INFLOW FORECASTING TO HYDRO POWER PROJECTS WITH FOCUS ON TEHRI PROJECT

by

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2. Need for Forecasts for hydropower schemes
3. Need for operational system for Tehri dam and advantages
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PART I

INFLOW FORECASTING AND CLASSIFICATION

Inflow forecasting to hydropower projects may be defined as ‘Estimation of future inflows to the hydropower schemes during monsoon and non-monsoon flows’.

Depending upon the lead time the inflow forecasts may be classified as:

Immediate or nowcasting (0-6 hours)

Short term forecasting (6 hours – 72 hours)

Medium term forecasting (72 hours to 12 days)

Seasonal forecasting/ Extended forecasts (> 12 days)

NEED FOR FORECASTS FOR HYDROPOWER SCHEMES

The advanced information abut the incoming flows in hydropower projects is required for the following two purposes:

- To regulate the release of water through spillways
- To generate optimum electricity

Need for operational inflow forecasting system for Tehri dam and advantages

1. A flood space of 4.8 m to route the PMF has been provided at Tehri dam. An operational flood forecasting system may provide the additional flood space of 2-3 meters by converting the conservation space into flood space at the time of floods. The system provides 24 hours advanced information to regulate the release of water through spillways.
2. The system is helping in the generation of optimum electricity during non-monsoon season.
3. The hydro-meteorology of the entire catchment of Tehri Dam is better known to THDCIL;
4. The impact of land use land cover changes in the catchment and the climatic changes in the catchment are better known to THDCIL. Hence, the impact of these changes on power generation is better known in short as well as long terms.

How THDCIL has advanced in this direction

- Human Resource Development- 2007
- Review of Hydrology of the Tehri dam- 2008
- Review of power generation- 2010
- Initiation of the development of the inflow forecasting system for Tehri dam- 2012
- Start of the system- June 1, 2016
- Start of the operational forecasting system – July 1, 2018

  More details of this in a little while

How Other power developers can proceed

i. With dynamic tariff of electricity the information about incoming flows in advance will be useful in better planning of power generation schedule. The better planning shall result in higher return of tariff.

ii. Lot of advancement is taking place in the forecasting of rainfall beyond 1 day i.e. a week and more by IMD and NCMRWF. With linking of forecasted rainfall of more than one day in the inflow forecasting models shall be further useful to power sector.

iii. Setting up of hydro-meteorological network in their project catchment will help in better understanding of your catchments. It will help in analyzing the implications of land use land cover changes and climatic changes on power generation of the projects

iv. The initiative of SJVNL and CBIP is a welcome step in this direction

Queries on basic concepts?

PART II

About Tehri Hydropower Project

TEHRI HYDRO POWER PROJECT

Type of Scheme	:	Storage (Multipurpose)
Location	:	Tehri (Garhwal)
River	:	Bhagirathi
Dam Type	:	Earth & Rockfill (Fourth highest in world in earth and rockfill category)
Dam Height	:	260.5 m
Dam Base Width	:	1128 m
Dam Width at top	:	25.5 m
Dam Length at top	:	575 m

TEHRI HYDRO POWER COMPLEX

- Total Generation of 2400 MW in Three Stages

- Stage – I : Tehri HPP (1000 MW)
  - Status : Commissioned in 2006

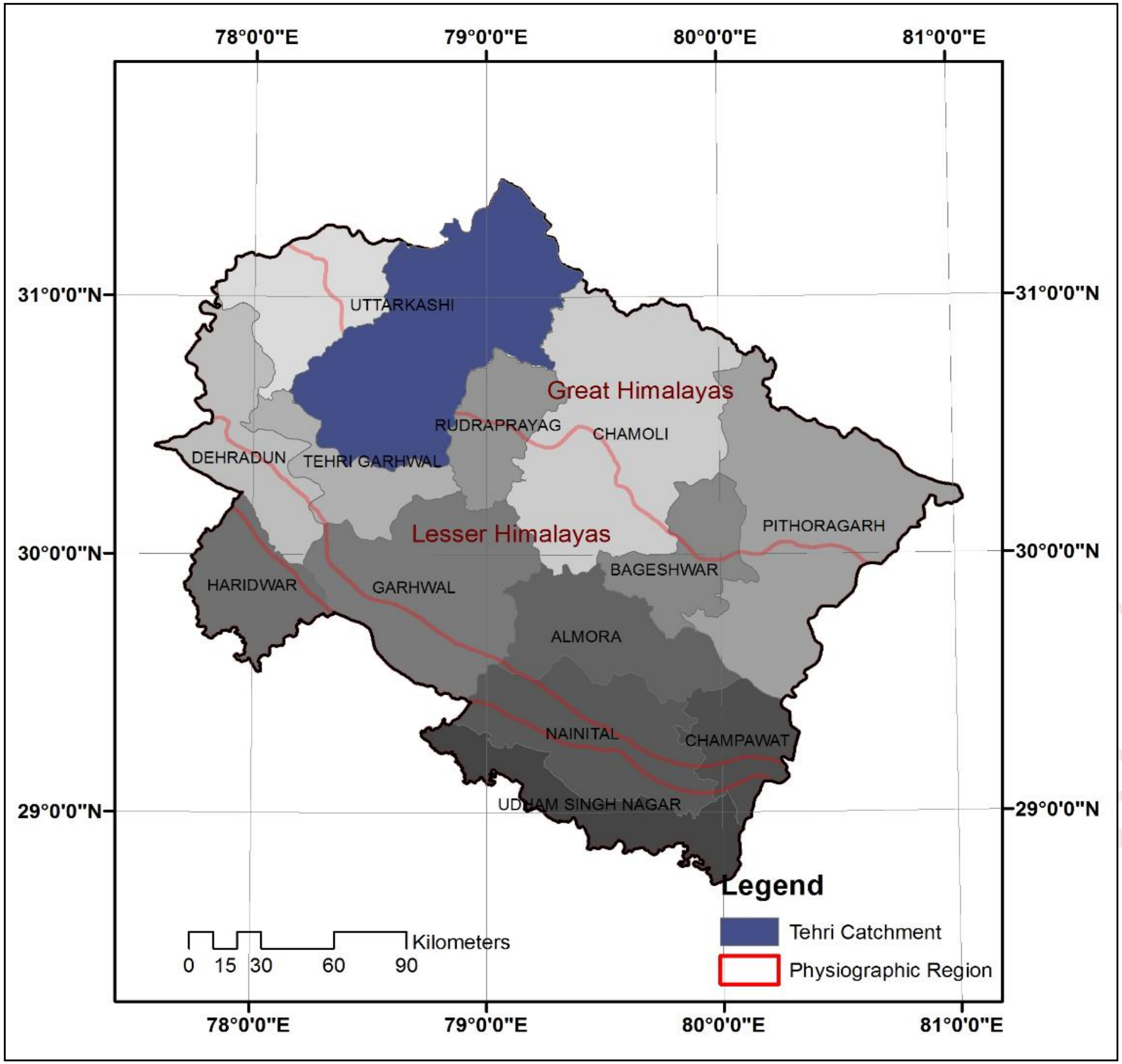
- Stage – II : Koteshwar HEP (400 MW)
  - Status : Commissioned in 2011

- Stage – III : Tehri PSP (1000 MW)
  - Status : Work is in progress

HYDRLOGICAL PARAMETERS

Design Flood	:	15,540 Cumecs
Gross Storage	:	3,540 MCM
Live Storage	:	2,615 MCM
Mean Annual Run-off	:	8,000 MCM
Catchment Area	:	7,287 sq km
Snowbound	:	2,424 sq km
Rainfed	:	4,863 sq km
Annual rainfall	:	1,016 to 2,630 mm
River Discharge	:	28 to 7500 Cumecs
Max. Flood Level	:	EL 835 m
Full Reservoir Level	:	EL 830 m
MDDL	:	EL 740 m

Tehri Catchment on map of Uttarakhand



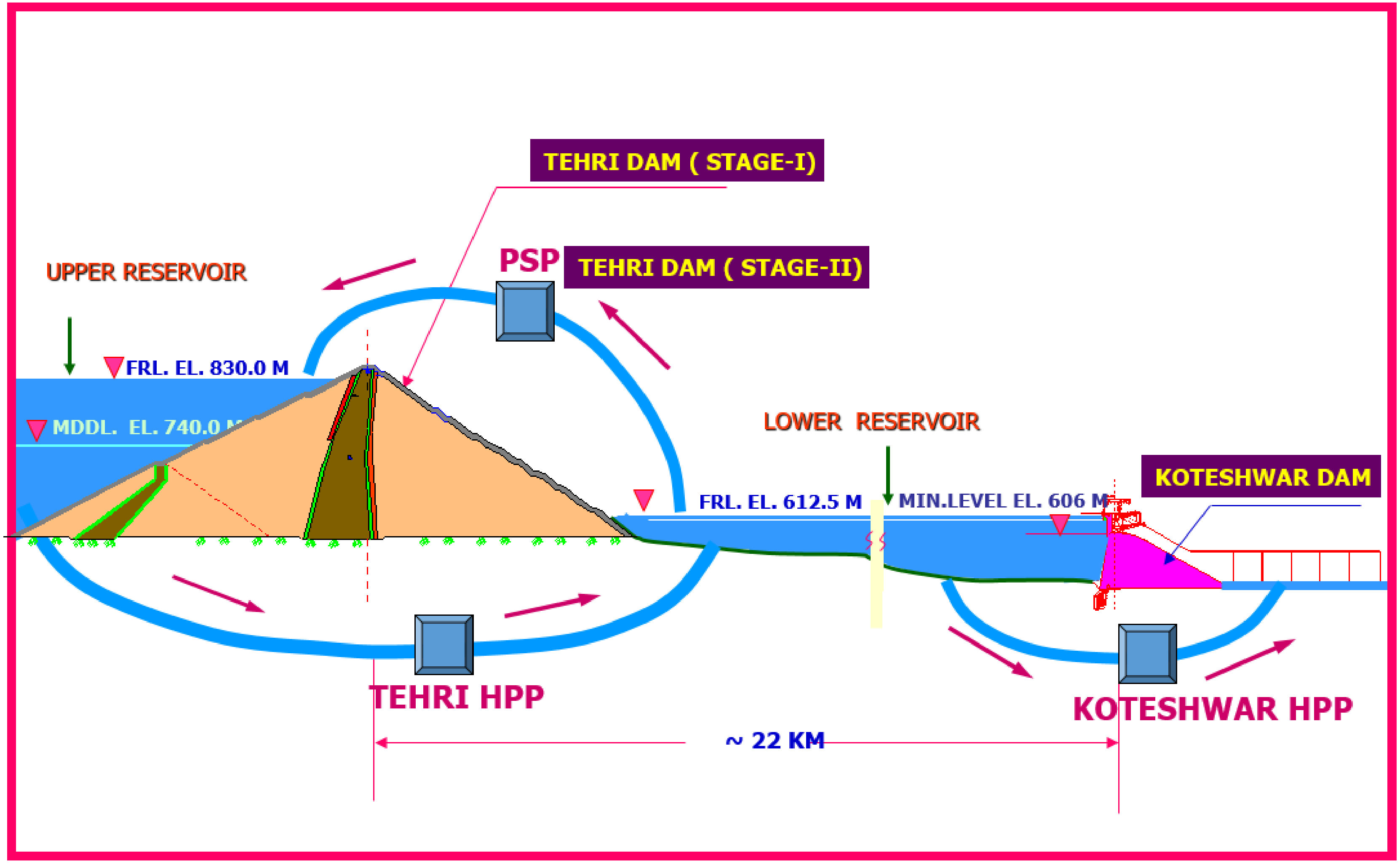
Tehri Dam

Tehri Reservoir extends from Ghansali to Dharasu on FRL (70 Km; area 42 km^2)

