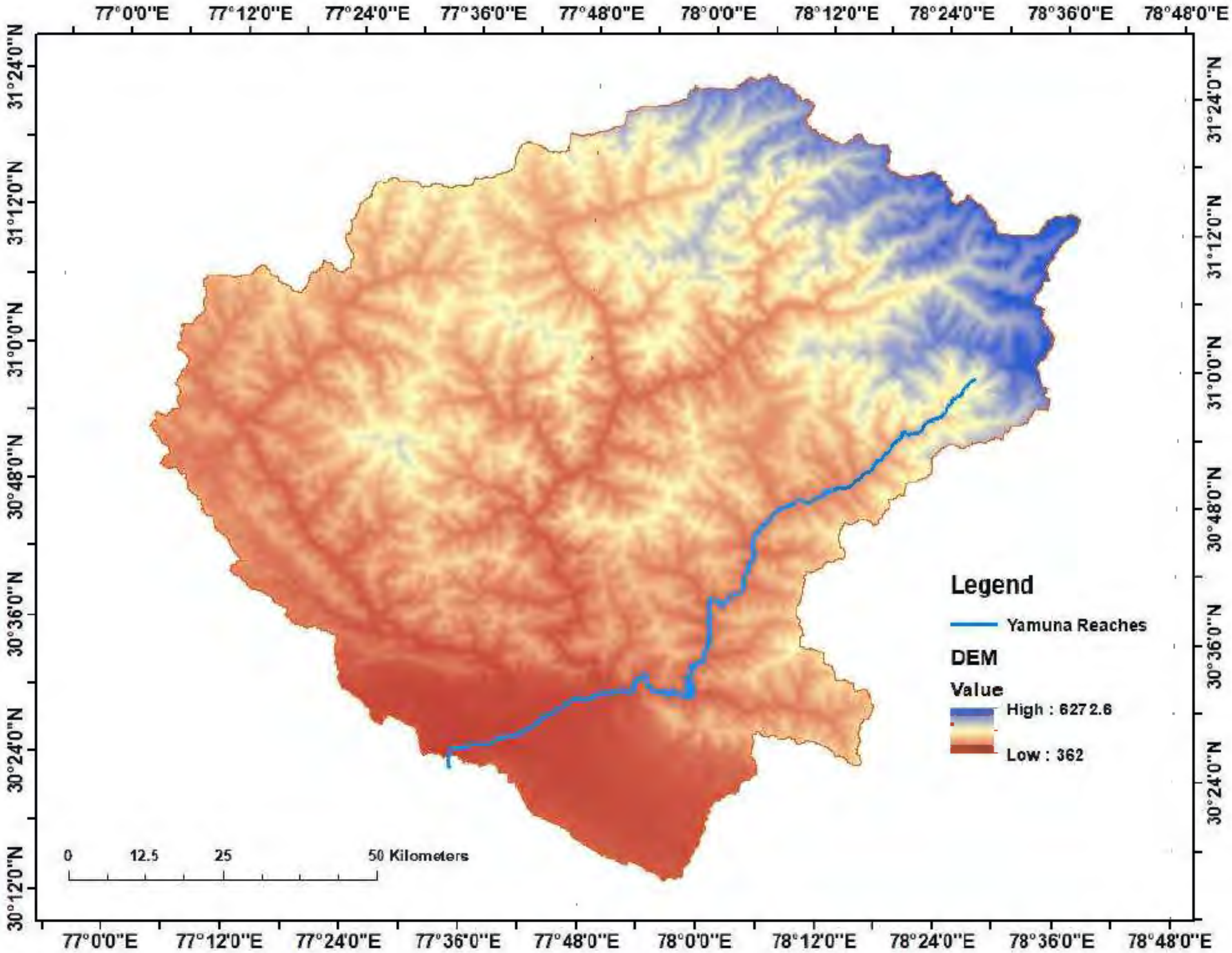


Figure 39. Hybrid DEM for Yamuna Basin

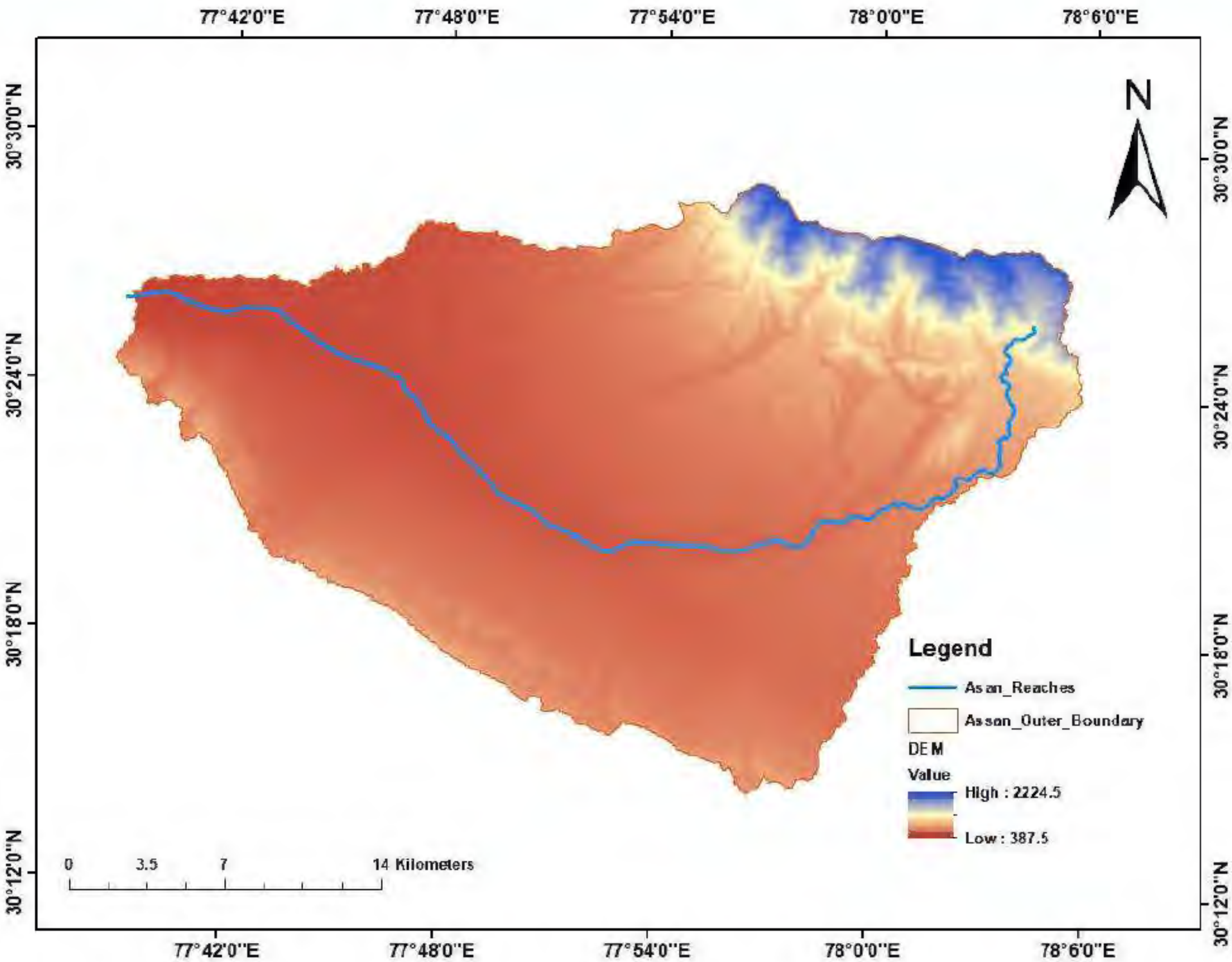


Figure 40. Hybrid DEM for Asan Basin

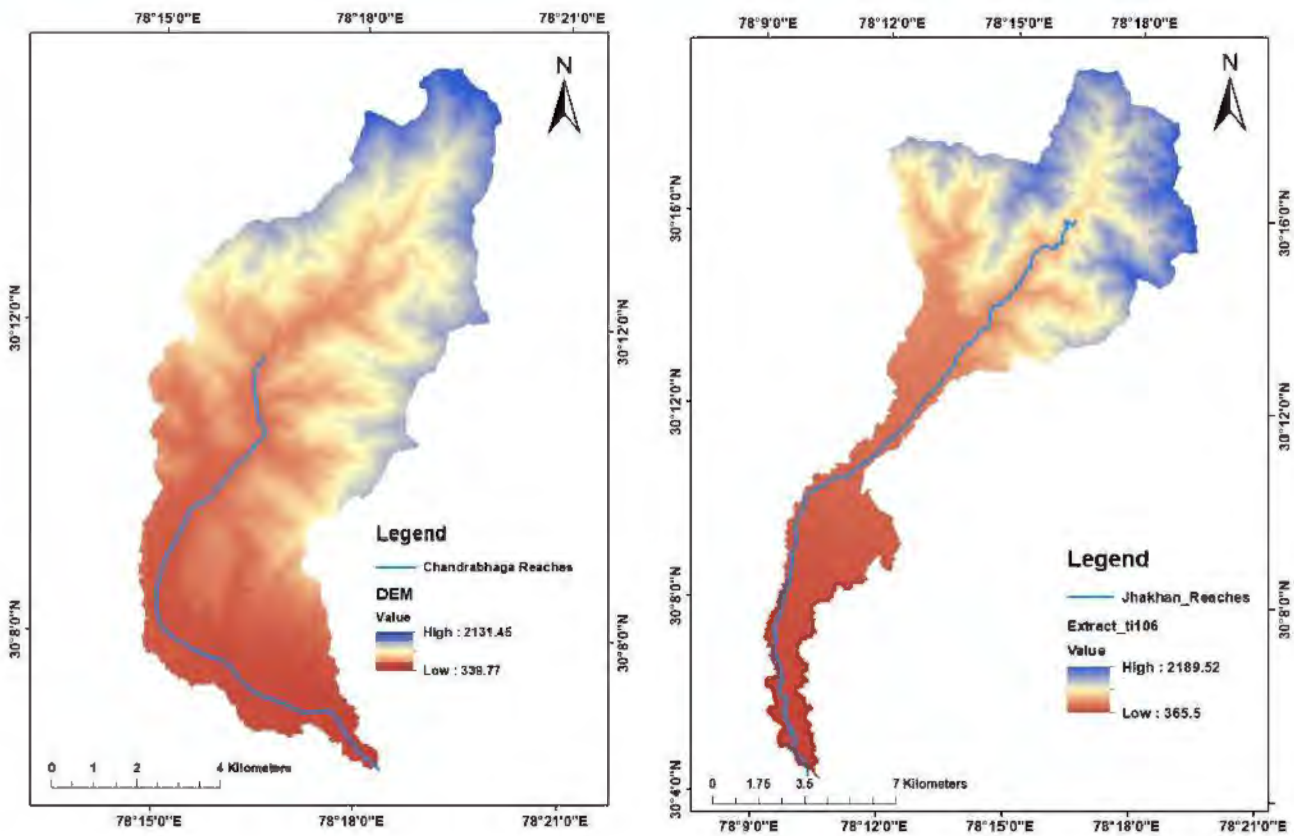


Figure 41. Hybrid DEM for Chandrabhaga & Jhakhan basin

6.2 Soil Type

The soil map of the area has been procured from the National bureau of Soil Science & Land Use Planning (NBSS-LUP), Nagpur.

