Operational National Hydrological Modeling System

Under
National Hydrology Project

Team

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NHP

nrsc

Overview

The objectives of the study taken up under NHP are:

- To establish National level hydrological modeling framework for in season hydrological fluxes estimation at daily/weekly/fortnightly time step
- To establish a comprehensive field experimentation setup for calibration and validation of model computed flux outputs (Soil Moisture, ET)
- To develop of web-enabled in-season hydrological fluxes information for the entire country on India-WRIS/Bhuvan

Deliverables
Grid-wise periodic Water Fluxes (Evapotranspiration, Soil Moisture, Runoff) at daily/weekly/fortnightly time step
Web based geo-spatial hydrological products and services (India-WRIS/Bhuvan) (Drought Indices, forecast surface runoff)
Forecast of inflows into selected reservoirs & corresponding reservoir storage estimation
Design & in-season field experimentation and establishing SM network
Calibration and Validation of SM & ET with in-situ observation

Hydrological Model

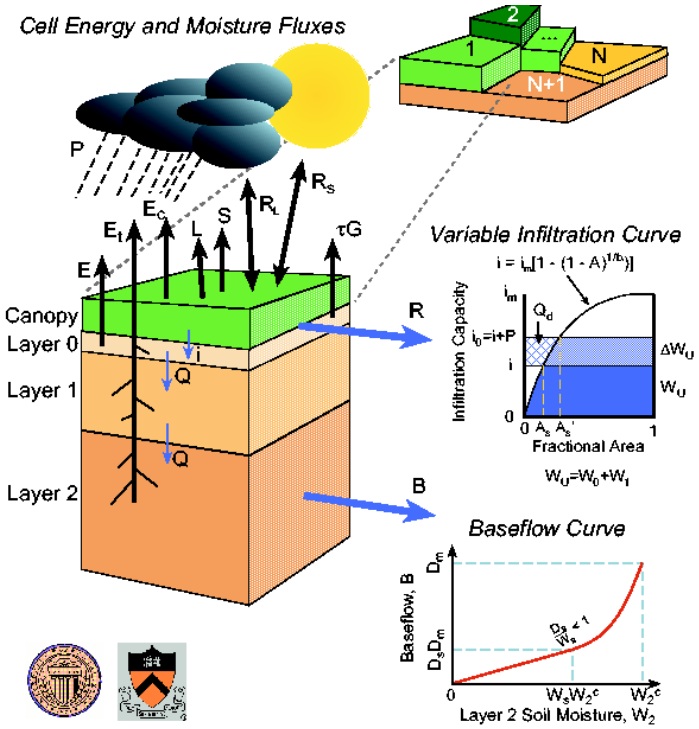
Variable Infiltration Capacity Model

- Open source; Grid-wise water and energy balance
- Sub-grid heterogeneity of Land cover
- Soil depth-wise hydrological response
- Vegetation phenological changes
- Daily time step; 0.05 degree resolution
- Inputs: LULC, Soil, Meteorological Data

❑ 3 min (~ 5.5km) Grid-wise data base

❑ Geo-spatial data

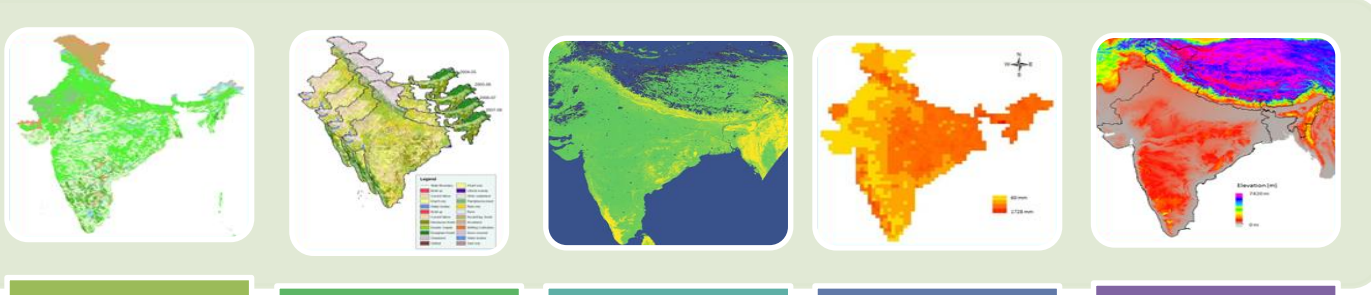
- Terrain - Topographic, Soil (NBSSLUP), LULC (NRC-250k), LAI, Albedo
- Meteorological – Rainfall, Temperature, … (IMD & CPC)
- Hydrological - River discharge, Reservoir Storage/Releases



Model Outputs:

- Daily Water Balance Components
  1. Surface Runoff
  2. Soil Moisture
  3. Evapotranspiration
- Routed discharge