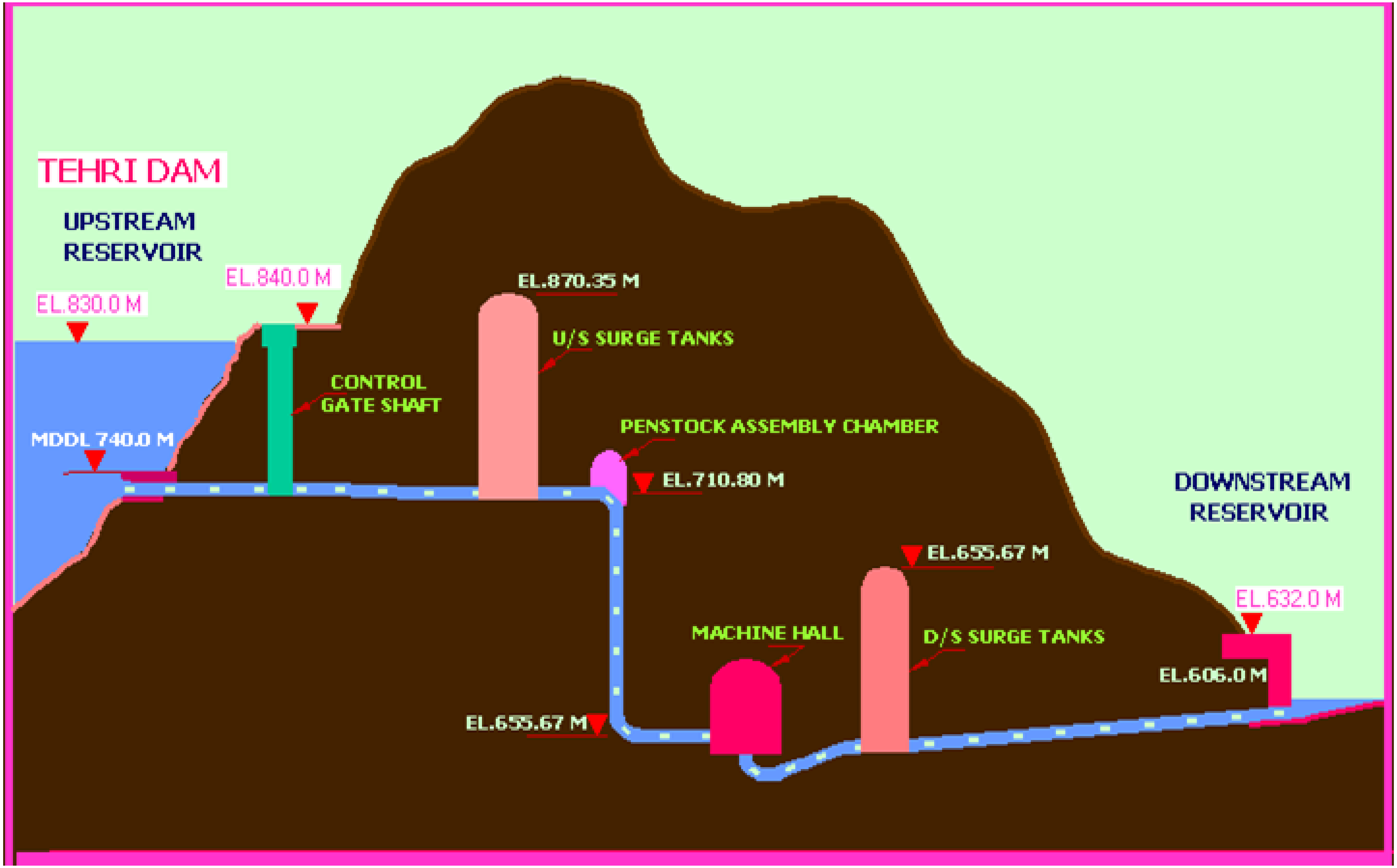
Upstream View of Chute Spillway

Downstream View of Chute Spillway

Schematic view of upper and Lower Reservoirs



Pump Storage Plant - 1000MW cross section through water way



COMPONENTS OF OPERATIONAL INFLOW FORECASTING SYSTEM

1. Observation of hydro-meteorological data
2. Transmission of data
    - Remote Stations to Earth Station
    - Earth Station to Modelling centres
3. Processing of data at Earth Station
4. Forecast formulation and verification
5. Dissemination of Forecast

Observation of hydro-meteorological Data- Requirements

1. Network Design of Hydro-meteorological Stations
    - Density depends upon the variability of the data
    - Acceptable error in estimation
2. Type of sensors to be used
    - Inflow forecast model;
    - Expandability of the system;
    - Use of the AWS data in other studies and operations like rescue operations; aviation etc.
3. Frequency of recording the data: Purpose
4. Validation of AWS and Automatic G &D sites through manual observatories and manual G&D sites

Observation of Hydro-meteorological data- Steps

1. Identification of locations of the hydro-meteorological stations; agreements of watch and ward with the land owners etc.;
2. Preparation of the specifications of the required instruments;
3. Calling for the tenders; award of the work; testing of equipment;
4. Establishment of the automatic weather stations at different locations; testing of the functioning of the instruments;
5. Establishment of manual observatories at identified locations for verification of data at 4;
6. Establishment of automatic gauge and discharge sites at the identified locations;
7. Establishment of manual Gauge and discharge sites at identified locations for verification of 6;

Pinpointing of the Sites at different locations

- Accessibility of the sites;
- Safety and security of the instruments;
- Availability and strength of mobile signals;
- Availability of electricity and local electrician;
- Stay arrangements for the field engineers;
- Consent and arrangements with the landowners

COMPONENTS OF DATA COLLECTION PLATFORM (DCP)

- Data Collection Unit (DCU)
  - Data Collection and storage (Data Logger)
- Sensors
- Transmitter antenna
- Enclosure
- Lighting, lightning protection equipment
- Memory card and readers
- Solar Panel, Power supply (battery)

  - Sensors may vary from station to station
  - Data logger, Data Collection and Transmission unit must be expandable for future need.

Sensors in automatic Weather Stations

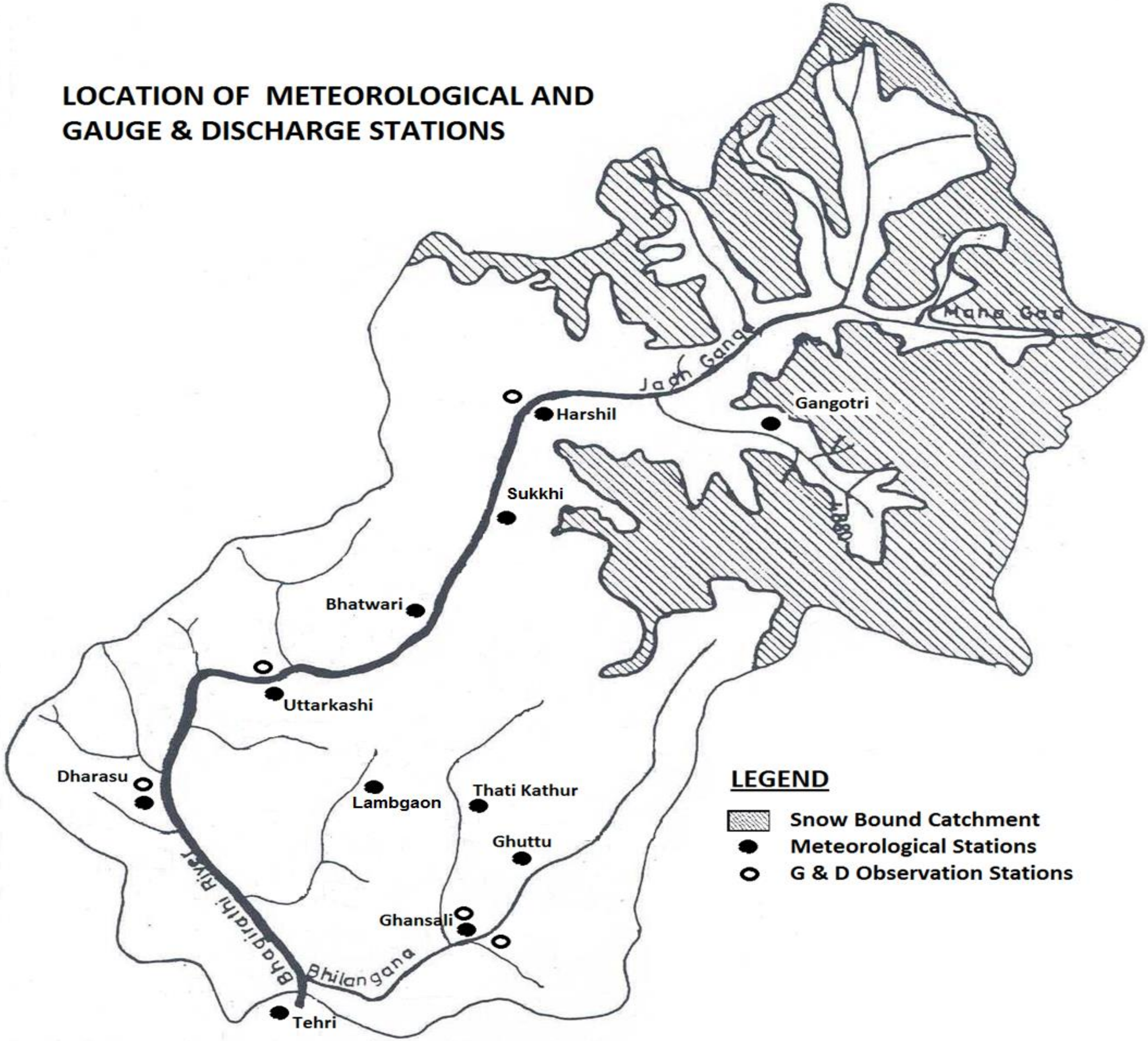
- Precipitation
  - Rainfall
  - Snowfall (only at few locations)
- Air Temperature and Relative Humidity
- Wind Speed
- Wind Direction
- Solar Radiation
- Gauge and Discharge Measurement
- Observation of gauge and Discharge using contact free radar based system

Location of automatic Weather Stations

AWS Sites: 11 Locations

- Gangotri
- Harshil
- Sukkhi
- Bhatwari
- Uttarkashi
- Dharasu
- Lambgoan
- Tehri
- Ghansali
- Dhopardhar
- Bishan

LOCATION OF METEOROLOGICAL AND GAUGE & DISCHARGE STATIONS



Automatic weather station at Harshil

AWS and Manual observatory at Uttarkashi

Panel Box of Data logger

Automatic Gauge and Discharge Sensors

- The automatic gauge and discharge site consist of the radar-based gauge and discharge sensors. These two sensors have been combined in RQ-30 of M/S Sommer.
- The RQ-30 radar sensor is a continuous measurement device for the contact-free determination of the discharge of open rivers and channels.
- It combines two contact-free radar methods for water level and velocity measurements in one system. These two measurements are internally combined and provide the discharge using a predefined calibration of the measurement site.