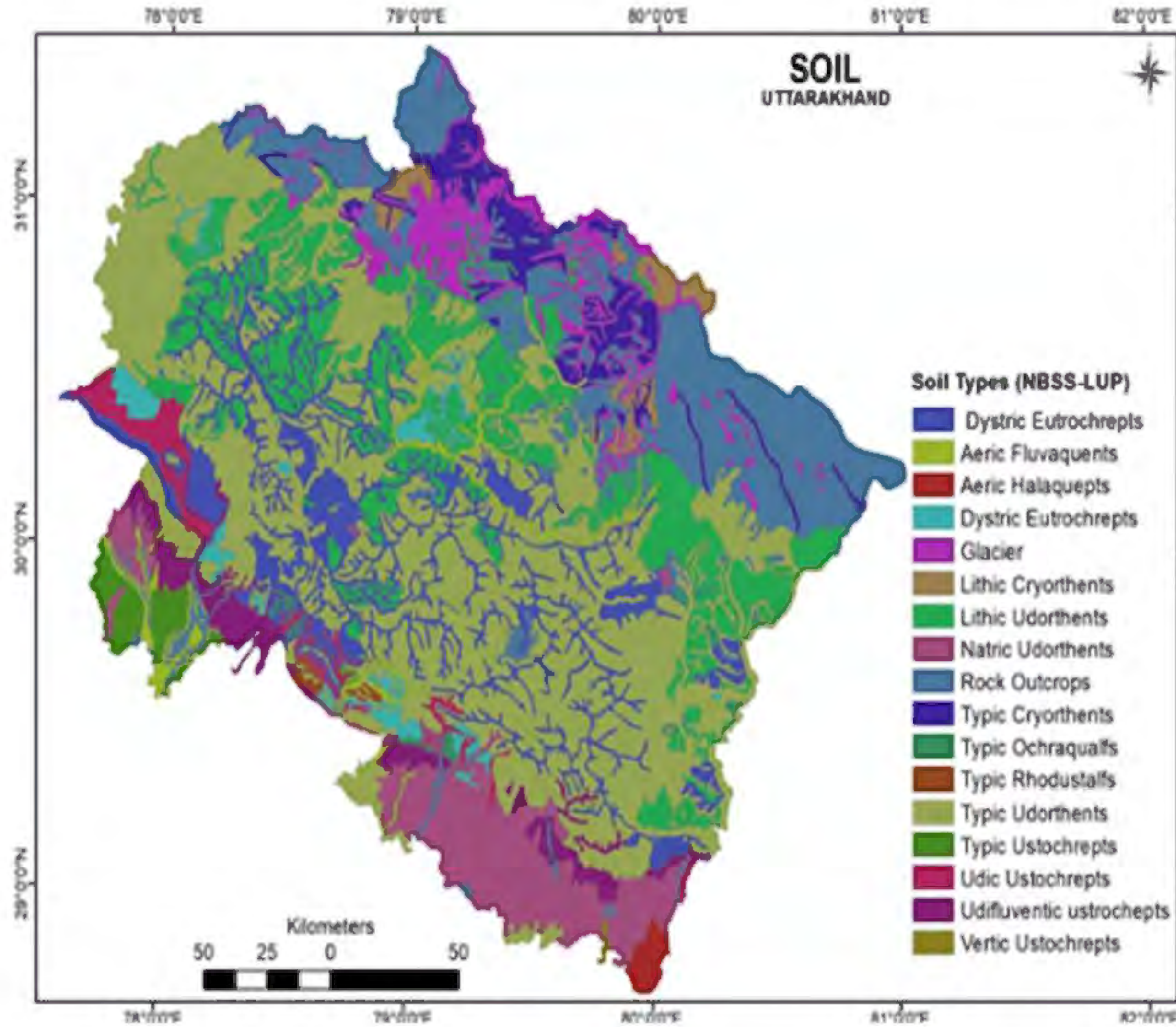


Figure 42. NBSS LUP Soil Map of India

7. River Geometry Creation in RAS Mapper

In the RAS tab of HEC-RAS, the projection and datum (UTM Zone 43 N, WGS 84) have been defined. The Cartosat DEM and Google Earth images have been added to define the river geometry for 1D flow modeling. River geometry (channel central line, bank lines, flow paths, transverse cross-sections, and levee) has been created using Cartosat digital elevation model (DEM) (Shown in fig. 44-46) and geomorphological map. Manning's N values for built-up areas, barren land, forest, river bed, scrub and arable land on a transverse cross- section has been taken from Chow (1959) and Syme (2008). The maximum LU/LC category on a cross-section is 20. In other words, on a cross-section, HECRAS can plot a maximum of 20 Manning's N values.

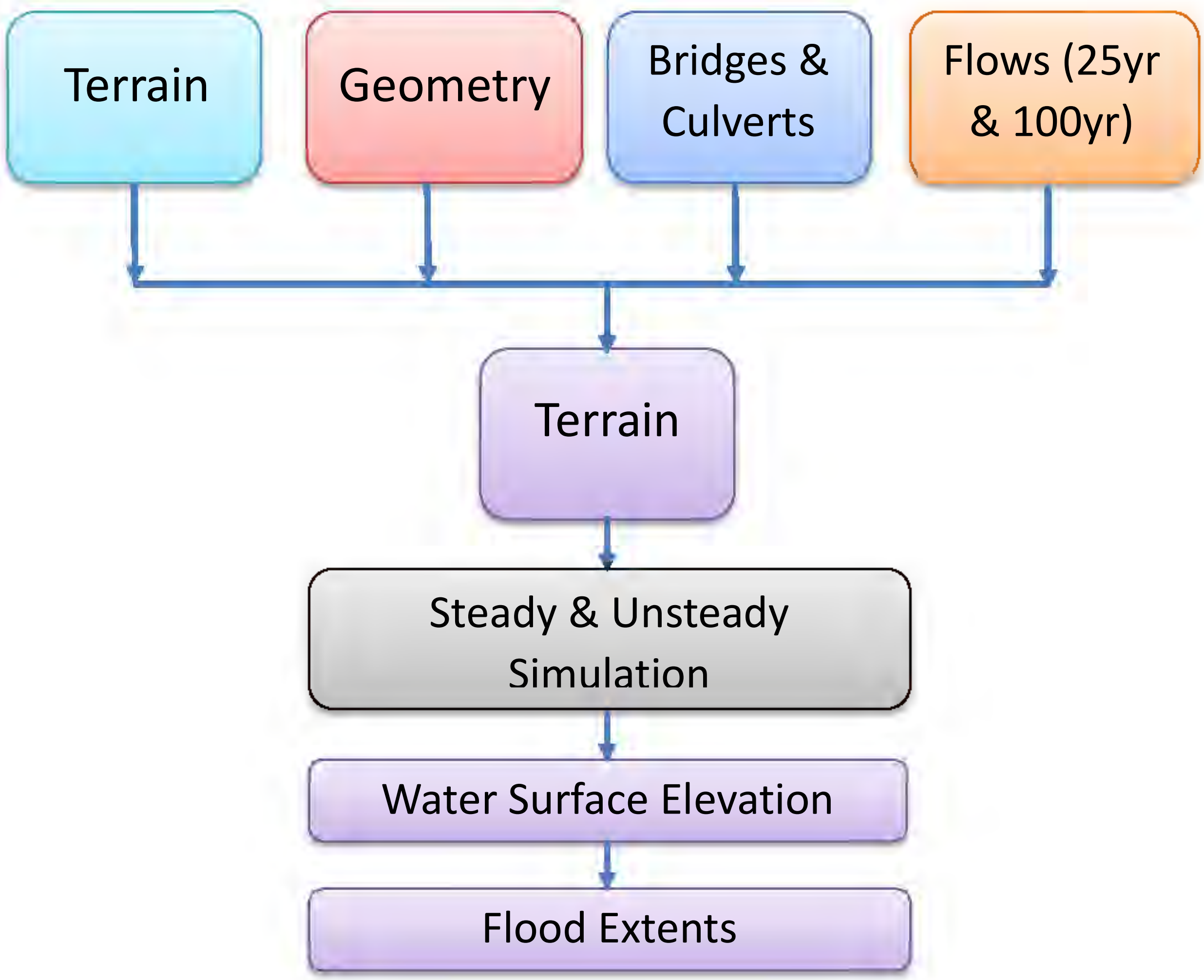


Figure 43. Flow Chart for Flood Modelling

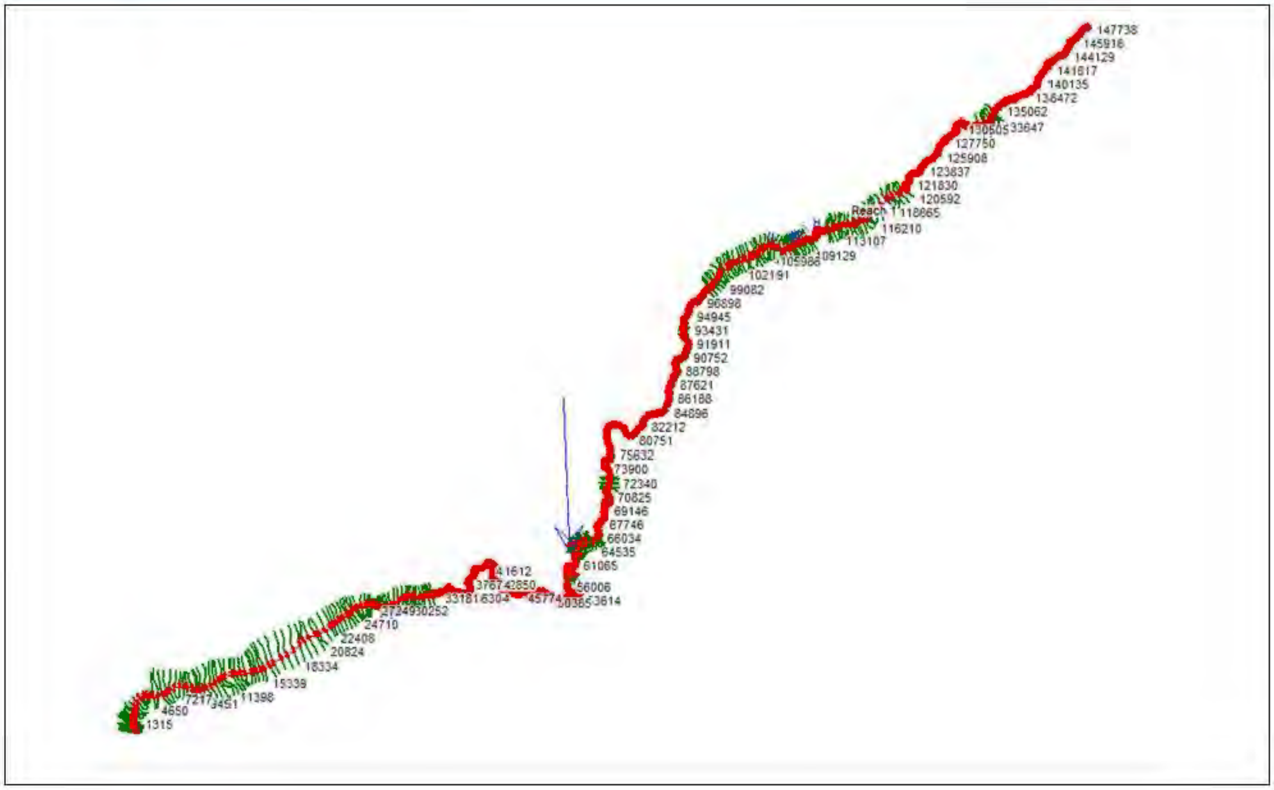


Figure:44 River geometry with cross section for Yamuna River.

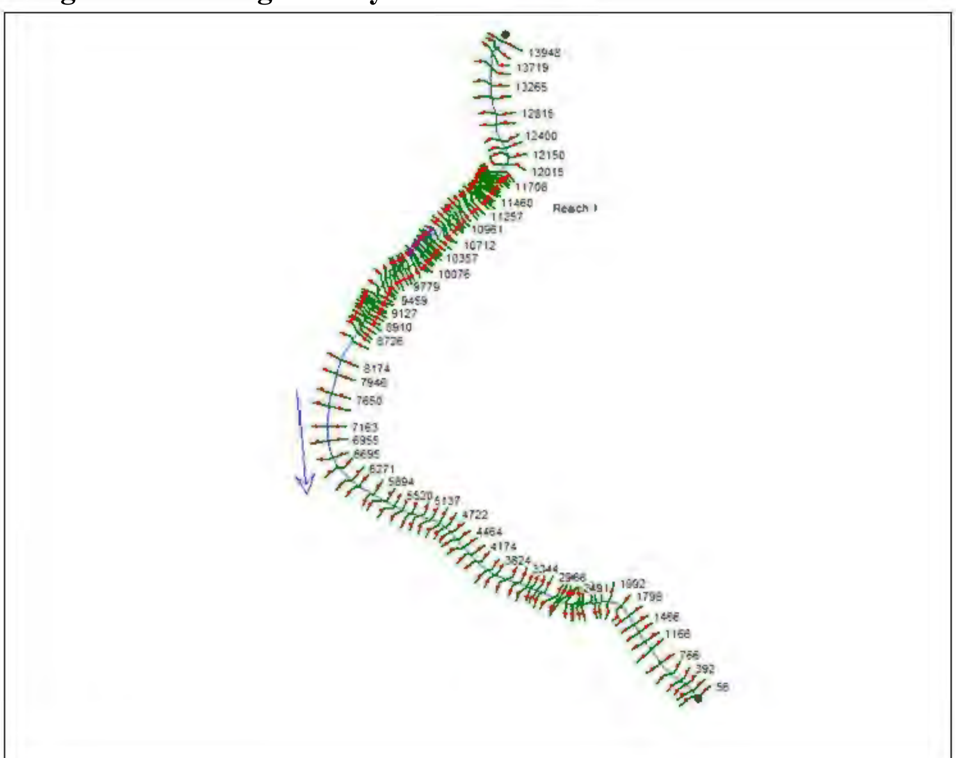


Figure:45 River geometry with cross section for Chandrabhaga River.