Locations of G & D sites

G&D Sites: 5 Locations

- Harshil on river Bhagirathi
- Uttarkashi on river Bhagirathi (Outflows from MBII scheme from UJVNL)
- Dharasu on river Bhagirathi
- Ghansali on river Bhilangana
- Sarasgaon on river Balganga

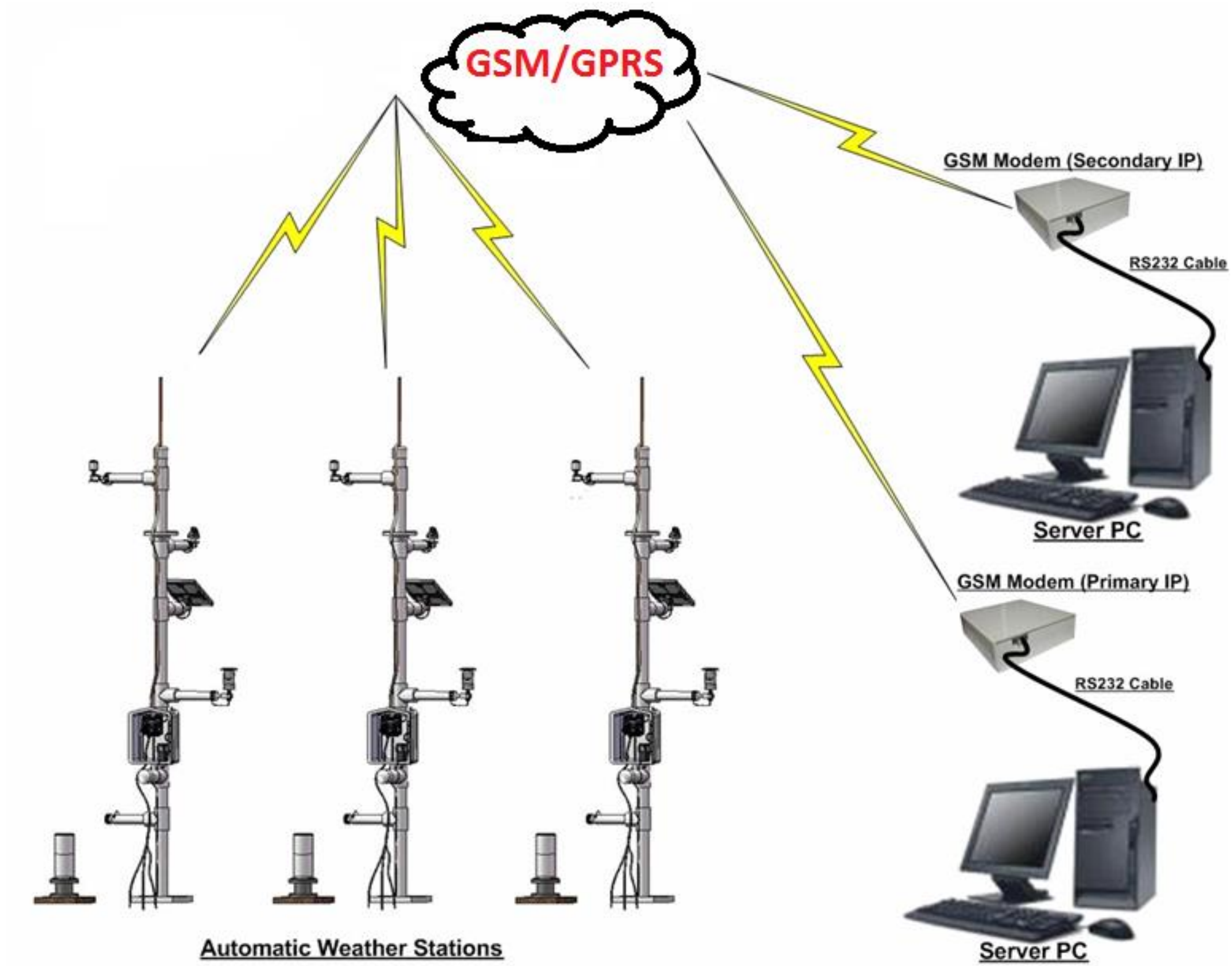
Automatic G&D station at Sarasgaon on River Balganga

Manual G&D site on River Balganga at Sarasgaon on downstream of the Bridge

DATA TRANSMISSION

- From Data Collection Platform (DCP) to earth station receiver through GSM/GPRS with optional INSAT/VSAT transmission
- Server room is provided with internet connectivity through leased lines
- Server room to modelling centres through Internet
    - GSM- Global System for Mobiles
    - GPRS- General Packet Radio Service
    - INSAT- Indian National satellite System
    - VSAT- Very Small Aperture Terminal

Data Transmission from DCP to Earth Station through GSM/GPRS



Forecast Formulation

Forecast formulation is the heart of any operational Inflow forecasting system. A number of inflow forecasting models have been developed in the past. These models vary from simple gauge to gauge correlation methods to complex physically based time variant distributed models.

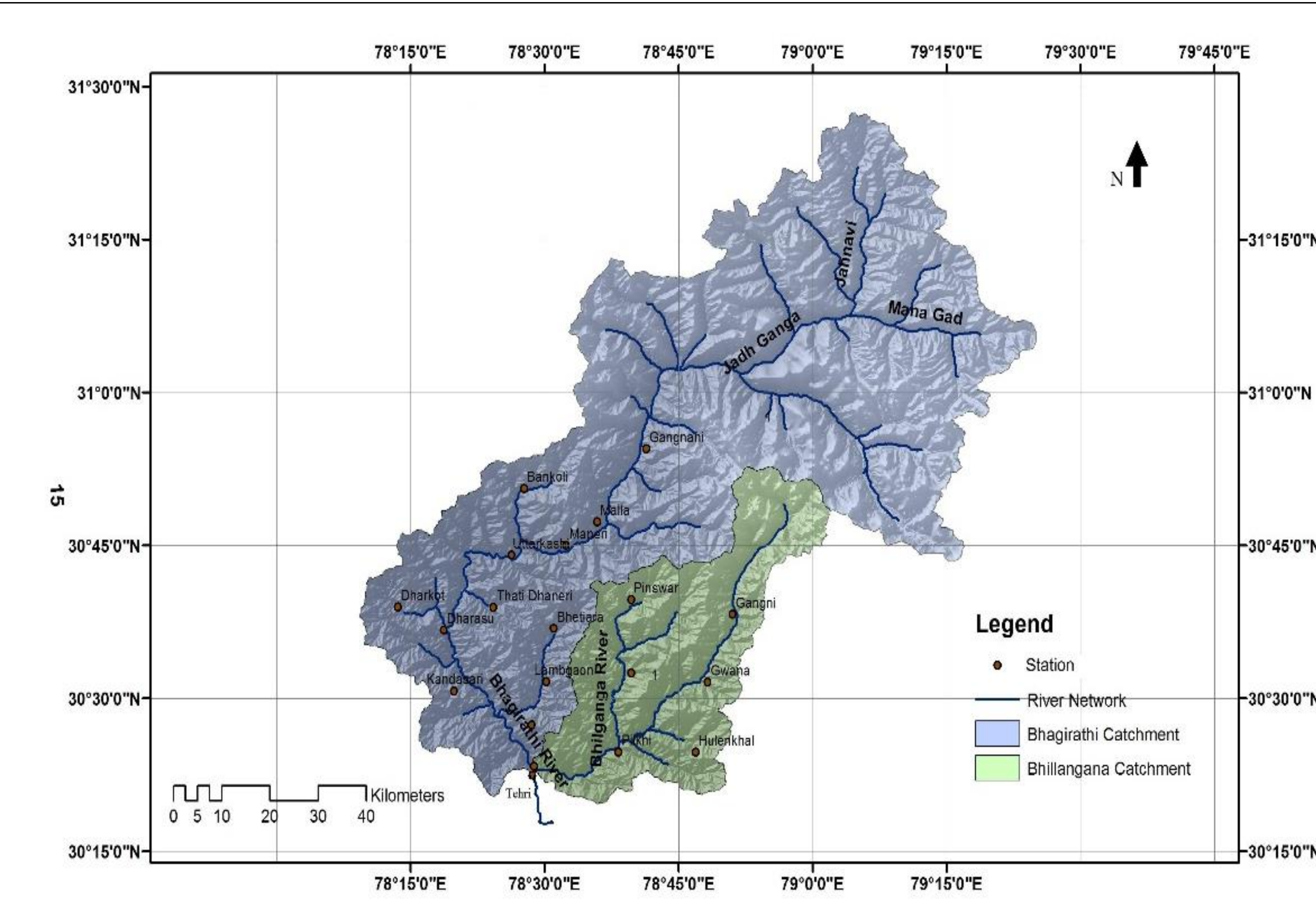
The following factors govern the choice of the model:

- Physiographic factors
- Data availability
- Warning time required
- Computational facilities
- Purpose of forecast.

Steps in Forecast Formulation

- Critical evaluation of the catchment system;
- Selection of the model
- Model Details
- Downloading of the information about components of the system from different sources
- Forecast formulation
- Uploading of the results
- Forecast Verification

Catchment Map



Forecast Formulation

1. Delineation of catchment and sub-catchments

Tehri catchment has been divided into four parts.

i. Bhagirathi up to Maneri Bhali II,

ii. Bhilangana up to Ghansali,

iii. Balganga up to Sarasgaon, and

iv. Intermediate catchment with geomorphologic features of 16 streams falling directly into the reservoir.