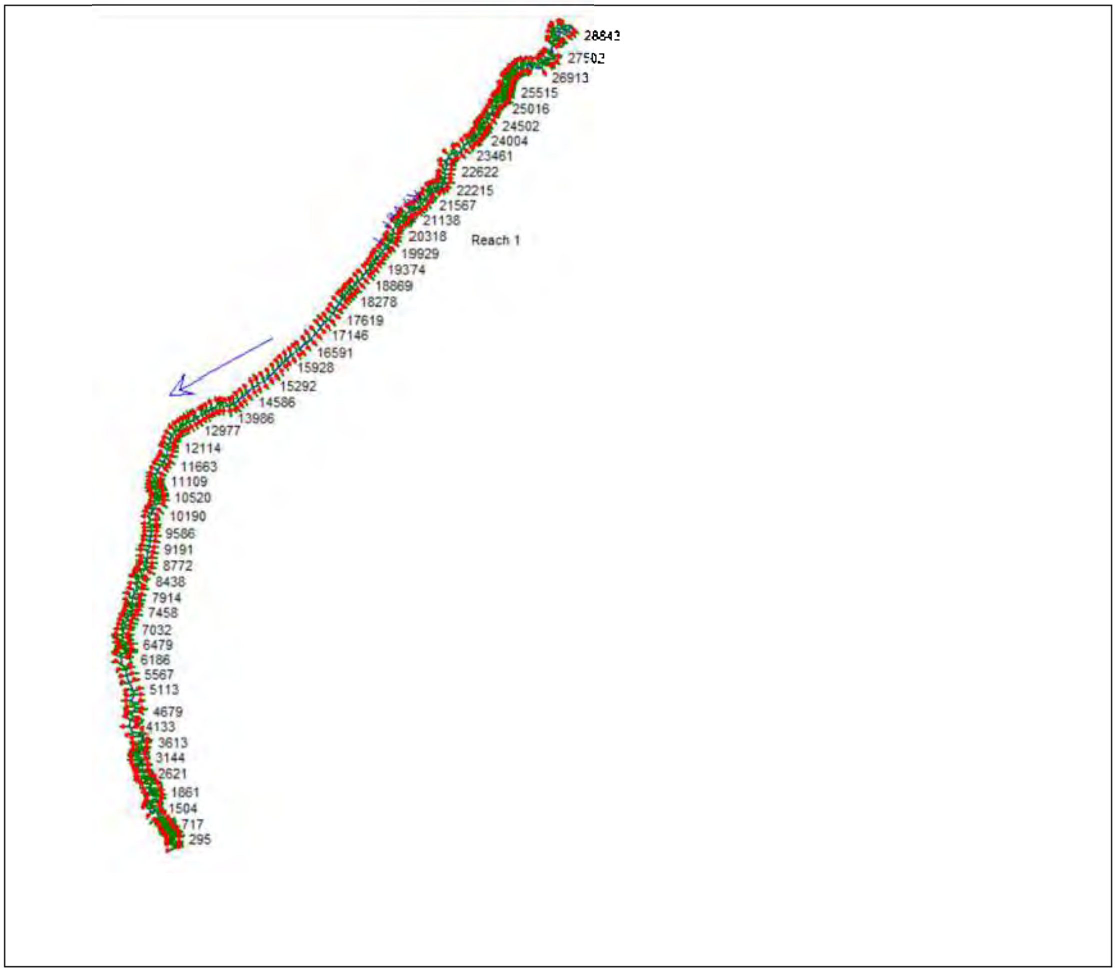
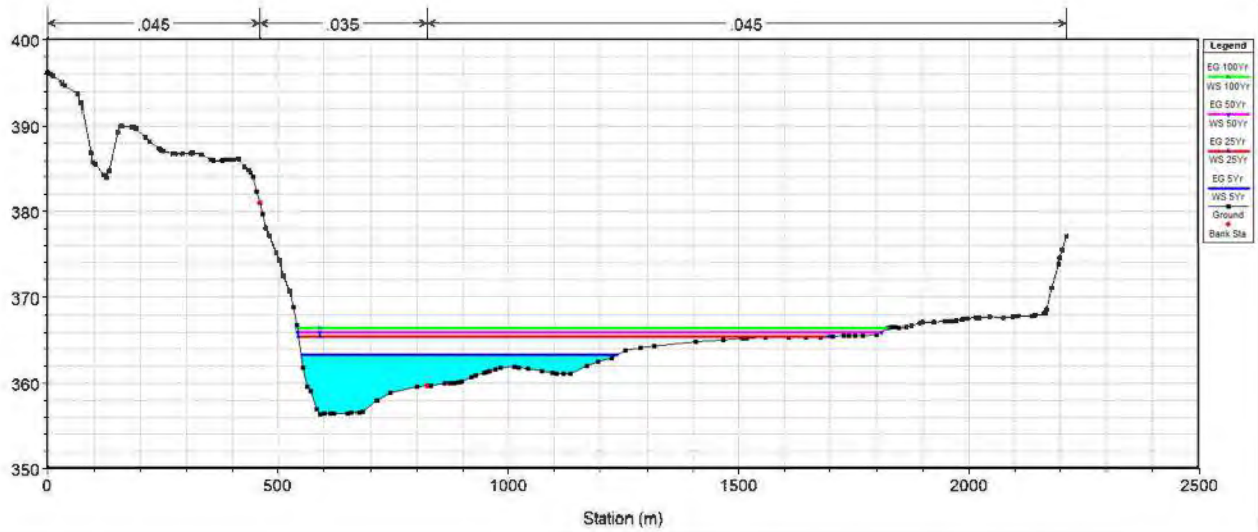


Figure 46. River geometry with cross section for Jhakhan River.

Below mentioned fig 47-50 shows the water surface elevation of different return period for selected river at different locations.



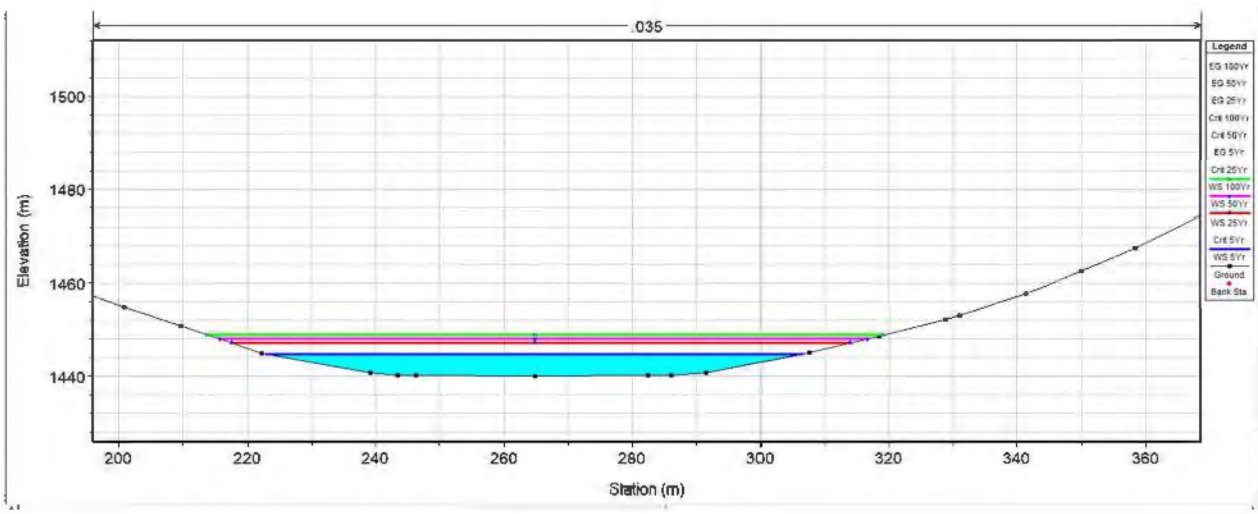
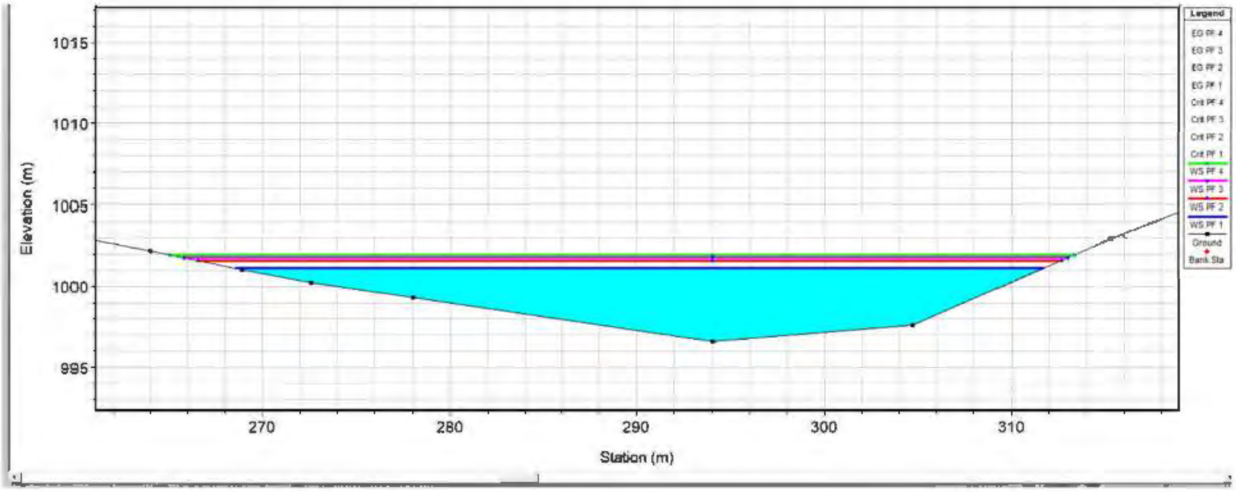


Figure 47. Transverse cross-section at Yamuna showing WSE at different RP.



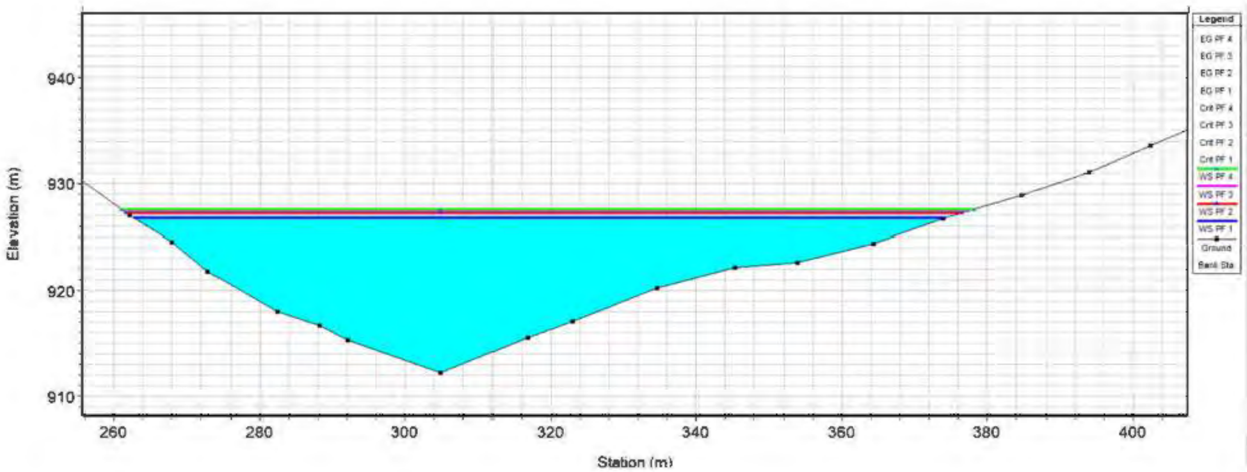


Figure 48. Transverse cross-section of Asan River showing WSE at different RP

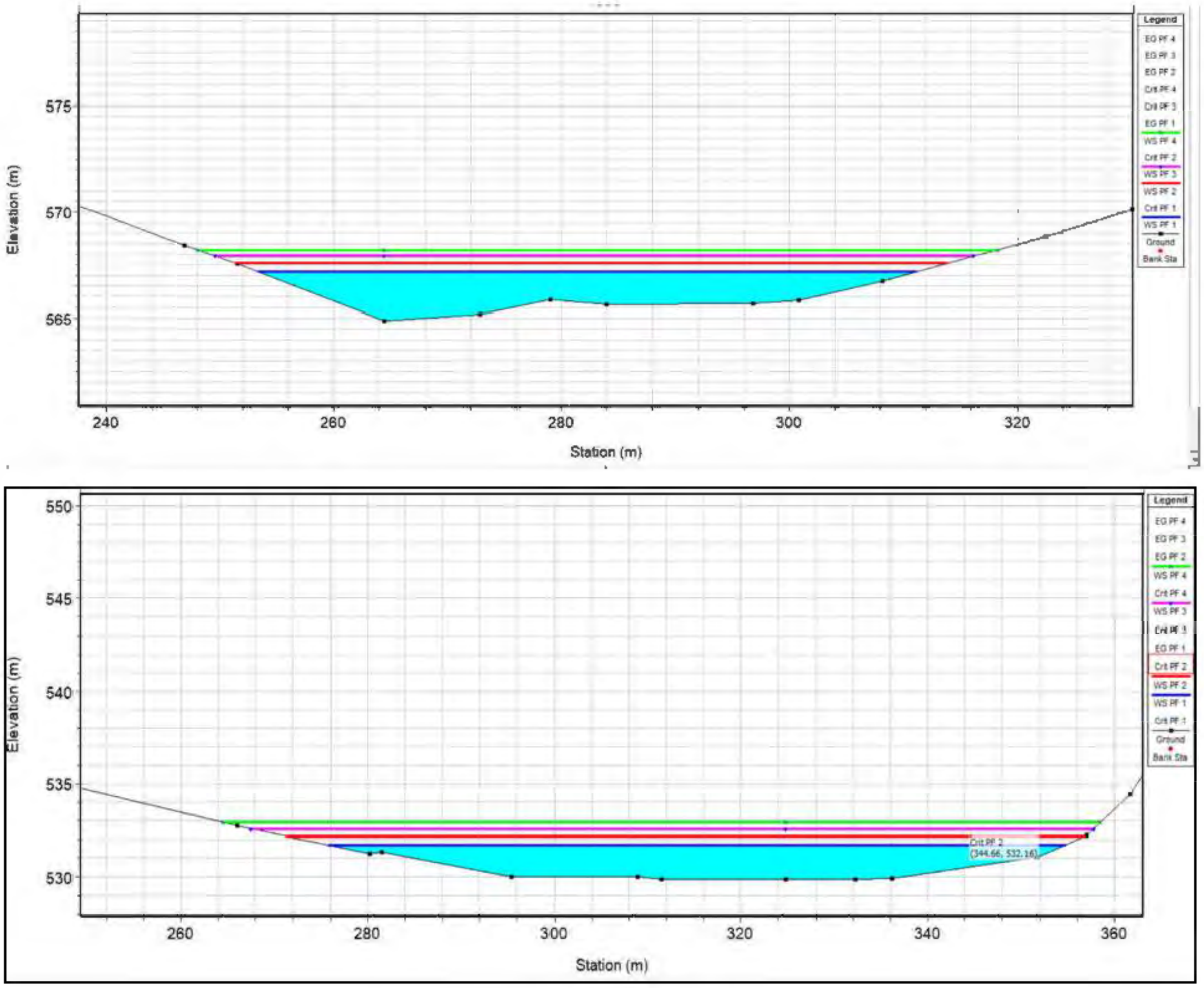


Figure 49: Transverse cross-section of Chandrabhaga River showing WSE at different RP