The catchment

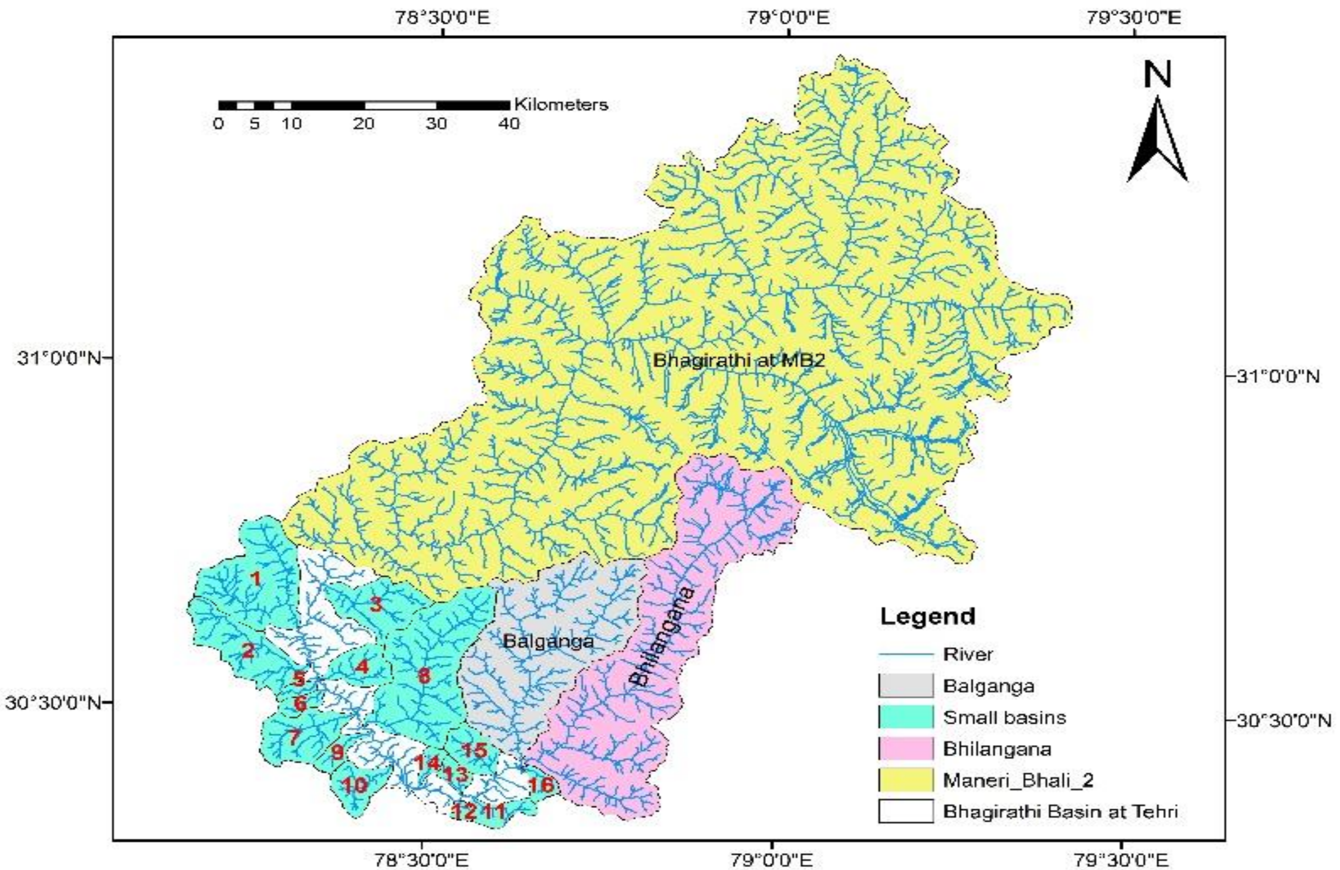
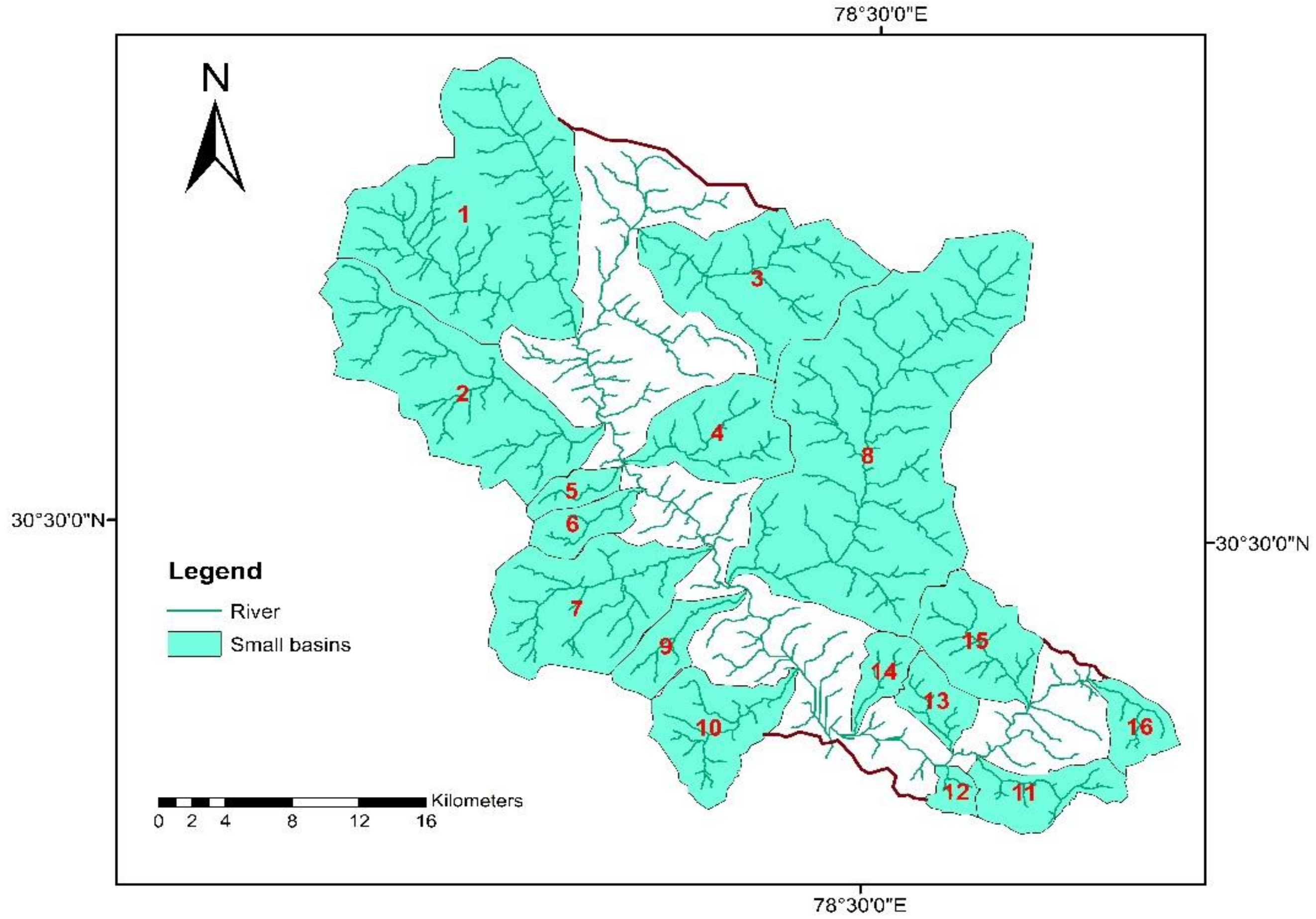


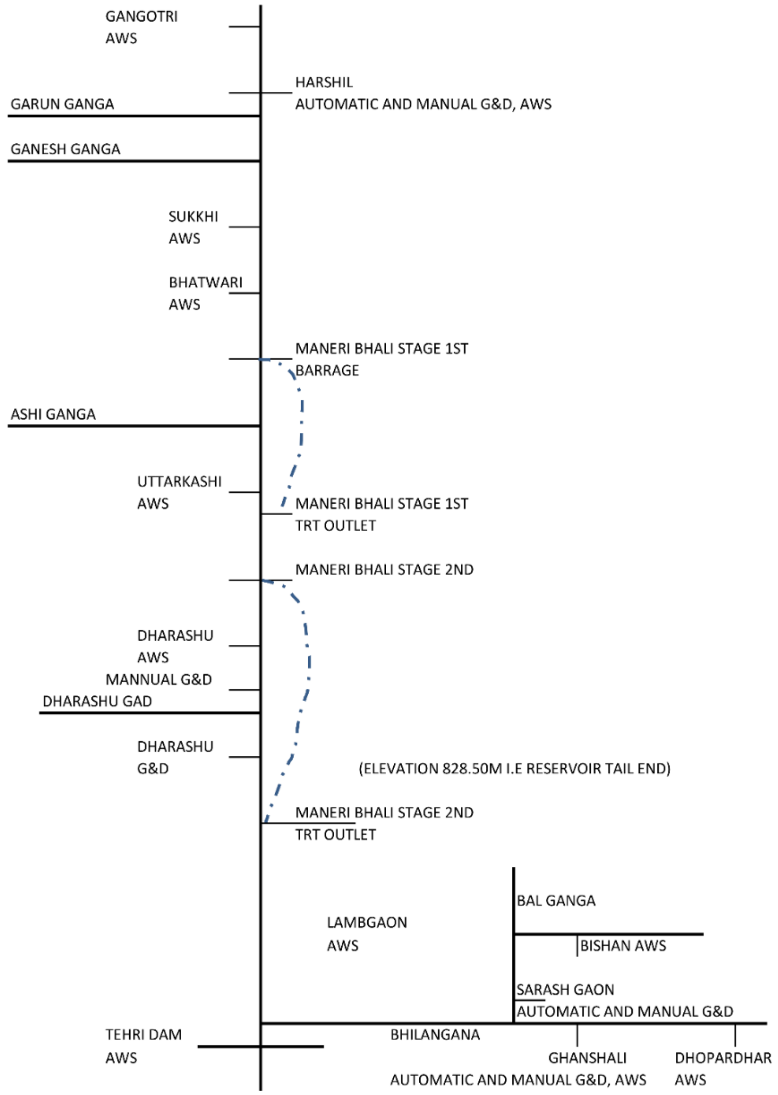
Figure show the Tehri catchment.

Intermediate Catchment



System Conceptualization

LINE DIAGRAM OF MAIN FEATURES OF CATCHMENT



Details of Forecasting Model

For inflow forecast to Tehri Reservoir a hybrid model has been developed. The salient features of the model are:

- The hybrid model is combination of a GIUH based deterministic model for intermediate catchment directly contributing to the reservoir and Stochastic models of ARMAX type for the three stations namely Maneri Bhali II, Ghansali and Sarasgaon. The parameter updating for the Stochastic models is done using recursive least square algorithm.
- Inflow Routing upto the Reservoir
- Lead times are 6 hours and 24 hours;

Forecasted Rainfall

- The following type of rainfall forecasts are available and used in the model
  - 1day, 2day, and 3day rainfall forecasts by NCMRWF for 0.25X0.25 degree gridded rainfall
  - 1day to 7day rainfall forecasts of Bhagirathi basin using WRF, GFS and MME models

Details of Stochastic Models at three locations

The following type of stochastic models have been developed

AR (p) model is represented as

$$Q_t = \varphi_1 Q_{t-1} + \ldots\ldots + \varphi_p Q_{t-p} + \varepsilon_t \quad (1)$$

ARMA (p, q) model;

$$Q_t = \varphi_1 Q_{t-1} + \ldots\ldots + \varphi_p Q_{t-p} + \Theta_1 \varepsilon_{t-1} + \ldots\ldots + \Theta_q \varepsilon_{t-q} + \ldots\ldots + \varepsilon_t \quad (2)$$

ARX (p, r) model;

$$Q_t = \varphi_1 Q_{t-1} + \ldots\ldots + \varphi_p Q_{t-p} + b_1 d_{t-1} + \ldots\ldots + b_r d_{t-r} + \varepsilon_t \quad (3)$$

ARMAX (p, q, r) model;

$$Q_t = \varphi_1 Q_{t-1} + \ldots\ldots + \varphi_p Q_{t-p} + \Theta_1 \varepsilon_{t-1} + \ldots\ldots + \Theta_q \varepsilon_{t-q} + b_1 d_{t-1} + \ldots\ldots + b_r d_{t-r} + \varepsilon_t \quad (4)$$

Cont…

Parameter estimations

Mathematical expression for ARMAX (p, q, r) model with exogenous variable inputs is

$$Q_t = \varphi_1 Q_{t-1} + \ldots\ldots + \varphi_p Q_{t-p} + \Theta_1 \varepsilon_{t-1} + \ldots\ldots + \Theta_q \varepsilon_{t-q} + b_1 d_{t-1} + \ldots\ldots + b_r d_{t-r} + \varepsilon_t$$

$$Q_{t+1} = \varphi_1 Q_{t+1-1} + \ldots\ldots + \varphi_p Q_{t+1-p} + \Theta_1 \varepsilon_{t+1-1} + \ldots\ldots + \Theta_q \varepsilon_{t+1-q} + b_1 d_{t+1-1} + \ldots\ldots + b_r d_{t+1-r} + \varepsilon_t$$

$$Q_{t+T} = \varphi_1 Q_{t+T-1} + \ldots\ldots + \varphi_p Q_{t+T-p} + \Theta_1 \varepsilon_{t+T-1} + \ldots\ldots + \Theta_q \varepsilon_{t+T-q} + b_1 d_{t+T-1} + \ldots\ldots + b_r d_{t+T-r} + \varepsilon_t$$

Where φ_p is the p-th autoregressive coefficient of the AR(p) model, Θ_q is the q-th moving average coefficient of the MA(q), b_r is the r-th exogenous variable coefficient of the X(r).

AR(p), p = 1, 2, 3……… MA(q), q = 1, 2, 3……… X(r), r = 1, 2, 3………

Cont…

Which may be written as matrix notation for ARMAX

$$\begin{bmatrix} Q_t \\ \vdots \\ \vdots \\ \vdots \\ Q_{t+T} \end{bmatrix} = \begin{bmatrix} Q_{t-1} & \varepsilon_{t-1} & d_{t-1} \\ \vdots & \vdots & \vdots \\ \vdots & \vdots & \vdots \\ \vdots & \vdots & \vdots \\ Q_{t+T-1} & \varepsilon_{t+T-1} & d_{t+T-1} \end{bmatrix} \begin{bmatrix} \varphi_p \\ \vdots \\ \Theta_q \\ \vdots \\ b_r \end{bmatrix}$$

Where, $Y = \begin{bmatrix} Q_t \\ \vdots \\ \vdots \\ \vdots \\ Q_{t+T} \end{bmatrix}, \; H = \begin{bmatrix} Q_{t-1} & \varepsilon_{t-1} & d_{t-1} \\ \vdots & \vdots & \vdots \\ \vdots & \vdots & \vdots \\ \vdots & \vdots & \vdots \\ Q_{t+T-1} & \varepsilon_{t+T-1} & d_{t+T-1} \end{bmatrix}, \; \Theta = \begin{bmatrix} a_p \\ \vdots \\ \Theta_q \\ \vdots \\ b_r \end{bmatrix}$

$$[Y] = [H]\,[\Theta]$$

$$[H^T]\,[Y] = [H^T]\,[H]\,[\Theta] \qquad (10)$$

Then, efficient coefficient parameters [Θ] is

$$[\Theta] = [H^T \times H]^{-1}[H^T]\,[Y] \qquad (11)$$

Modelling of Intermediate catchment

1. There are 16 ungauged tributaries (Dharashu gad, Siyansu gad, Jalkur gad , Koti gad etc) which are falling directly into the reservoir.
2. The contribution of these tributaries in the runoff at Tehri is varying between 8 to 40%
3. Modelling of the runoff of these tributaries is important.
4. GIUH based Nash models have been used to develop 1 hour unit hydrograph for all the 16 tributaries using physiographic characteristics of the catchment of each tributaries.
5. Hourly rain fall of Dharashu, Lambgaon, Ghansali and Tehri stations have been used to convolute the flood.

GIUH-Nash Model:

- The concepts of GIUH and the Nash IUH models are used to derive the GIUH based Nash model. The complete shape of the GIUH can be obtained by linking q_p and t_p of the GIUH with the scale k and shape parameter n of Nash IUH model.

$$u(t) = \frac{1}{k\Gamma(n)}(t / kn)^{n-1} \exp(-t / k)$$

$$\frac{(n-1)}{\Gamma(n)}\exp[-(n-1)].(n-1)^{n-1} = 0.5764[R_b / R_a]^{0.55} * R_l^{\ 0.05}$$

$$k = \frac{0.44 l_\Omega}{V}.\left(\frac{R_b}{R_a}\right)^{0.55}.R_l^{\ -0.38}.\frac{1}{(n-1)}$$

Verification and Dissemination of Forecast

- Based on the inflow to the reservoir, the forecasted water level of the reservoir is computed using outflow from the reservoir and reservoir elevation capacity curve
- Outflow from the reservoir depends upon the generation schedule which is finalized and uploaded on the website of NRLDC and the reservoir levels of Tehri and Koteshwar.
- Based on this forecasts are made and uploaded on the website http://117.239.95.84/THDC/Default.aspx

View of Home page

Real Time Fl

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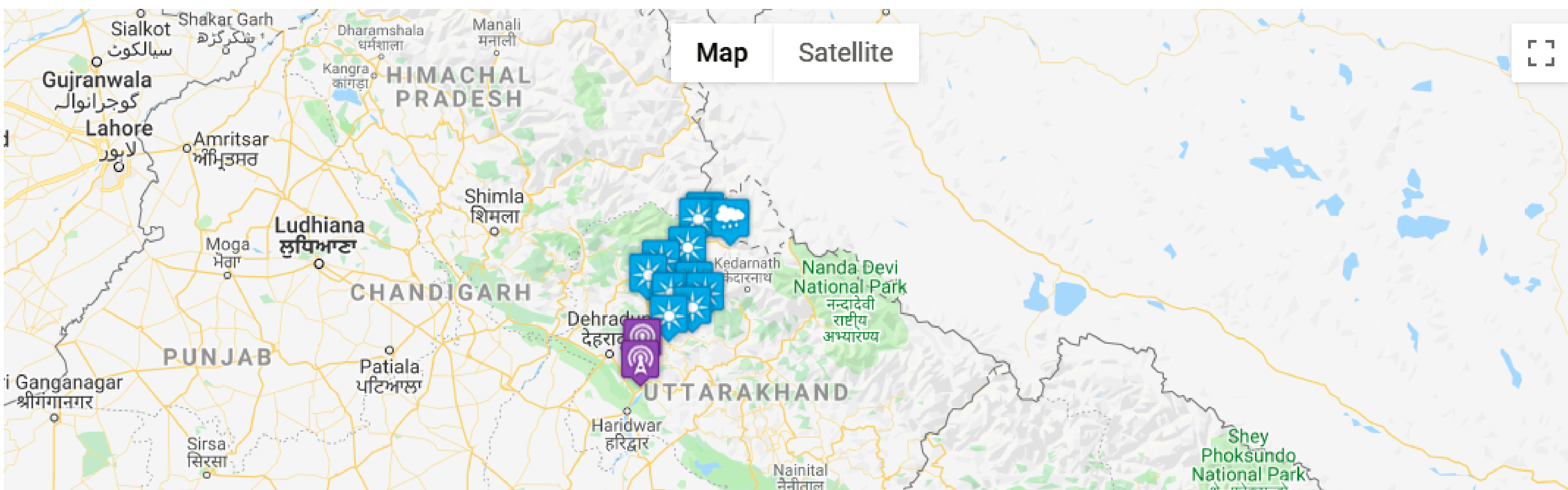
Map View

Inflow & Level Forecast of Tehri Reservoir

Forecast Issued Date	Forecast Issued Time	Forecast Date	Forecast Time	Inflow (Cumecs)	Level (Mtr)	Remark
23-04-2019	10:01	24-04-2019	09:01	111.730	764.060	Outflow = 235.55
23-04-2019	09:01	23-04-2019	15:01	112.130	764.500	Outflow = 145.97

Category: Weather Station



Performance of the operational Forecasting system

- The hybrid model developed for the study was calibrated using the data of 2016-17 and validated using the data 2017-18 for the three sites of the basin where the gauging is being done and also at the Tehri reservoir using the reservoir water level.
- From July 1, 2018, the model has been used in real time. The six hourly forecasts are issued at 9 am and 4 pm.
- From November 1, 2018, the daily forecasts are also being issued. More than 50% of the days, the forecasted reservoir level are having an accuracy of $\pm$ 2 cm.

Some Typical Snapshots of the Site

Home page of the site

Real

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Map View

Inflow & Level Forecast of Tehri Reservoir

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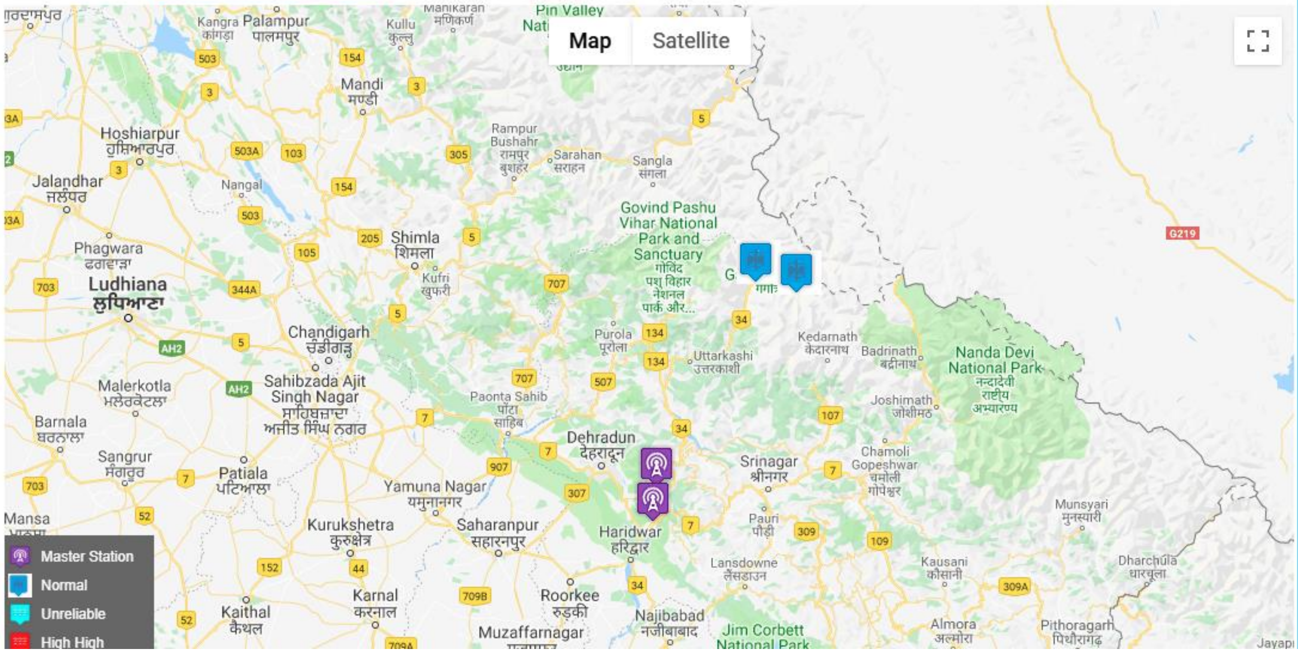
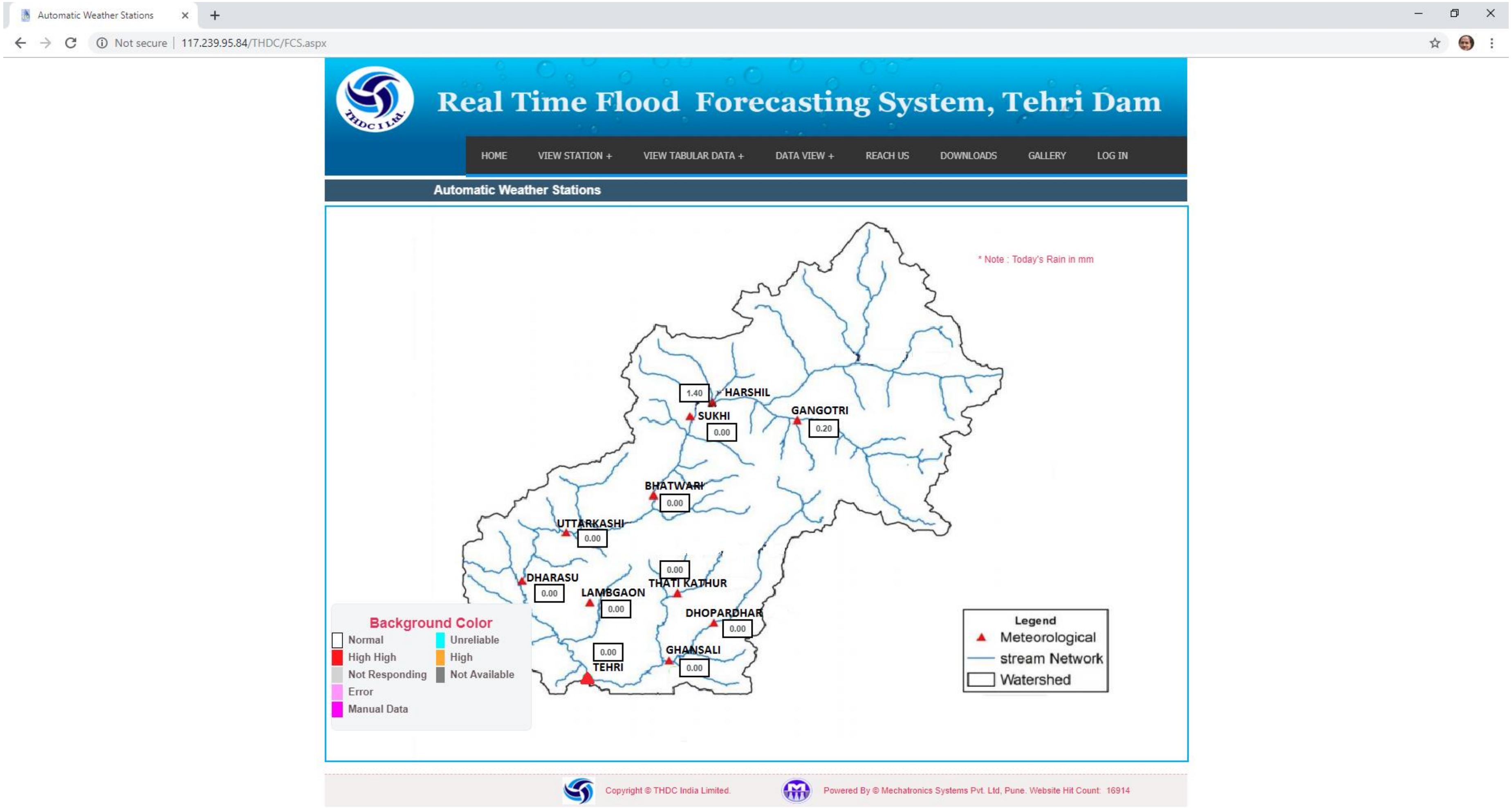
23-04-2019	09:01	23-04-2019	15:01	112.130	764.500	Outflow = 145.97