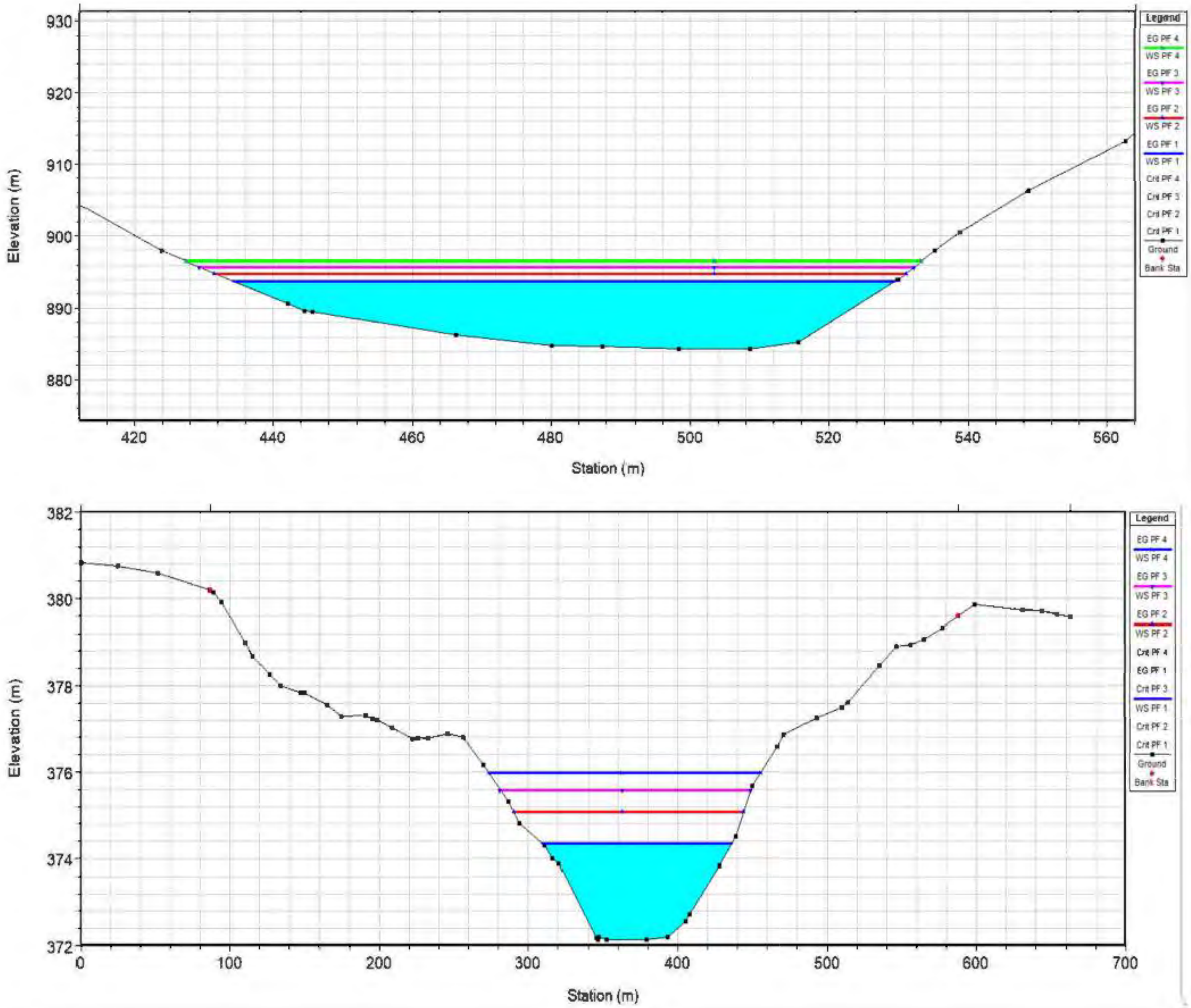


Figure 50 Transverse cross-section of Jhakhan River showing WSE at different RP

8. RAS Geometry used in HEC-RAS 1D Flow Modelling & Flood Plain Zoning:

In HEC RAS, the boundary conditions at downstream cross-sections have been defined on the basis of normal depth. The normal depth method utilizes an energy slope (average bed slope in m/m) to compute flood depth using Manning's N values. The estimated discharges at different return periods (5, 25, 50 and 100 years) for each ungauged watershed have been considered in HEC RAS by adding flow change location from upstream to downstream. Based on the input data (Manning's N values, normal depth, and discharges), the HEC-RAS computed rating curves for entire cross- sections. A sum of 701 cross-sections was drawn for 1D flow modeling. In other words, six cross-sections per kilometer have been made on the basis of channel curvature. Here from fig. 51-54 shows the modelled rating curve at outlet of each river.