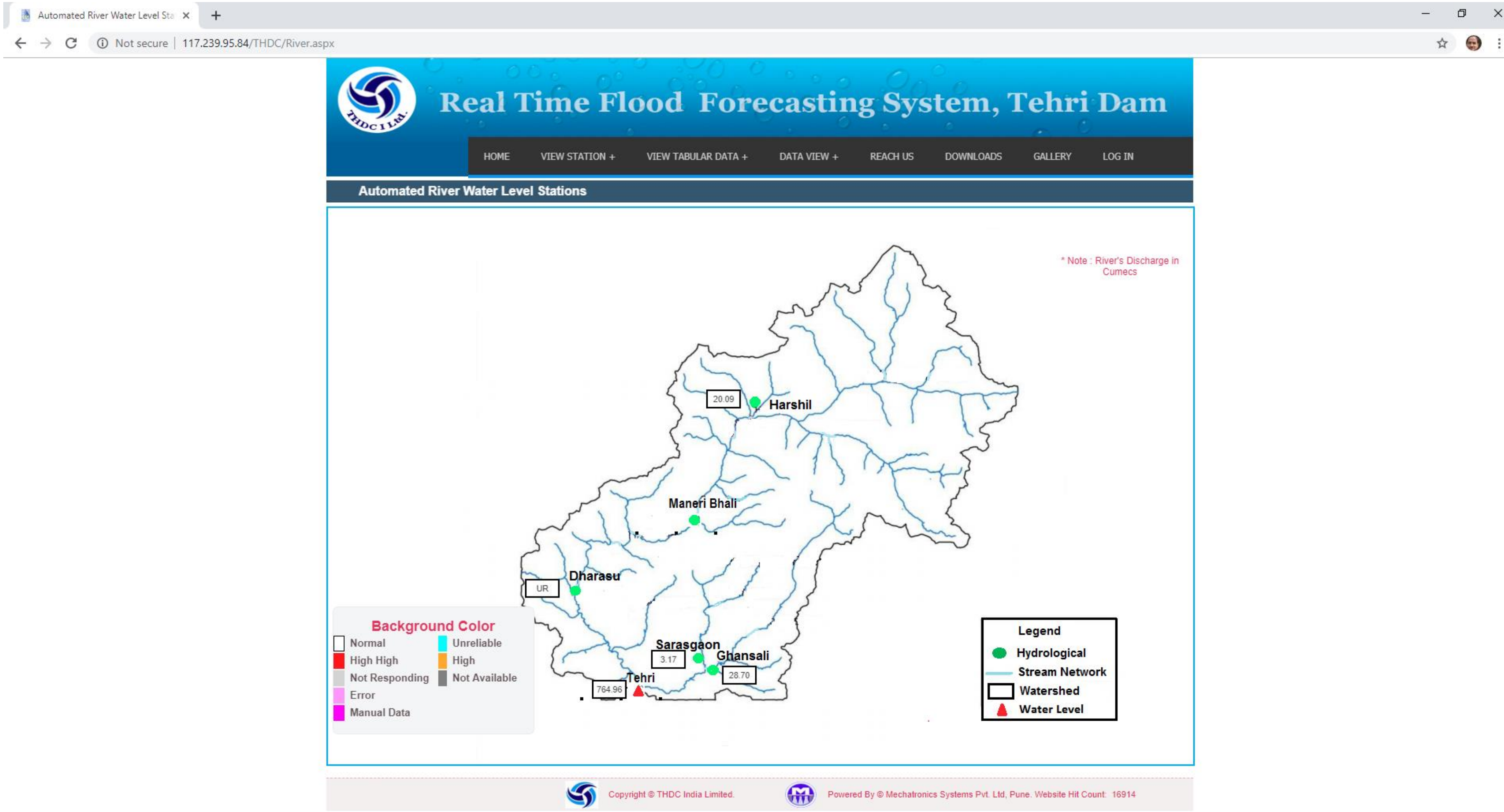
Category: Snowgauge Station



Automatic Weather Stations



G&D Sites


Automated River Water Level Sta
Not secure | 117.239.95.84/THDC/River.aspx
Real Time Flood Forecasting System, Tehri Dam
HOME
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REACH US
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GALLERY
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Automated River Water Level Stations
* Note : River's Discharge in Cumecs
20.09
Harshil
Maneri Bhali
Dharasu
UR
Sarasgaon
3.17
Ghansali
28.70
Tehri
764.96
Background Color
Normal
Unreliable
High High
High
Not Responding
Not Available
Error
Manual Data
Legend
Hydrological
Stream Network
Watershed
Water Level
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BasinID=1

Real Time Flood Forecasting System, Tehri Dam

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Current Data for Automatic Weather Stations

Refresh Data

Total Commissioned Location: 11

Friday 5 April 2019 17 : 28 : 51

Sukhie
Today's Rain : 0.00 (mm)
Total Rain : 882.80 (mm)
Temperature : 13.00 (°C)
Relative Humidity : 61.40 (%)
Wind Speed : 1.05 (m/s)
Wind Direction : 18 (°N)
Atmospheric pressure : 740.40 (hpa)
Solar Radiation : 0 (W/m2)
Last Updated Date and Time : 05-04-2019 17:00

Bhatwari
Today's Rain : 0.00 (mm)
Total Rain : 1439.40 (mm)
Temperature : 17.30 (°C)
Relative Humidity : 71.80 (%)
Wind Speed : 0.55 (m/s)
Wind Direction : 179 (°N)
Atmospheric pressure : 839.10 (hpa)
Solar Radiation : 0 (W/m2)
Last Updated Date and Time : 04-04-2019 22:00

Uttarkashi
Today's Rain : 0.00 (mm)
Total Rain : 1658.60 (mm)
Temperature : 26.40 (°C)
Relative Humidity : 44.60 (%)
Wind Speed : 0.98 (m/s)
Wind Direction : 68 (°N)
Atmospheric pressure : 888.30 (hpa)
Solar Radiation : 722 (W/m2)
Last Updated Date and Time : 05-04-2019 12:00

Dharasu
Today's Rain : 0.00 (mm)
Total Rain : 610.80 (mm)
Temperature : 29.60 (°C)
Relative Humidity : 35.50 (%)
Wind Speed : 1.96 (m/s)
Wind Direction : 98 (°N)
Atmospheric pressure : 898.10 (hpa)
Solar Radiation : 108 (W/m2)
Last Updated Date and Time : 05-04-2019 17:00

Lambgaon
Today's Rain : 0.00 (mm)
Total Rain : 1113.80 (mm)
Temperature : 27.40 (°C)
Relative Humidity : 38.60 (%)
Wind Speed : 5.50 (m/s)
Wind Direction : 340 (°N)
Atmospheric pressure : 875.30 (hpa)
Solar Radiation : 169 (W/m2)
Last Updated Date and Time : 05-04-2019 17:00

Dhopardhar
Today's Rain : 10.20 (mm)
Total Rain : 1972.80 (mm)
Temperature : 16.70 (°C)
Relative Humidity : 79.50 (%)
Wind Speed : 1.10 (m/s)
Wind Direction : 262 (°N)
Atmospheric pressure : 840.50 (hpa)
Solar Radiation : 0 (W/m2)
Last Updated Date and Time : 05-04-2019 17:00

Bishan (Thati Katur)
Today's Rain : 0.00 (mm)
Total Rain : 1806.20 (mm)
Temperature : 20.10 (°C)
Relative Humidity : 38.50 (%)
Wind Speed : 0.77 (m/s)
Wind Direction : 353 (°N)
Atmospheric pressure : 849.30 (hpa)
Solar Radiation : 695 (W/m2)
Last Updated Date and Time : 03-04-2019 10:00

Tehri Dam
Today's Rain : 0.00 (mm)
Total Rain : 850.80 (mm)
Temperature : 30.00 (°C)
Relative Humidity : 36.20 (%)
Wind Speed : 3.26 (m/s)
Wind Direction : 76 (°N)
Atmospheric pressure : 917.40 (hpa)
Solar Radiation : 271 (W/m2)
Last Updated Date and Time : 05-04-2019 17:00

Ghansali
Today's Rain : 0.00 (mm)
Total Rain : 1104.20 (mm)
Temperature : 29.20 (°C)
Relative Humidity : 38.70 (%)
Wind Speed : 0.34 (m/s)
Wind Direction : 349 (°N)
Atmospheric pressure : 914.70 (hpa)
Solar Radiation : 662 (W/m2)
Last Updated Date and Time : 05-04-2019 12:00

Gangotri
Today's Rain : 0.20 (mm)
Total Rain : 372.40 (mm)
Temperature : -2.60 (°C)
Relative Humidity : 55.30 (%)
Wind Speed : 0.12 (m/s)
Wind Direction : 56 (°N)
Atmospheric pressure : 702.50 (hpa)
Solar Radiation : 130 (W/m2)
Last Updated Date and Time : 24-01-2019 15:00

Harsil
Today's Rain : 1.40 (mm)
Total Rain : 281.20 (mm)
Temperature : -3.00 (°C)
Relative Humidity : 76.80 (%)
Wind Speed : 0.39 (m/s)
Wind Direction : 312 (°N)
Atmospheric pressure : 756.30 (hpa)
Solar Radiation : 0 (W/m2)
Last Updated Date and Time : 03-01-2019 23:00