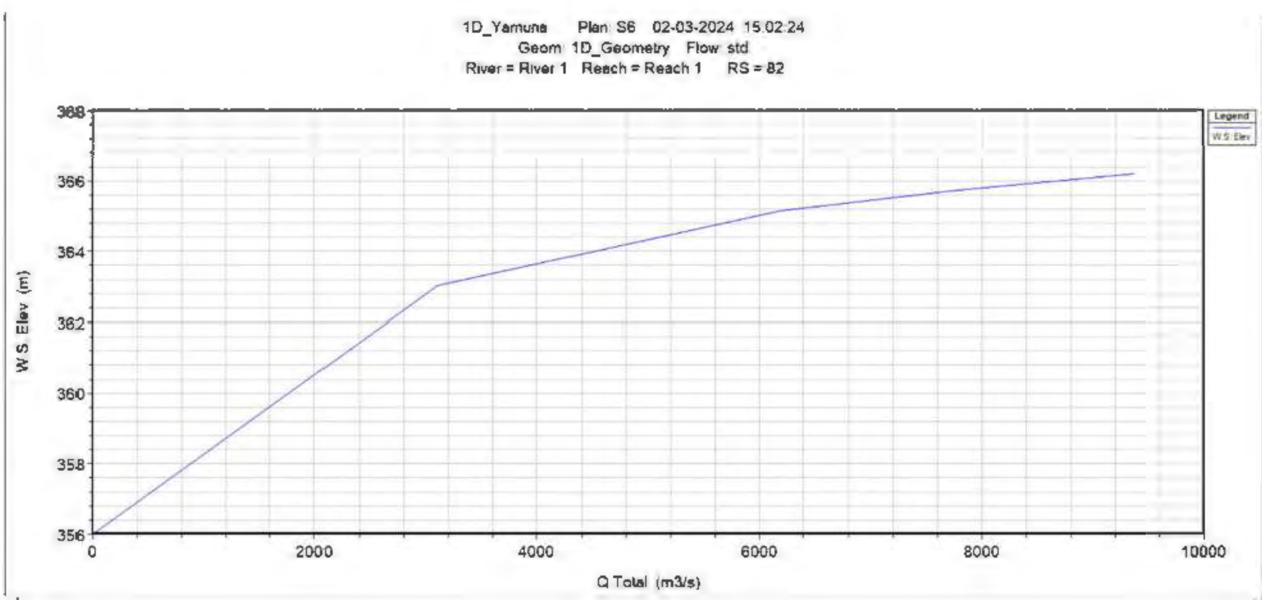


Figure 51: Modelled Rating Curve at Outlet of Yamuna River

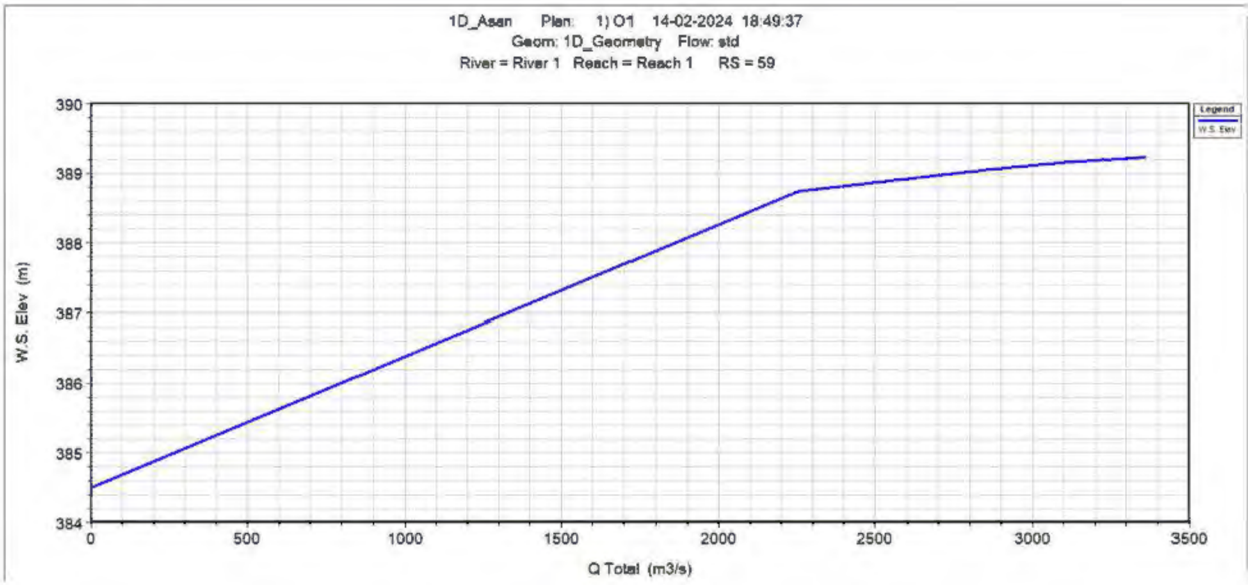


Figure 52: Modelled Rating Curve at Outlet of Asan River

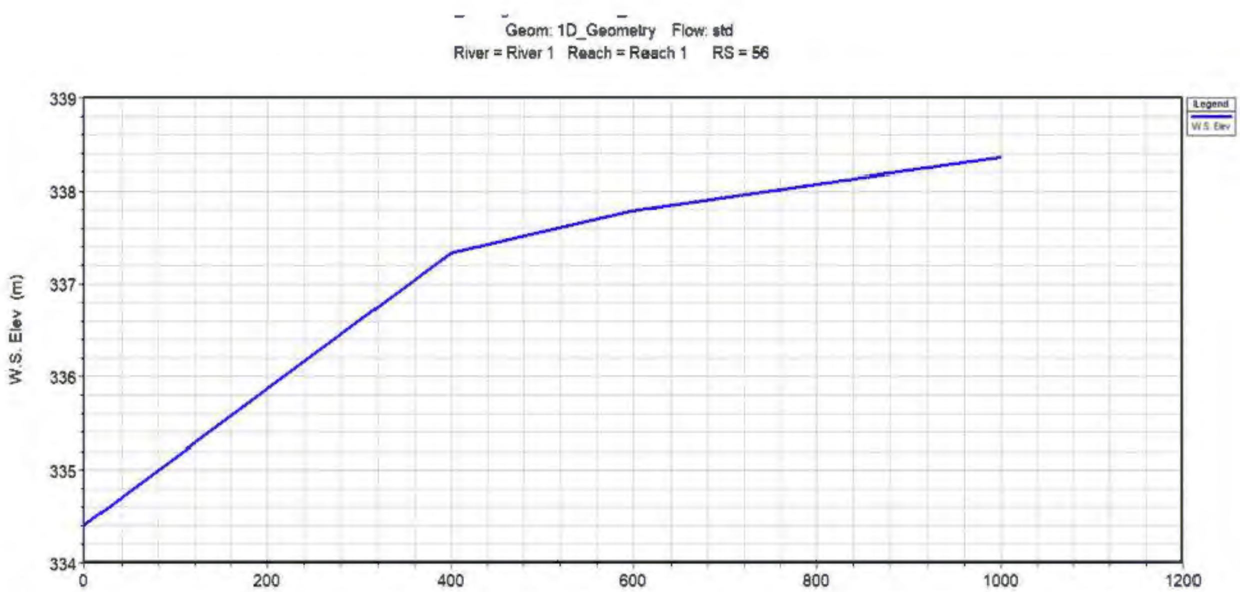


Figure 53: Modelled Rating Curve at Outlet of Chandrabhaga River

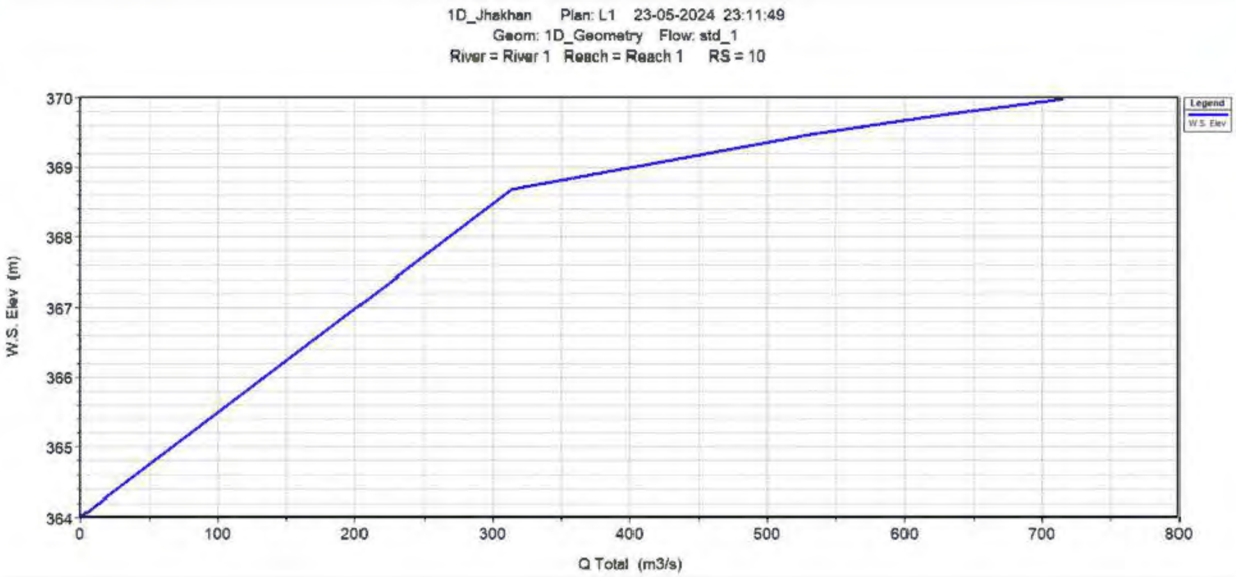


Figure 54: Modelled Rating Curve at Outlet of Jhakhan River

From Fig, 55 to to 58 modelled flood inundation maps are shown for 100-year return period

Figure 55: Flood inundation for Yamuna River at D/S portion

Fig. 56: Flood inundation for Asan River at D/S portion

Fig. 57: Flood inundation for Chandrabhaga River at Rishikesh

Table 92: Discharges (in m^3/sec) at different return periods considered at flow change location in HEC-RAS steady flow modeling. (Yamuna River)

Identification Name	Catchment Area of Drain(km^2)	Catchment Area (km^2)	Return Period (Year) Flow (cumec)			
			5	25	50	100
Janki Chatti	65	65	65	71	73	75
Kharadi	385	450	284	392	434	474
Barkote	295	745	418	612	690	766
Bagasu	36	781	433	638	721	802
Naugaon	29	810	445	659	745	830
Lakha Mandal	245	1055	545	832	951	1068
Dakpathar	1281	2336	1002	1679	1977	2282
Dakpathar (After Conf. with tons)	5153.974	7489.974	2443	4696	5779	6942
At Outlet	2764.496	10254.47	3108	6197	7717	9370

Fig. 58: Flood inundation for Jhakhan River at Confluence with Song River

Table 93: Discharges (in m^3/sec) at different return periods considered at flow change location in HEC-RAS steady flow modeling. (**Asan River**)

Identification Name	Catchment Area of Drain(km^2)	Catchment Area (km^2)	Return Period (Year) Flow (cumec)			
			5	25	50	100
Raja Dhunga	41.1	41.1	134	170	185	199
Birpur Barrage	2.6	43.7	142	180	196	212
Tapkeshwar Mahadev	6.3	50	163	206	225	243
Bajap	43	93	302	384	418	451
Tons Bridge School	68.06	161.06	524	665	723	782
Regional Science Centre	44.94	206	670	851	925	1000
Shishambara Plant	51.09	257.09	836	1062	1155	1248
Sabhowala Bridge	84.21	341.3	1110	1410	1533	1656
Vikasnagar	50.7	392	1275	1619	1761	1902
Asan Bridge	94	486	1581	2007	2183	2358
At Outlet	9	493	2219	2387	2420	2442

Table 93(a): Discharges (in m^3/sec) at different return periods considered at flow change location in HEC-RAS steady flow modeling. (**Tributaries of Asan River**)

Tributaries	Area (Sq km)	Q5	Q25	Q50	Q100
Sitla Rao					
Sahaspur Langh Bridge	40	151	204	243	282
Sheetla River Bridge	46	173	234	279	324
At Outlet	56	211	285	340	394
Swarna River					
Swarna Pul	25	94	127	152	176
Swarna Bridge Chakrata Bridge	36	136	183	218	253
At Outlet	41	154.5	208.7	248.6	288.5
Nimi River					
Shri Devbhoomi Institute	17	64	87	103	120
Nimi Nadi Pul	20	75	102	121	141
At Outlet	24	90	122	146	169
Nun River					
Santla Devi	26	98	132	158	183
Le Meridein Resort	32	121	163	194	225
Dhaulas Bridge	35	132	178	212	246
At Outlet	41	154	209	249	289

Table 94: Discharges (in m^3/sec) at different return periods considered at flow change location in HEC-RAS steady flow modeling. (Chandrabhaga River)

Identification Name	Catchment Area of Drain(km^2)	Catchment Area (km^2)	Return Period (Year) Flow (cumec)			
			5	25	50	100
Kandari Gaon	22	22	134	220	256	302
Iron Bridge Narendra Nagar	9	31	189	310	361	426
Hanuman Jhula	8	39	236	387	450	531
Chandrabhaga Bridge	31	70	426	698	813	959
At Confluence with Ganga	4	74	450	738	859	1013

Table 95: Discharges (in m^3/sec) at different return periods considered at flow change location in HEC-RAS steady flow modeling. (Jhakhan River)

Identification Name	Catchment Area of Drain(km^2)	Catchment Area (km^2)	Return Period (Year) Flow (cumec)			
			5	25	50	100
Silla Chowki	40.89	40.89	154	208	248	288
Golden Gate Bridge	14.27	55.16	208	281	334	388
Bangai Ghat Bridge	5.89	61.05	230	311	370	430
Jauligrant	32.94	93.99	354	478	570	661
Jhakhan River Crossing	3.12	97.11	366	494	589	683
Jeevan Wala	1.19	98.3	370	500	596	692
Majari Grant	3.13	101.43	382	516	615	714
Naturoville	12.86	114.29	431	582	693	804
At Confluence	6.71	121	456	616	734	852

9. Results Analysis & Physical Validation:

For validation, the floodplain modeling is correlated recent year flood mark. Modeled flood extent is matching with the observed flood extent between at various bridge locations. Mostly crop land and open land will be submerged.

10. Sensitivity Waterway:

The analysis incorporates the estimated discharge at a 25-year return period for each location of flow change to determine the necessary channel width or Lacey's Waterway. The provision of waterway width varies based on the riverbed conditions, ranging from 0.25 to 0.9 times Lacey's Waterway, contingent upon the site's topography. In this study, areas where the natural waterway measures less than 0.65 times Lacey's Waterway are classified as sensitive zones. (Reference: Theory and Design of Irrigation Structures by Dr. Varshney)

Table 96: Lacey's Waterway (in m) at 25-year Return flood considered at flow change location (Yamuna River).

Identification Name	Catchment Area of Drain (Sq. km)	Cumulative Catchment Area (sq.km.)	Q25	Lacey's Waterway	Reqd. Min, Waterway (m)
Janki Chatti	65	65	98	47	31
Hanuman Chatti	193	258	286	80	52
Syanchatti	35	293	315	84	55
Kuthnaur	91	384	389	94	61
Kharadi	66	450	440	100	65
Nandgaon	164	614	560	112	73
Tilari Shaheed Sthal	91	705	623	119	77
Barkote	40	745	650	121	79
Bagasu	36	781	674	123	80
Naugaon	29	810	694	125	81
Pankhet	131	941	779	133	86
Lakha Mandal	114	1055	851	139	90
Damta	106	1161	917	144	93
Nainbagh	202	1363	1038	153	99
Yamuna Bridge	351	1714	1239	167	109
Juddo bridge	60	1774	1273	169	110
Jikala	184	1958	1374	176	114

Dakpathar (Before Confluence)	16	1974	1383	177	115
Dakpathar (After Confluence)	5178	7152	3749	291	189
Before Confluence with Giri	130	7282	3801	293	190
After Confluence with Giri	2630	9912	4827	330	215
After Confluence with Asan	699	10611	5089	339	220
At Outlet (State Border	663	11274	5333	347	225

Table 97: Lacey's Waterway (in m) at 25-year Return flood considered at flow change location. (Asan River)

Identification Name	Catchment Area of Drain(km^2)	Cumulative Catchment Area (km^2)	Q25 (cumec)	Lacey's Waterway(m)	Required Min. Waterway (m)
Raja Dhunga	41.1	41.1	170	61.93	40.26
Birpur Barrage	2.6	43.7	180	63.73	41.42
Tapkeshwar Mahadev	6.3	50	206	68.18	44.31
Bajawala	43	93	384	93.08	60.50
Tons Bridge School	68.06	161.06	665	122.49	79.62
Regional Science Centre	44.94	206	851	138.57	90.07
Shishambara Plant	51.09	257.09	1062	154.79	100.62
Sabhowala Bridge	84.21	341.3	1410	178.36	115.94
Vikasnagar	50.7	392	1619	191.12	124.23
Asan Bridge	94	486	2007	212.80	138.32

Table 97(a): Lacey's Waterway (in m) at 25-year Return flood considered at flow change location. (Tributaries of Asan River)

Identification Name	Catchment Area of Drain(km^2)	Cumulative Catchment Area (km^2)	Q25 (cumec)	Lacey's Waterway(m)	Required Min. Watereway (m)
Sitla Rao					
Sahaspur Langh Bridge	40	40	204	67.8	40.7
Sheetla River Bridge	6	46	234	72.7	43.6
At Outlet	10	56	285	80.2	48.1
Swarna River					
Swarna Pul	25	25	127	53.6	32.2
Swarna Bridge Chakrata Bridge	11	36	183	64.3	38.6
At Outlet	5	41	209	68.6	41.2
Nimi River					
Shri Devbhumi Institute	17	17	87	44.2	26.5
Nimi Nadi Pul	3	20	102	47.9	28.8
At Outlet	4	24	122	52.5	31.5
Nun River					
Santla Devi	26	26	132	54.6	32.8
Le meridein Resort	6	32	163	60.6	36.4
Dhaulas Bridge	3	35	178	63.4	38.0
At Outlet	6	41	209	68.6	41.2

Table 98: Lacey's Waterway (in m) at 25-year Return flood considered at flow change location. (Chandrabhaga River)

Identification Name	Catchment Area of Drain(km^2)	Cumulative Catchment Area (km^2)	Q25 (cumec)	Lacey's Waterway(m)	Required Min. Watereway (m)
Kandari Gaon	22	22	220	70.45	45.80
Iron Bridge Narendra Nagar	9	31	310	83.63	54.36
Hanuman Jhula	8	39	387	93.44	60.74
Chandrabhaga Bridge	31	70	698	125.49	81.57
At Confluence with Ganga	4	74	738	129.04	83.88

Table 99: Lacey's Waterway (in m) at 25-year Return flood considered at flow change location. (Jhakhan River)

Identification Name	Catchment Area of Drain(km^2)	Cumulative Catchment Area (km^2)	Q25 (cumec)	Lacey's Waterway(m)	Required Min. Watereway (m)
Silla Chowki	40.89	40.89	208	68.5	44.5
Golden Gate Bridge	14.27	55.16	281	79.6	51.7
Bangai Ghat Bridge	5.89	61.05	311	83.7	54.4
Jauligrant	32.94	93.99	478	103.9	67.5
Jhakhan River Crossing	3.12	97.11	494	105.6	68.6
Jeevan Wala	1.19	98.3	500	106.3	69.1
Majari Grant	3.13	101.43	516	107.9	70.2
Naturoville	12.86	114.29	582	114.6	74.5
At Confluence	6.71	121	616	117.9	76.6

11. Results & Finding: -

The flood inundation area map was created utilizing flood propagation modeling, employing optimized roughness parameters acquired through automated calibration with HEC-RAS within a GIS environment. To address uncertainties in hydrological input, an uncertainty analysis was conducted using a Monte Carlo framework. Notably, the novelty of this approach lies in its consideration of the return time of flooding rather than solely focusing on the hydrograph. While a deterministic approach typically advocates for the consideration of fixed hydrodynamic variables based on a flood hydrograph with predetermined return periods, our study delved into discharges at specific return periods. Additionally, boundary conditions for each cross-section were established using the average bed slope.

Flood inundation lines for 5, 25, 50, 100 Yr return periods are established in order to facilitate the FPZ in conformity to NDMA guidelines which are again verified, cross checked by the field staffs of the Department of Irrigation.

Table 100: Discharges and Waterways at some prominent places for different return periods (Yamuna River)

Identification Name	Q25 (cumec)	Q50 (cumec)	Q100 (cumec)	Lacey's Waterway at Q 25(m)	Lacey's Waterway at Q50 (m)	Lacey's Waterway Q100 (m)
Janki Chatti	98	108	117	47.02	49.36	51.38
Hanuman Chatti	286	321	355	80.33	85.10	89.50
Syanchatti	315	355	394	84.30	89.50	94.28
Kuthnaur	389	439	489	93.68	99.52	105.04
Kharadi	440	498	556	99.64	106.00	112.00
Nandgaon	560	637	713	112.41	119.88	126.83
Tilari Shaheed Sthal	623	710	797	118.56	126.57	134.10
Barkote	650	742	833	121.10	129.39	137.09
Bagasu	674	770	866	123.32	131.81	139.78
Naugaon	694	793	891	125.13	133.76	141.79
Pankhet	779	893	1005	132.58	141.94	150.58
Lakha Mandal	851	977	1102	138.57	148.47	157.68
Damta	917	1054	1190	143.84	154.21	163.86
Nainbagh	1038	1196	1354	153.04	164.27	174.78
Yamuna Bridge	1239	1434	1628	167.20	179.87	191.66
Juddo bridge	1273	1473	1674	169.48	182.30	194.34
Jikala	1374	1593	1812	176.07	189.58	202.20
Dakpathar (Before Confluence)	1383	1603	1824	176.65	190.18	202.86
Dakpathar (After Confluence)	3749	4435	5131	290.84	316.33	340.25
Before Confluence with Giri	3801	4499	5206	292.85	318.60	342.72
After Confluence with Giri	4827	5741	6670	330.01	359.90	387.93
After Confluence with Asan	5089	6058	7045	338.85	369.71	398.69
At Outlet (State Border	5333	6356	7397	346.88	378.69	408.53

Table 101: Discharges and Waterways at some prominent places for different return periods (Asan River)

Identification Name	Q25 (cumec)	Q50 (cumec)	Q100 (cumec)	Lacey's Waterway at Q 25(m)	Lacey's Waterway at Q50 (m)	Lacey's Waterway Q100 (m)
Raja Dhunga	170	61.93	40.26	61.93	37.38	30.14
Birpur Barrage	180	63.73	41.42	63.73	37.92	30.57
Tapkeshwar Mahadev	206	68.18	44.31	68.18	39.22	31.62
Bajapur	384	93.08	60.5	93.08	45.83	36.95
Tons Bridge School	665	122.49	79.62	122.49	52.57	42.38
Regional Science Centre	851	138.57	90.07	138.57	55.91	45.08
Shishambara Plant	1062	154.79	100.62	154.79	59.10	47.65
Sabhowala Bridge	1410	178.36	115.94	178.36	63.44	51.15
Vikasnagar	1619	191.12	124.23	191.12	65.67	52.94
Assan Bridge	2007	212.8	138.32	212.80	69.29	55.86
At Outlet	2387	2420	2442	232.07	233.67	234.73

Table 102: Discharges and Waterways at some prominent places for different return periods (Asan River Tributaries)

Identification Name	Q25 (cumec)	Q50 (cumec)	Q100 (cumec)	Lacey's Waterway at Q 25(m)	Lacey's Waterway at Q50 (m)	Lacey's Waterway Q100 (m)
Sitla Rao						
Sahaspur Langh Bridge	204	243	282	67.84	74.05	79.77
Sheetla River Bridge	234	279	324	72.66	79.34	85.50
At Outlet	285	340	394	80.19	87.59	94.28
Swarna River						
Swarna Pul	127	152	176	53.53	58.56	63.02
Swarna Bridge Chakrata Bridge	183	218	253	64.26	70.13	75.55
At Outlet	208.7	248.6	288.5	68.62	74.89	80.68
Nimi River						
Shri Devbhoomi Institute	87	103	120	44.31	48.21	52.03
Nimi Nadi Pul	102	121	141	47.97	52.25	56.40
At Outlet	122	146	169	52.47	57.39	61.75
Nun River						
Santla Devi	132	158	183	54.57	59.71	64.26
Le Meridein Resort	163	194	225	60.64	66.16	71.25
Dhaulas Bridge	178	212	246	63.37	69.16	74.50
At Outlet	209	249	289	68.67	74.95	80.75

Table 103: Discharges and Waterways at some prominent places for different return periods (Chandrabhaga River)

Identification Name	Q25 (cumec)	Q50 (cumec)	Q100 (cumec)	Lacey's Waterway at Q 25(m)	Lacey's Waterway at Q50 (m)	Lacey's Waterway Q100 (m)
Kandari Gaon	220	256	302	70.45	76.00	82.55
Iron Bridge Narendra Nagar	310	361	426	83.63	90.25	98.04
Hanuman Jhula	387	450	531	93.44	100.76	109.46
Chandrabhaga Bridge	698	813	959	125.49	135.44	147.10
At Confluence with Ganga	738	859	1013	129.04	139.22	151.18

Table 104: Discharges and Waterways at some prominent places for different return periods (Jhakhan River)

Identification Name	Q25 (cumec)	Q50 (cumec)	Q100 (cumec)	Lacey's Waterway at Q 25(m)	Lacey's Waterwa y at Q50 (m)	Lacey's Waterway Q100 (m)
Silla Chowki	208	248	288	68.51	74.80	80.61
Golden Gate Bridge	281	334	388	79.62	86.81	93.56
Bangai Ghat Bridge	311	370	430	83.77	91.37	98.50
Jauligrant	478	570	661	103.85	113.40	122.12
Jhakhan River Crossing	494	589	683	105.57	115.28	124.14
Jeevan Wala	500	596	692	106.21	115.96	124.95
Majari Grant	516	615	714	107.90	117.80	126.92
Naturoville	582	693	804	114.59	125.04	134.69
At Confluence	616	734	852	117.89	128.69	138.65

12. FLOOD PROTECTION MEASURES

The areas with settlement along the river have been considered as critical areas and the same has been analyzed for required minimum waterway. Critical areas considered along all the river under study, respective location in their rivers is mentioned. The required minimum waterway as worked out above using Lacey's Equation was compared with the natural water at 25-year return period flood as given in Table 105-109 below.

Table 105: Required minimum and natural waterways at some prominent places for 25-year return period (Yamuna River).

Identification Name	Q25	Reqd. Min. Waterway	Natural waterway
Janki Chatti	98	31	31.2
Hanuman Chatti	286	52	34.3
Syanchatti	315	55	39.9
Kuthnaur	389	61	77.8
Kharadi	440	65	91.7
Nandgaon	560	73	53.8
Tilari Shaheed Sthal	623	77	291
Barkote	650	79	249
Bagasu	674	80	81
Naugaon	694	81	68.7
Pankhet	779	86	145
Lakha Mandal	851	90	85.2
Damta	917	93	60.8
Nainbagh	1038	99	64.7
Yamuna Bridge	1239	109	97.6
Juddo bridge	1273	110	67.5
Jikala	1374	114	138
Dakpathar (Before Confluence)	1383	115	971
Dakpathar (After Confluence)	3749	189	602
Before Confluence with Giri	3801	190	1242
After Confluence with Giri	4827	215	552
After Confluence with Asan	5089	220	1356
At Outlet (State Border	5333	225	644

Table 106: Required minimum and natural waterways at some prominent places for 25-year return period (Asan River).

Identification Name	Q25 (cumec)	Reqd. Min Waterway (m)	Natural Waterway (m)
Raja Dhunga	134	35.74	23.5
Birpur Barrage	142	36.79	21
Tapkeshwar Mahadev	163	39.42	7.81
Bajawala	302	53.66	89.4
Tons Bridge School	524	70.68	180
Regional Science Centre	670	79.92	249
Shishambara Plant	836	89.27	306
Sabhowala Bridge	1110	102.87	368
Vikasnagar	1275	110.25	295
Assan Bridge	1581	122.76	206
At Outlet	2219	145.44	414

Table 107: Required minimum and natural waterways at some prominent places for 25-year return period (Asan Tributary).

Identification Name	Q25 (cumec)	Reqd. Min. Waterway (m)	Natural waterway (m)
Sitla Rao			
Sahaspur Langh Bridge	204	44.1	193
Sheetla River Bridge	234	47.2	157
At Outlet	285	52.1	257
Swarna River			
Swarna Pul	127	34.8	184
Swarna Bridge Chakrata Bridge	183	41.8	127
At Outlet	208.7	44.6	143
Nimi River			
Shri Devbhoomi Institute	87	28.8	22
Nimi Nadi Pul	102	31.2	34
At Outlet	122	34.1	45
Nun River			
Santla Devi	132	35.5	62.1
Le Meridein Resort	163	39.4	71.89
Dhaulas Bridge	178	41.2	95.4
At Outlet	209	44.6	96

Table 108: Required minimum and natural waterways at some prominent places for 25-year return period (Chandrabhaga River).

Identification Name	Q25 (cumec)	Reqd. min. waterway (m)	Natural waterway (m)
Kandari Gaon	220	45.80	168
Iron Bridge Narendra Nagar	310	54.36	39
Hanuman Jhula	387	60.74	91.2
Chandrabhaga Bridge	698	81.57	273
At Confluence with Ganga	738	83.88	166

Table 109: Required minimum and natural waterways at some prominent places for 25-year return period (Jhakhan River).

Identification Name	Q25 (cumec)	Reqd. Min Waterway (m)	Natural waterway(m)
Silla Chowki	208	44.53	49.5
Golden Gate Bridge	281	51.76	27.4
Bangai Ghat Bridge	311	54.45	161
Jauligrant	478	67.50	233
Jhakhan River Crossing	494	68.62	181
Jeevan Wala	500	69.04	149
Majari Grant	516	70.13	98.3
Naturoville	582	74.48	43.5
At Confluence	616	76.63	130

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Annexures

ANNEXURE-1

Probability paper based on (Cs,T)

Here mentioning the logarithmic probability paper used for flood frequency & D-index calculations.

Coefficient of skew, C_s	Recurrence interval T in years						
	2	10	25	50	100	200	1000
3.0	–0.396	1.180	2.278	3.152	4.051	4.970	7.250
2.5	–0.360	1.250	2.262	3.048	3.845	4.652	6.600
2.2	–0.330	1.284	2.240	2.970	3.705	4.444	6.200
2.0	–0.307	1.302	2.219	2.912	3.605	4.298	5.910
1.8	–0.282	1.318	2.193	2.848	3.499	4.147	5.660
1.6	–0.254	1.329	2.163	2.780	3.388	3.990	5.390
1.4	–0.225	1.337	2.128	2.706	3.271	3.828	5.110
1.2	–0.195	1.340	2.087	2.626	3.149	3.661	4.820
1.0	–0.164	1.340	2.043	2.542	3.022	3.489	4.540
0.9	–0.148	1.339	2.018	2.498	2.957	3.401	4.395
0.8	–0.132	1.336	1.998	2.453	2.891	3.312	4.250
0.7	–0.116	1.333	1.967	2.407	2.824	3.223	4.105
0.6	–0.099	1.328	1.939	2.359	2.755	3.132	3.960
0.5	–0.083	1.323	1.910	2.311	2.686	3.041	3.815
0.4	–0.066	1.317	1.880	2.261	2.615	2.949	3.670
0.3	–0.050	1.309	1.849	2.211	2.544	2.856	3.525
0.2	–0.033	1.301	1.818	2.159	2.472	2.763	3.380
0.1	–0.017	1.292	1.785	2.107	2.400	2.670	3.235
0.0	**0.000**	**1.282**	**1.751**	**2.054**	**2.326**	**2.576**	**3.090**
–0.1	0.017	1.270	1.716	2.000	2.252	2.482	2.950
–0.2	0.033	1.258	1.680	1.945	2.178	2.388	2.810
–0.3	0.050	1.245	1.643	1.890	2.104	2.294	2.675
–0.4	0.066	1.231	1.606	1.834	2.029	2.201	2.540
–0.5	0.083	1.216	1.567	1.777	1.955	2.108	2.400
–0.6	0.099	1.200	1.528	1.720	1.880	2.016	2.275
–0.7	0.116	1.183	1.488	1.663	1.806	1.926	2.150
–0.8	0.132	1.166	1.448	1.606	1.733	1.837	2.035
–0.9	0.148	1.147	1.407	1.549	1.660	1.749	1.910
–1.0	0.164	1.128	1.366	1.492	1.588	1.664	1.880
–1.4	0.225	1.041	1.198	1.270	1.318	1.351	1.465
–1.8	0.282	0.945	1.035	1.069	1.087	1.097	1.130
–2.2	0.330	0.844	0.888	0.900	0.905	0.907	0.910
–3.0	0.396	0.660	0.666	0.666	0.667	0.667	0.668