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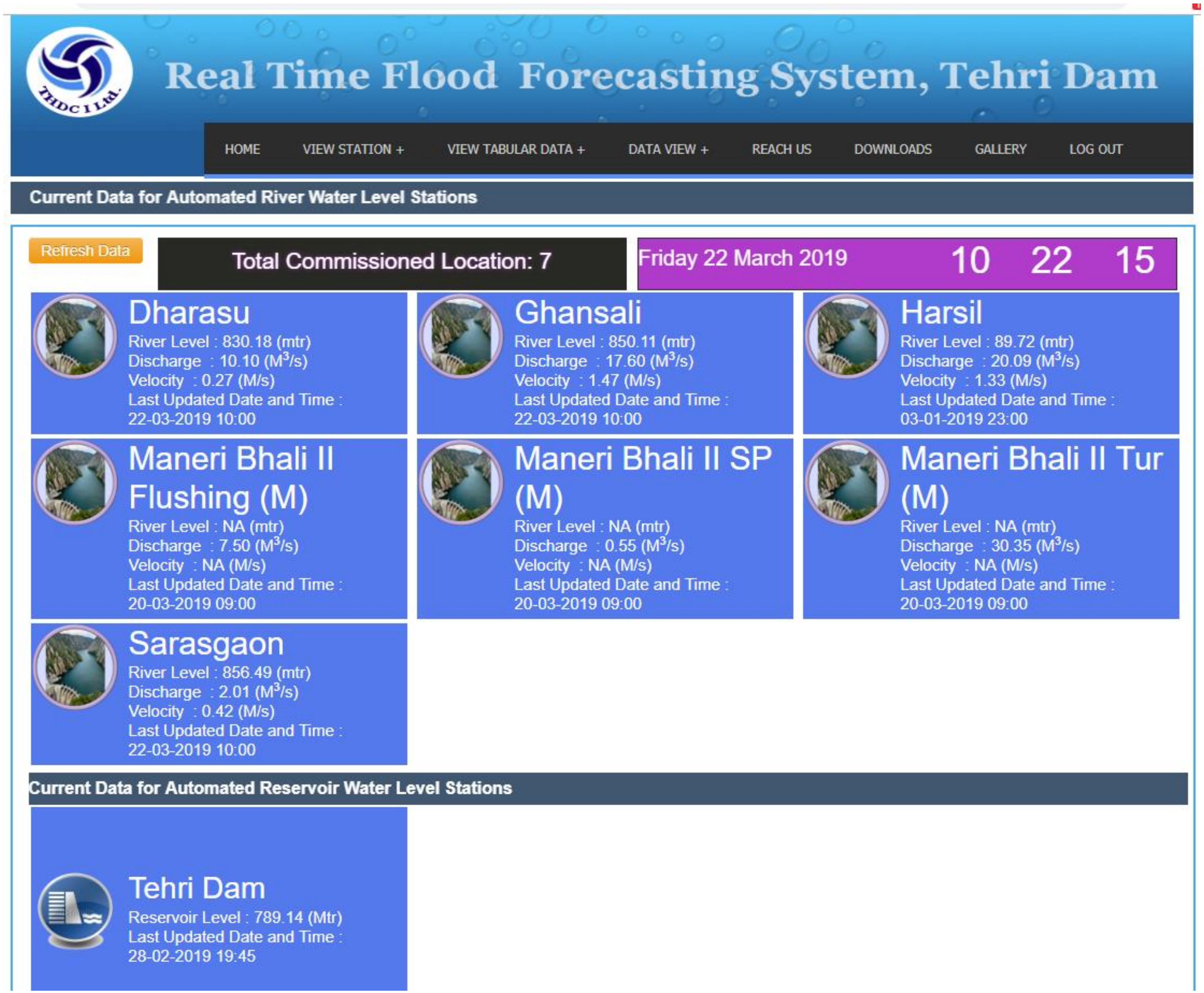
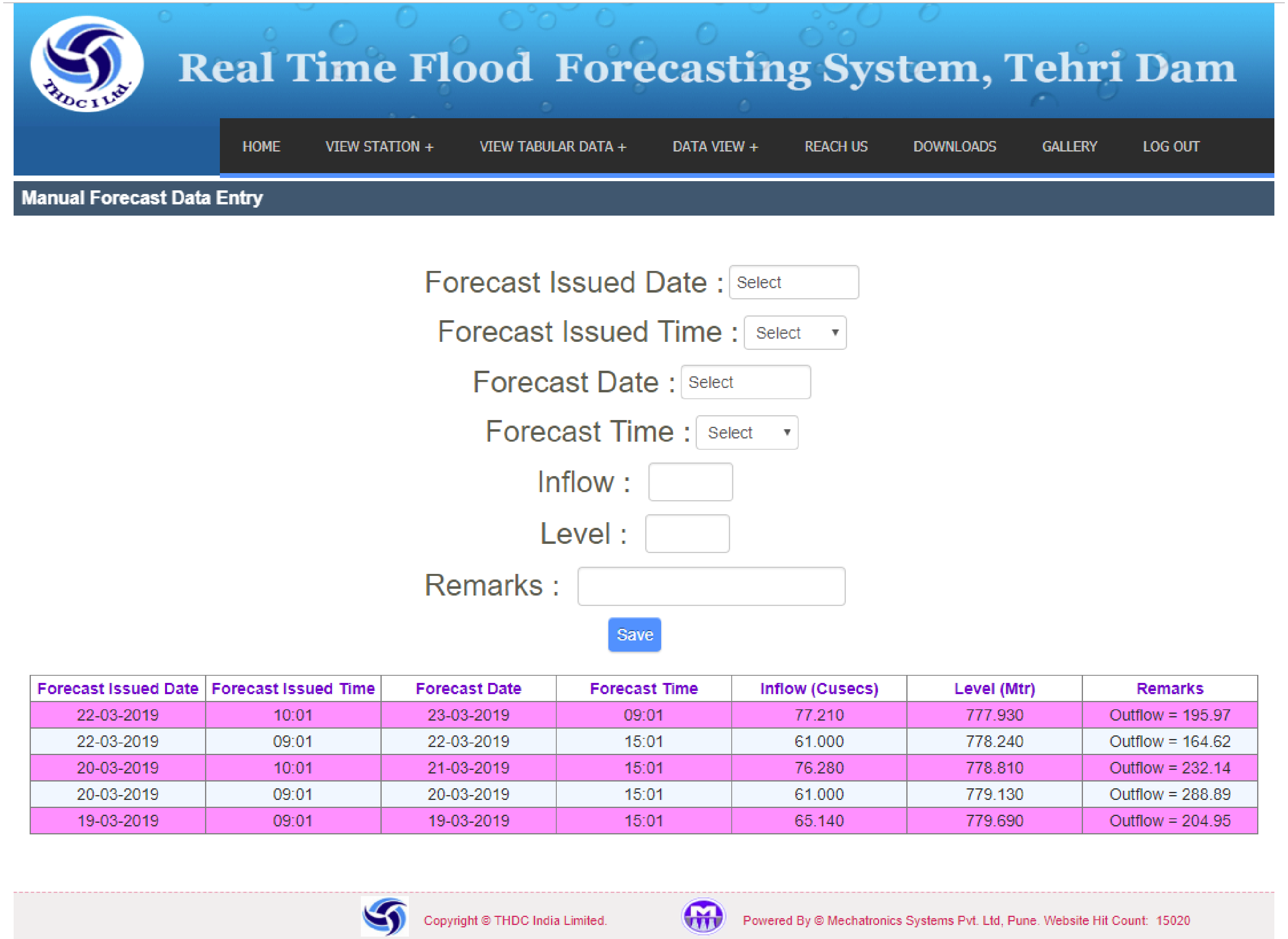


Data of Gauge & Discharge Stations



Real Time Flood Forecasting System, Tehri Dam

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Manual Forecast Data Entry

Forecast Issued Date : Select

Forecast Issued Time : Select

Forecast Date : Select

Forecast Time : Select

Inflow :

Level :

Remarks :

Save

Forecast Issued Date	Forecast Issued Time	Forecast Date	Forecast Time	Inflow (Cusecs)	Level (Mtr)	Remarks
22-03-2019	10:01	23-03-2019	09:01	77.210	777.930	Outflow = 195.97
22-03-2019	09:01	22-03-2019	15:01	61.000	778.240	Outflow = 164.62
20-03-2019	10:01	21-03-2019	15:01	76.280	778.810	Outflow = 232.14
20-03-2019	09:01	20-03-2019	15:01	61.000	779.130	Outflow = 288.89
19-03-2019	09:01	19-03-2019	15:01	65.140	779.690	Outflow = 204.95

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Manual Forecast Data Entry

Real Time Flood Forecasting System, Tehri Dam

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Historical Reports Data Available From 1 June 2016

Category: Weather Station   Location: Tehri Dam

◉ Regular ○ Hourly ○ Monthly ○ Yearly   From Date : 21/03/2019   To Date : 22/03/2019   Preview

1 of 1   Find | Next

Real Time Flood Forecasting System for Tehri Basin

Name of Basin :Tehri Dam

Automated Full Climate Station - Tehri Dam

River - Bhagirathi District - Tehri

Daily Report From 21-03-2019 To 22-03-2019

Date	Time	Hourly Rain (mm)	Today's Rain (mm)	Total Rain (mm) (From 1 June)	Temp. (°C)	Humidity (%)	Wind Speed (m/s)	Wind Direction (°N)	Atmospheric Pressure (hpa)	Solar Radiation (w/m²)
21/03/2019	09:00	0.00	0.00	834.80	14.10	68.40	4.44	234	926.50	0
	10:00	0.00	0.00	834.80	15.30	61.00	3.80	231	926.90	0
	11:00	0.00	0.00	834.80	18.10	43.40	2.36	240	926.90	0
	12:00	0.00	0.00	834.80	19.80	32.00	3.56	216	926.50	0
	13:00	0.00	0.00	834.80	22.10	29.40	2.05	192	925.10	0
	14:00	0.00	0.00	834.80	23.20	26.00	2.77	177	923.70	0
	15:00	0.00	0.00	834.80	27.00	21.90	1.21	95	923.30	0
	16:00	0.00	0.00	834.80	24.50	31.60	2.23	233	922.00	4
	17:00	0.00	0.00	834.80	23.30	27.90	1.27	239	922.10	4
	18:00	0.00	0.00	834.80	22.20	29.00	2.71	304	922.50	6

Historical Data of AWS

Conclusions

1. The indigenous system installed for the Tehri dam is performing satisfactorily for the last two and half years. This type of system can be developed and applied for any other hydropower project.
2. Autoregressive and Autoregressive models with exogenous inputs have performed very well for all the sites of Tehri catchment.
3. For the forecasting of monsoon flows with 6 hours lead time ARX (1,1) model has performed very well with NSE more than 82% at Tehri dam.
4. In one- day advance forecasting during the non-monsoon season, more than 90% of the time the reservoir level could be forecasted with less than or equal to 5 cm accuracy. More than 50% of the days, the reservoir level could be forecasted with $\pm$ 2 cm accuracy.

PART III
Extended hydrological Predictions

Questions Faced by Water Managers on Weeks to Seasonal Time Scales

- How much is the likely inflow – Next week? Next month? Next season? And next year?
- What is the range of uncertainty of the likely inflow and how best can this imperfect knowledge be integrated into water allocation and water delivery planning?