[**Note:** C_s = 0 corresponds to log-normal distribution]

ANNEXURE-2

Distribution Table

Annexure 5.1 (The Table is taken from CWC flood estimation report for western Himalayan Zone-7)

ZONE - 7

CATCHMENT AREA (Km²)	DESIGN STORM DURATION (HOURS) 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	CATCHMENT AREA (Km²)
0000	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	0000
50	94.00	95.20	96.40	96.83	97.27	97.70	97.79	97.88	97.97	98.07	98.16	98.25	98.31	98.38	98.44	98.50	98.56	98.62	98.69	98.75	98.81	98.88	98.94	99.00	50
100	89.00	90.95	92.90	93.73	94.57	95.40	95.58	95.77	95.95	96.13	96.32	96.50	96.62	96.75	96.88	97.00	97.12	97.25	97.38	97.50	97.62	97.75	97.87	98.00	100
150	84.50	87.00	89.50	90.70	91.90	93.10	93.42	93.73	94.05	94.37	94.68	95.00	95.17	95.33	95.50	95.67	95.83	96.00	96.17	96.33	96.50	96.67	96.83	97.00	150
200	80.75	83.47	86.20	87.40	88.40	89.80	90.42	91.03	91.63	92.27	92.88	93.50	93.71	93.92	94.12	94.33	94.54	94.75	94.96	95.17	95.37	95.58	95.79	96.00	200
250	77.25	80.12	83.00	84.83	86.67	88.50	89.08	89.67	90.25	90.83	91.42	92.00	92.27	92.53	92.80	93.07	93.33	93.60	93.87	94.13	94.40	94.67	94.93	95.20	250
300	74.25	77.12	80.00	82.07	84.13	86.20	86.92	87.63	88.35	89.07	89.78	90.50	90.82	91.15	91.47	91.80	92.12	92.45	92.77	93.10	93.42	93.75	94.07	94.40	300
350			77.20	79.43	81.67	83.90	84.77	85.63	86.50	87.37	88.23	89.10	89.48	89.87	90.25	90.63	91.02	91.40	91.78	92.17	92.55	92.93	93.32	93.70	350
400			74.50	76.87	79.23	81.60	82.62	83.65	84.67	85.70	86.72	87.75	88.19	88.62	89.06	89.50	89.94	90.37	90.81	91.25	91.69	92.12	92.56	93.00	400
450			72.00	74.50	77.00	79.50	80.67	81.83	83.00	84.17	85.33	86.50	86.98	87.47	87.95	88.43	88.92	89.40	89.88	90.37	90.85	91.33	91.82	92.30	450
500			70.00	72.40	74.80	77.20	78.54	79.88	81.22	82.57	83.91	85.25	85.78	86.31	86.84	87.37	87.90	88.42	88.95	89.48	90.01	90.54	91.07	91.60	500
600												83.00	83.60	84.21	84.81	85.42	86.02	86.62	87.23	87.83	88.44	89.04	89.65	90.25	600
700												81.00	81.67	82.33	83.00	83.67	84.33	85.00	85.67	86.33	87.00	87.67	88.33	89.00	700
800												79.60	80.30	81.00	81.70	82.10	83.10	83.80	84.50	85.20	85.90	86.60	87.30	88.00	800
900												78.40	79.12	79.83	80.55	81.27	81.98	82.70	83.42	84.13	84.85	85.57	86.28	87.00	900
1000												77.20	77.95	78.71	79.46	80.22	80.97	81.72	82.48	83.23	83.99	84.74	85.50	86.25	1000
1100												76.20	76.97	77.75	78.52	79.30	80.07	80.85	81.62	82.40	83.17	83.95	84.72	85.50	1100
1200												75.50	76.29	77.08	77.87	78.67	79.46	80.25	81.04	81.83	82.62	83.42	84.21	85.00	1200
1300																								84.50	1300
1400																								84.00	1400
1500																								83.50	1500
2000																								82.70	2000

42

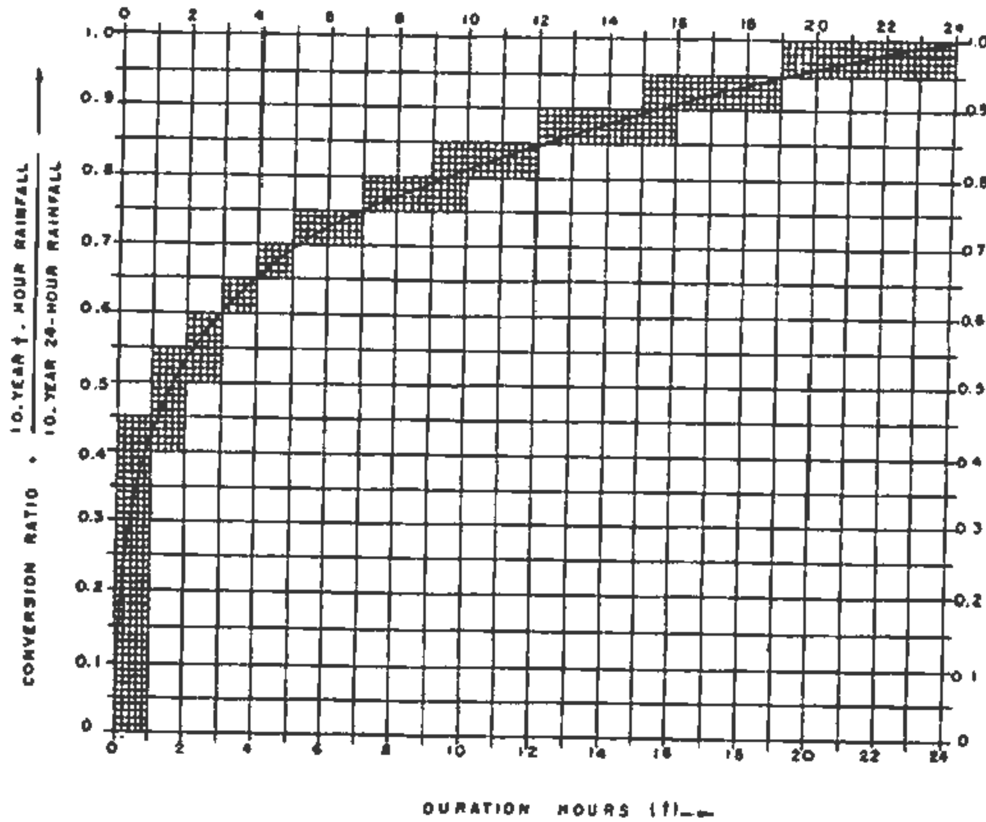
Annexure 5.2 (The Table is taken from CWC flood estimation report for western Himalayan Zone-7)

(Time distribution coefficient table for cumulative hourly rainfall)

INTER-MEDIATE HOURS	DESIGN STORM DURATION (HOURS)																							INTER-MEDIATE HOURS
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	
1	1.00	0.85	0.73	0.62	0.56	0.52	0.46	0.43	0.41	0.38	0.37	0.34	0.32	0.30	0.28	0.26	0.25	0.23	0.21	0.20	0.19	0.18	0.17	0.17	1
2		1.00	0.92	0.82	0.75	0.69	0.63	0.60	0.57	0.54	0.52	0.49	0.44	0.43	0.41	0.40	0.39	0.37	0.33	0.32	0.31	0.30	0.28	0.27	2
3			1.00	0.94	0.87	0.82	0.75	0.71	0.68	0.65	0.62	0.60	0.55	0.53	0.51	0.50	0.48	0.46	0.43	0.41	0.39	0.38	0.37	0.36	3
4				1.00	0.96	0.91	0.85	0.81	0.76	0.73	0.71	0.67	0.63	0.61	0.59	0.57	0.56	0.54	0.50	0.48	0.46	0.45	0.44	0.43	4
5					1.00	0.97	0.92	0.88	0.84	0.81	0.77	0.74	0.70	0.68	0.66	0.64	0.62	0.60	0.56	0.54	0.52	0.51	0.50	0.48	5
6						1.00	0.97	0.94	0.90	0.87	0.83	0.81	0.77	0.74	0.72	0.69	0.68	0.66	0.61	0.59	0.57	0.56	0.55	0.53	6
7							1.00	0.97	0.95	0.92	0.88	0.86	0.82	0.79	0.77	0.74	0.73	0.71	0.66	0.64	0.62	0.61	0.60	0.58	7
8								1.00	0.98	0.95	0.93	0.90	0.86	0.84	0.81	0.79	0.77	0.75	0.71	0.69	0.67	0.66	0.65	0.63	8
9									1.00	0.98	0.96	0.94	0.90	0.87	0.85	0.83	0.81	0.79	0.75	0.73	0.71	0.70	0.69	0.67	9
10										1.00	0.98	0.96	0.93	0.90	0.88	0.87	0.85	0.83	0.79	0.77	0.74	0.73	0.72	0.70	10
11											1.00	0.98	0.96	0.93	0.91	0.90	0.88	0.86	0.82	0.80	0.77	0.76	0.75	0.73	11
12												1.00	0.98	0.96	0.94	0.92	0.90	0.88	0.85	0.83	0.80	0.79	0.78	0.76	12
13													1.00	0.98	0.96	0.94	0.92	0.90	0.88	0.86	0.83	0.82	0.81	0.79	13
14														1.00	0.98	0.96	0.94	0.92	0.90	0.89	0.86	0.85	0.83	0.82	14
15															1.00	0.98	0.96	0.94	0.92	0.91	0.89	0.87	0.85	0.84	15
16																1.00	0.98	0.96	0.94	0.93	0.91	0.89	0.87	0.86	16
17																	1.00	0.98	0.96	0.95	0.93	0.91	0.89	0.88	17
18																		1.00	0.98	0.97	0.95	0.93	0.91	0.90	18
19																			1.00	0.99	0.97	0.95	0.93	0.92	19
20																				1.00	0.99	0.97	0.95	0.94	20
21																					1.00	0.99	0.97	0.96	21
22																						1.00	0.99	0.98	22
23																							1.00	0.99	23
24																								1.00	24

Annexure 5.3 (The Table is taken from CWC flood estimation report for western Himalayan Zone-7)

FIG. - 3.



RATIOS FOR 24-HOUR POINT RAINFALL TO SHORT DURATION RAINFALL.

DURATION (HOURS)	RATIOS
1	0.428
2	0.550
3	0.600
4	0.650
5	0.695
6	0.725
7	0.750
8	0.770
9	0.790
10	0.810
11	0.830
12	0.845
13	0.860
14	0.880
15	0.890
16	0.910
17	0.920
18	0.935
19	0.950
20	0.960
21	0.970
22	0.980
23	0.990
24	1.000

CURVE SUPPLIED BY IMD.

GOVERNMENT OF INDIA
CENTRAL WATER COMMISSION
HYDROLOGY (REGIONAL STUDIES) DTE.

WESTERN HIMALAYAS
ZONE — 7
DURATION VS. CONVERSION RATIO

DRAWN – S. N. MALHOTRA | CHECKED – K. K. AICH.

ANNEXURE-3

Annual Maximum Flood Discharges

Year wise Maximum Peak Flood at Tons

S.No	Year	Qmax
1	1980	464
2	1981	689
3	1982	306
4	1983	365
5	1984	580
6	1985	546
7	1986	746
8	1987	236
9	1988	670
10	1989	1003
11	1990	692
12	1991	422
13	1992	920
14	1993	731
15	1994	1701
16	1995	1492
17	1996	761
18	1997	1506
19	1998	465
20	1999	1449
21	2000	779
22	2001	308
23	2002	1563
24	2003	415
25	2004	235
26	2005	470
27	2006	381
28	2007	330
29	2008	734
30	2009	770
31	2010	745
32	2011	600
33	2012	512
34	2013	811
35	2014	587
36	2015	548
37	2016	354
38	2017	853
39	2018	644
40	2019	514
41	2020	318
42	2021	265
43	2022	859
44	2023	217

Year wise maximum peak flood at Pabar

S.No.	Year	Qmax
1	1980	191
2	1981	284
3	1982	205
4	1983	142
5	1984	227
6	1985	275
7	1986	560
8	1987	85
9	1988	593
10	1989	525
11	1990	306
12	1991	160
13	1992	225
14	1993	205
15	1994	571
16	1995	685
17	1996	226
18	1997	95
19	1998	206
20	1999	139
21	2000	187
22	2001	85
23	2002	209
24	2003	94
25	2004	74
26	2005	135
27	2006	110
28	2007	85
29	2008	187
30	2009	131
31	2010	618
32	2011	176
33	2012	191
34	2013	206
35	2014	250
36	2015	187
37	2016	145
38	2017	213
39	2018	295
40	2019	147
41	2020	71
42	2021	77
43	2022	397
44	2023	67