- The above two points come under Extended Hydrological Predictions

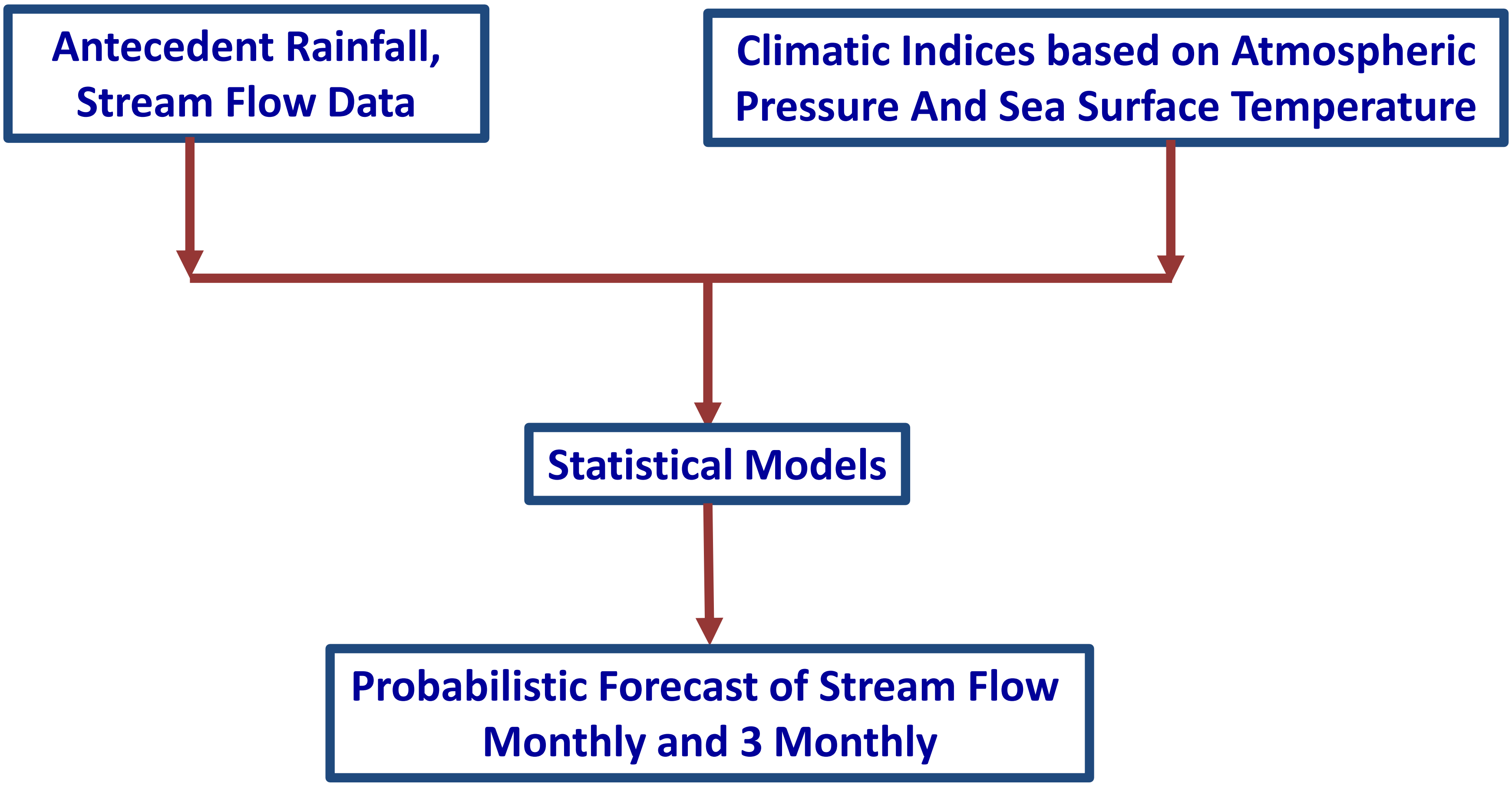
What is EHP?

- Extended Hydrological Prediction (EHP) is the prediction of hydrological variables for the period of time that exceeds the short term forecast lead time.
- The short term forecast is based on observed hydrological and meteorological variables (precipitation, air temperature, discharges, soil moisture etc.) and optionally on the forecast of these variables.
- EHP uses the observed values of hydrological and meteorological variables together with other climatologic drivers often dealing with them in a stochastic or statistic manner.
- The lead time of EHP thus may differ from weeks to months depending on the duration of the effect of the initial condition of the basin and the effect of other drivers used in EHP.
- This area is still emerging…

Models for EHP

- Statistical Models
- Dynamic Models
- Statistical and Dynamic Models (Ensemble Forecast)

Statistical Models (Flow Chart)



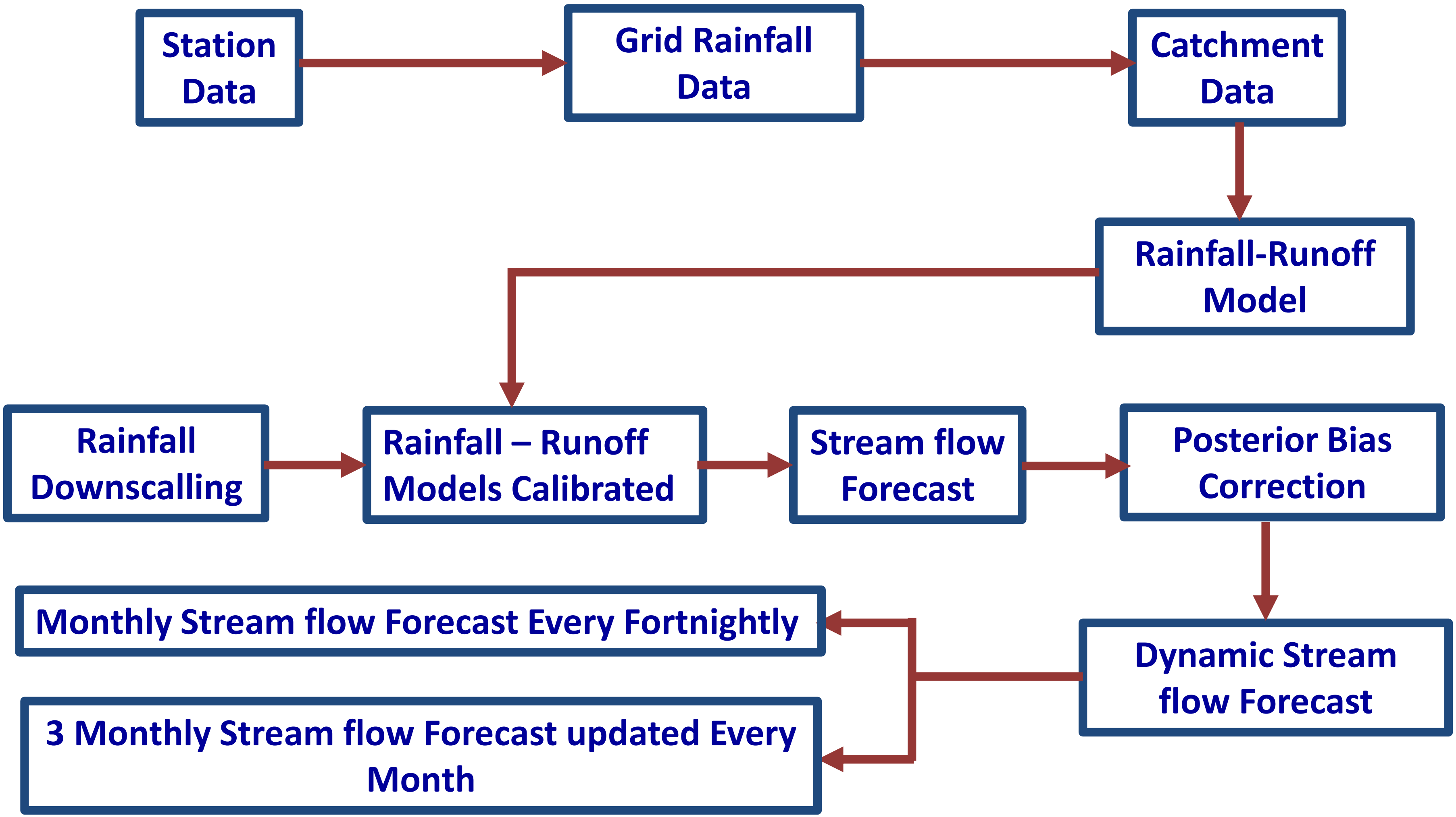
Building a Statistical Model

- Initial catchment condition predictors
  - Antecedent stream flow and rainfall

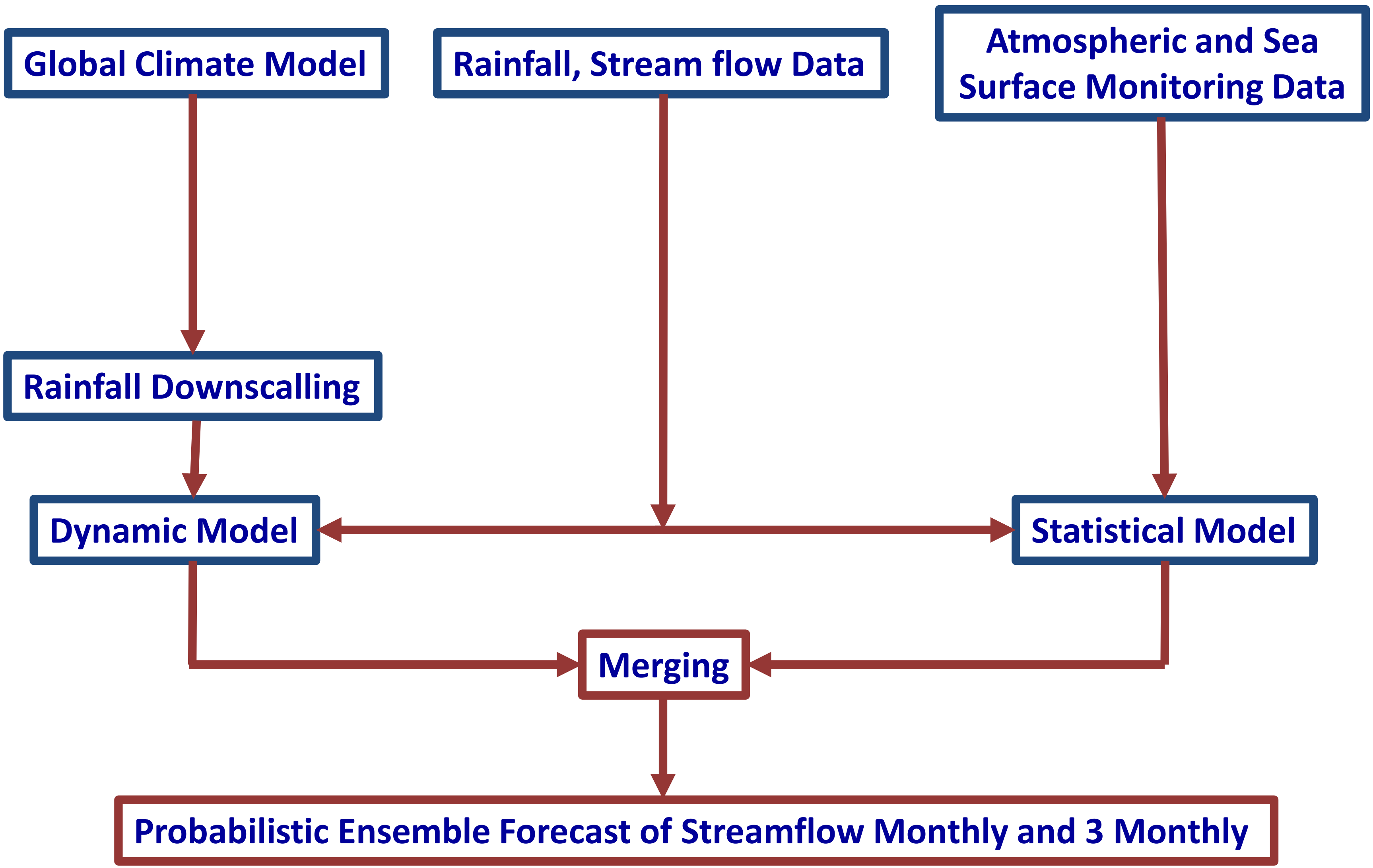
- Future climate condition predictors
  - Lagged climate indices
  - El Niño Southern Oscillation
  - Indian Ocean (e.g. IOD)

- The predictors are modelled jointly with future stream flow and rainfall

Dynamical Models (Flow Chart)



Combination of Statistical and Dynamic Models (Ensemble Forecast)



Advantages to power sector

- With dynamic tariff of electricity the information about incoming flows in advance will be useful in better planning of power generation schedule. The better planning shall result in higher returns of tariff.
- Lot of advancement is taking place in the forecasting of rainfall beyond 1 day i.e. a week and more by IMD and NCMRWF. With linking of forecasted rainfall of more than one day in the inflow forecasting models shall be further useful to power sector.
- Setting up of hydro-meteorological network in their project catchment will help in better understanding of your catchments. It will help in analyzing the implications of land use land cover changes and climatic changes on power generation of the projects
- The initiative of SJVNL and CBIP is a welcome step in this direction

WAY FORWARD…

Efforts should continue….

THANK YOU