Year wise maximum peak flood at Haripur

S.No.	Year	Qmax
1	1985	1206
2	1986	704
3	1987	188
4	1988	4498
5	1989	3154
6	1990	1342
7	1991	251
8	1992	1092
9	1993	1411
10	1994	1419
11	1995	3677
12	1996	1408
13	1997	1155
14	1998	1415
15	1999	1099
16	2000	1163
17	2001	1242
18	2002	1219
19	2003	848
20	2004	399
21	2005	923
22	2006	798
23	2007	526
24	2008	948
25	2009	1013
26	2010	1242
27	2011	1422
28	2012	579
29	2013	217
30	2014	144
31	2015	127
32	2016	226
33	2017	267
34	2018	877
35	2019	1727
36	2020	452
37	2021	493
38	2022	848
39	2023	2389

Year wise Maximum Peak Flood at Naugaon

S.No.	Year	Qmax
1	1982	635
2	1983	320
3	1984	281
4	1985	212
5	1986	689
6	1987	119
7	1988	684
8	1989	841
9	1990	454
10	1991	255
11	1992	289
12	1993	599
13	1994	39
14	1995	294
15	1996	271
16	1997	236
17	1998	417
18	1999	349
19	2000	221
20	2001	323
21	2002	279
22	2003	250
23	2004	234
24	2005	481
25	2006	256
26	2007	254
27	2008	425
28	2009	322
29	2010	469
30	2011	408
31	2012	207
32	2013	255
33	2014	169
34	2015	208
35	2016	268
36	2017	125
37	2018	189
38	2019	377
39	2020	228
40	2021	264
41	2022	435
42	2023	495

Year wise Maximum Peak Flood at Bausan

S.No.	Year	Qmax
1	1985	738
2	1986	746
3	1987	216
4	1988	1287
5	1989	1641
6	1990	330
7	1991	202
8	1992	689
9	1993	634
10	1994	580
11	1995	588
12	1996	498
13	1997	979
14	1998	1784
15	1999	288
16	2000	498
17	2001	977
18	2002	1065
19	2003	835
20	2004	359
21	2005	1532
22	2006	677
23	2007	794
24	2008	705
25	2009	463
26	2010	1794
27	2011	1673
28	2012	515
29	2013	754
30	2014	458
31	2015	589

Year wise Maximum Peak Flood at Asan Barrag

S.No.	Year	Qmax
1	2010	2028
2	2011	898
3	2012	1794
4	2013	1570
5	2014	1877
6	2015	1832
7	2016	1656
8	2017	1570
9	2018	1657
10	2019	1271
11	2020	1333
12	2021	1656
13	2022	1427

ANNEXURE-4

Chow's table for Manning's N

Type of Channel and Description	Minimum	Normal	Maximum
1. Main Channels			
a. clean, straight, full stage, no rifts or deep pools	0.025	0.03	0.033
b. same as above, but more stones and weeds	0.03	0.035	0.04
c. clean, winding, some pools and shoals	0.033	0.04	0.045
d. same as above, but some weeds and stones	0.035	0.045	0.05
e. same as above, lower stages, more ineffective slopes and sections	0.04	0.048	0.055
f. same as "d" with more stones	0.045	0.05	0.06
g. sluggish reaches, weedy, deep pools	0.05	0.07	0.08
h. very weedy reaches, deep pools, or floodways with heavy stand of timber and underbrush	0.075	0.1	0.15
2. Mountain streams, no vegetation in channel, banks usually steep, trees and brush along banks submerged at high stages			
a. bottom: gravels, cobbles, and few boulders	0.03	0.04	0.05
b. bottom: cobbles with large boulders	0.04	0.05	0.07
3. Floodplains			
a. Pasture, no brush			
1.short grass	0.025	0.03	0.035
2. high grass	0.03	0.035	0.05
b. Cultivated areas			
1. no crop	0.02	0.03	0.04
2. mature row crops	0.025	0.035	0.045
3. mature field crops	0.03	0.04	0.05
c. Brush			
1. scattered brush, heavy weeds	0.035	0.05	0.07
2. light brush and trees, in winter	0.035	0.05	0.06
3. light brush and trees, in summer	0.04	0.06	0.08
4. medium to dense brush, in winter	0.045	0.07	0.11
5. medium to dense brush, in summer	0.07	0.1	0.16
d. Trees			
1. dense willows, summer, straight	0.11	0.15	0.2
2. cleared land with tree stumps, no sprouts	0.03	0.04	0.05
3. same as above, but with heavy growth of sprouts	0.05	0.06	0.08

4. heavy stand of timber, a few down trees, little undergrowth, flood stage below branches	0.08	0.1	0.12
5. same as 4. with flood stage reaching branches	0.1	0.12	0.16
4. Excavated or Dredged Channels			
a. Earth, straight, and uniform			
1. clean, recently completed	0.016	0.018	0.02
2. clean, after weathering	0.018	0.022	0.025
3. gravel, uniform section, clean	0.022	0.025	0.03
4. with short grass, few weeds	0.022	0.027	0.033
b. Earth winding and sluggish			
1. no vegetation	0.023	0.025	0.03
2. grass, some weeds	0.025	0.03	0.033
3. dense weeds or aquatic plants in deep channels	0.03	0.035	0.04
4. earth bottom and rubble sides	0.028	0.03	0.035
5. stony bottom and weedy banks	0.025	0.035	0.04
6. cobble bottom and clean sides	0.03	0.04	0.05
c. Dragline-excavated or dredged			
1. no vegetation	0.025	0.028	0.033
2. light brush on banks	0.035	0.05	0.06
d. Rock cuts			
1. smooth and uniform	0.025	0.035	0.04
2. jagged and irregular	0.035	0.04	0.05
e. Channels not maintained, weeds and brush uncut			
1. dense weeds, high as flow depth	0.05	0.08	0.12
2. clean bottom, brush on sides	0.04	0.05	0.08
3. same as above, highest stage of flow	0.045	0.07	0.11
4. dense brush, high stage	0.08	0.1	0.14
5. Lined or Constructed Channels			
a. Cement			
1. neat surface	0.01	0.011	0.013
2. mortar	0.011	0.013	0.015
b. Wood			
1. planed, untreated	0.01	0.012	0.014
2. planed, creosoted	0.011	0.012	0.015

3. unplaned	0.011	0.013	0.015
4. plank with battens	0.012	0.015	0.018
5. lined with roofing paper	0.01	0.014	0.017
c. Concrete			
1. trowel finish	0.011	0.013	0.015
2. float finish	0.013	0.015	0.016
3. finished, with gravel on bottom	0.015	0.017	0.02
4. unfinished	0.014	0.017	0.02
5. gunite, good section	0.016	0.019	0.023
6. gunite, wavy section	0.018	0.022	0.025
7. on good excavated rock	0.017	0.02	
8. on irregular excavated rock	0.022	0.027	
d. Concrete bottom float finish with sides of:			
1. dressed stone in mortar	0.015	0.017	0.02
2. random stone in mortar	0.017	0.02	0.024
3. cement rubble masonry, plastered	0.016	0.02	0.024
4. cement rubble masonry	0.02	0.025	0.03
5. dry rubble or riprap	0.02	0.03	0.035
e. Gravel bottom with sides of:			
1. formed concrete	0.017	0.02	0.025
2. random stone mortar	0.02	0.023	0.026
3. dry rubble or riprap	0.023	0.033	0.036
f. Brick			
1. glazed	0.011	0.013	0.015
2. in cement mortar	0.012	0.015	0.018
g. Masonry			
1. cemented rubble	0.017	0.025	0.03
2. dry rubble	0.023	0.032	0.035
h. Dressed ashlar/stone paving	0.013	0.015	0.017
i. Asphalt			
1. smooth	0.013	0.013	
2. rough	0.016	0.016	
j. Vegetal lining	0.03		0.5

ANNEXURE-5

Area between 5 Year & 25 Year

Area between 25 Year & 100 Year

YEARLY WISE YAMUNA RIVER FLOOD ZONE AREA							
Sl. No.	**Lot No.**	**Name of the River**	**Right Bank**	**Area (in Ac.) (A)**	**Left Bank**	**Area (in Ac.) (B)**	**Total Area in Ac. (A+B)**
1	LOT - 1	Yamuna	5 YR	8581.951	NA	NA	8581.951
2			5-25 YR_RB (25)	838.561	5-25 YR_LB (25)	212.444	1051.005
3			25-50 YR_RB (50)	142.169	25-50 YR_LB (50)	142.598	284.766
4			50-100 YR_RB (100)	103.521	50-100 YR_LB (100)	137.805	241.326
Total				**9666.202**		**492.847**	**10159.049**

YEARLY WISE NUN RIVER FLOOD ZONE AREA							
Sl. No.	**Lot No.**	**Name of the River**	**Right Bank**	**Area (in Ac.) (A)**	**Left Bank**	**Area (in Ac.) (B)**	**Total Area in Ac. (A+B)**
1	Lot-1	Nun	5 YR	169.368	NA	NA	169.368
2			5-25 YR_RB (25)	11.147	5-25 YR_LB (25)	10.412	21.559
3			25-50 YR_RB (50)	7.163	25-50 YR_LB (50)	7.674	14.838
4			50-100 YR_RB (100)	18.875	50-100 YR_LB (100)	29.926	48.801
Total				**206.553**		**48.012**	**254.565**

YEARLY WISE NIMI RIVER FLOOD ZONE AREA							
Sl. No.	**Lot No.**	**Name of the River**	**Right Bank**	**Area (in Ac.) (A)**	**Left Bank**	**Area (in Ac.) (B)**	**Total Area in Ac. (A+B)**
1	LOT - 1	Nimi	5 YR	172.199	NA	NA	172.199
2			5-25 YR_RB (25)	7.753	5-25 YR_LB (25)	7.569	15.322
3			25-50 YR_RB (50)	5.138	25-50 YR_LB (50)	5.500	10.638
4			50-100 YR_RB (100)	17.464	50-100 YR_LB (100)	14.785	32.248
Total				**202.553**		**27.854**	**230.407**

YEARLY WISE JHAKHAN RIVER FLOOD ZONE AREA							
Sl. No.	**Lot No.**	**Name of the River**	**Right Bank**	**Area (in Ac.) (A)**	**Left Bank**	**Area (in Ac.) (B)**	**Total Area in Ac. (A+B)**
1	LOT - 1	Jhakhan	5 YR	815.633	NA	NA	815.633
2			5-25 YR_RB (25)	36.374	5-25 YR_LB (25)	22.070	58.444
3			25-50 YR_RB (50)	21.415	25-50 YR_LB (50)	17.303	38.718
4			50-100 YR_RB (100)	24.659	50-100 YR_LB (100)	53.281	77.940
Total				**898.080**		**92.654**	**990.734**

YEARLY WISE SITLA RAO RIVER FLOOD ZONE AREA							
Sl. No.	Lot No.	Name of the River	Right Bank	Area (in Ac.) (A)	Left Bank	Area (in Ac.) (B)	Total Area in Ac. (A+B)
1	LOT - 1	Sitla Rao	5 YR	215.538	NA	NA	215.538
2			5-25 YR_RB (25)	7.612	5-25 YR_LB (25)	10.830	18.442
3			25-50 YR_RB (50)	10.012	25-50 YR_LB (50)	8.436	18.448
4			50-100 YR_RB (100)	11.945	50-100 YR_LB (100)	10.430	22.375
Total				**245.107**		**29.696**	**274.803**

YEARLY WISE SWARNA RIVER FLOOD ZONE AREA							
Sl. No.	Lot No.	Name of the River	Right Bank	Area (in Ac.) (A)	Left Bank	Area (in Ac.) (B)	Total Area in Ac. (A+B)
1	LOT - 1	Swarna	5 YR	748.734	NA	NA	748.734
2			5-25 YR_RB (25)	39.878	5-25 YR_LB (25)	22.087	61.965
3			25-50 YR_RB (50)	28.175	25-50 YR_LB (50)	23.450	51.625
4			50-100 YR_RB (100)	57.162	50-100 YR_LB (100)	40.512	97.675
Total				**873.950**		**86.049**	**959.999**

YEARLY WISE ASAN RIVER FLOOD ZONE AREA							
Sl. No.	Lot No.	Name of the River	Right Bank	Area (in Ac.) (A)	Left Bank	Area (in Ac.) (B)	Total Area in Ac. (A+B)
1	LOT - 1	Asan	5 YR	3005.648	NA	NA	3005.648
2			5-25 YR_RB (25)	78.799	5-25 YR_LB (25)	56.329	135.128
3			25-50 YR_RB (50)	52.749	25-50 YR_LB (50)	52.652	105.401
4			50-100 YR_RB (100)	159.339	50-100 YR_LB (100)	359.010	518.349
Total				**3296.535**		**467.991**	**3764.526**

YEARLY WISE CHANDRABHAGA RIVER FLOOD ZONE AREA							
Sl. No.	Lot No.	Name of the River	Right Bank	Area (in Ac.) (A)	Left Bank	Area (in Ac.) (B)	Total Area in Ac. (A+B)
1	LOT - 1	Chandrabhaga	5 YR	963.860	NA	NA	963.860
2			5-25 YR_RB (25)	26.466	5-25 YR_LB (25)	13.969	40.435
3			25-50 YR_RB (50)	23.671	25-50 YR_LB (50)	16.368	40.039
4			50-100 YR_RB (100)	27.810	50-100 YR_LB (100)	23.224	51.034
Total				**1041.808**		**53.560**	**1095.368**
Grand Total				**16430.789**		**1298.662**	**17729.451**