Methodology –



NBSSLUP Soil Map

- Layer Wise Soil Texture information
- Soil Hydraulic Properties

NRC LULC 250k

- Vegetation Fraction
- Root Library

MODIS Land Products

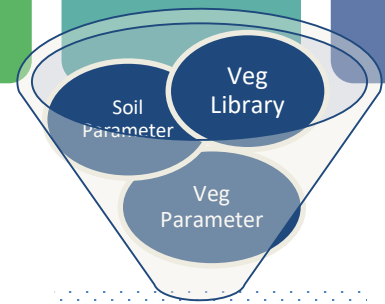
- LAI
- Albedo

Meteorological Forcing Data

- Rainfall
- Temperature
- Wind Speed

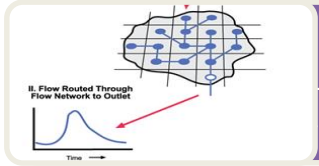
Digital Elevation Model

- Grid Flow Direction
- Grid Flow Fraction



Revised Soil Parameter

VIC Model



Routing

- Flow Direction
- Flow Fraction

Not Satisfied

Calibration

Satisfied

CWC River Discharge

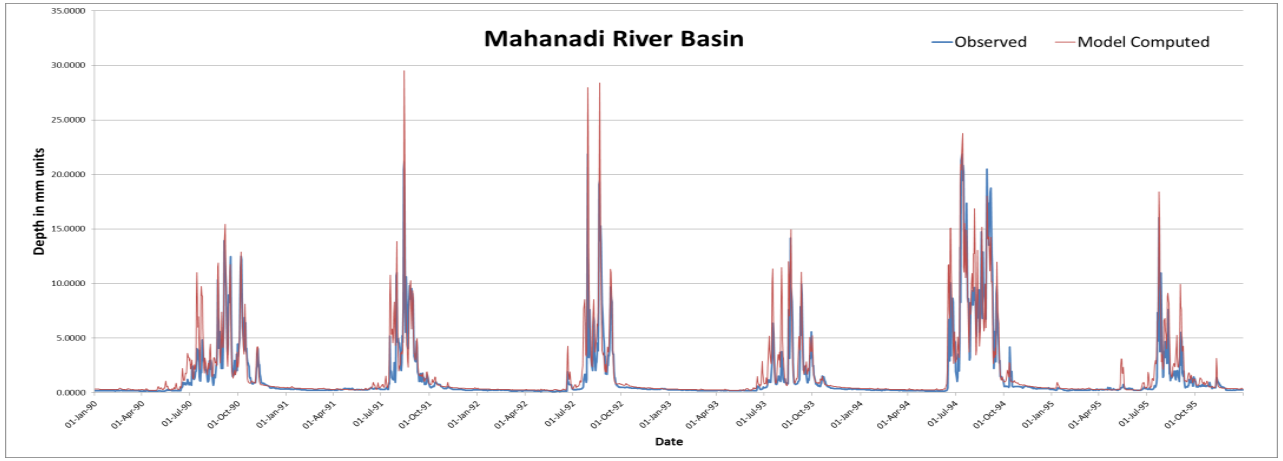
Daily Water Balance Components

Model Calibration and Validation

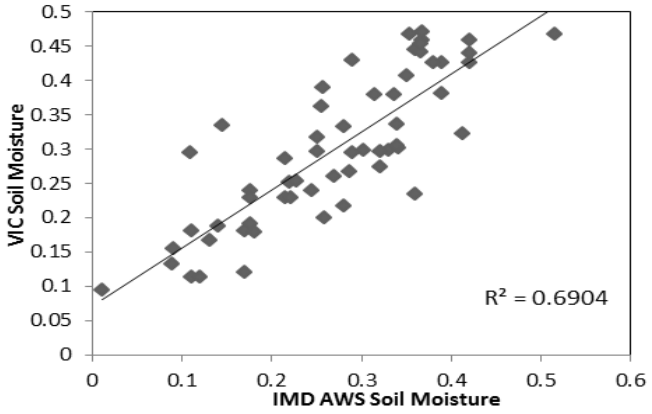
- Model is calibrated using CWC river discharge data at river basin scale for the period 1972-2006.
- Average Nash Sutcliff coefficient (NSE) of 0.71 is observed.

Fig. Mahanadi Basin

Mahanadi	NSE
1990	0.82
1991	0.85
1992	0.85
1993	0.62
1994	0.83
1995	0.54



Soil Moisture Validation



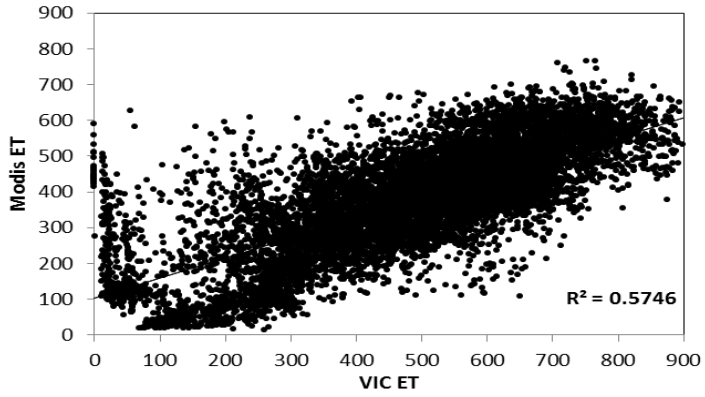
Over Agriculture Field

Observed Data: IMD Soil Moisture Data, 2013

Pearson Correlation Coefficient (**R^2**) ~ 0.3 - 0.7

Number of Observation Stations: 130

ET Validation



Observed Data: MODIS 1km 8day Product, 2013

Comparison of **VIC ET** Vs **MODIS ET** estimates.

Pearson Correlation Coefficient (**R^2**) ~ 0.5 - 0.6

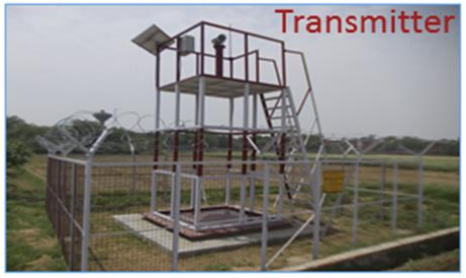
Setting of Flux Towers and Soil moisture Probes (10 nos)

Existing flux towers in country

Proposed sites for establishing flux network in the country in phase 1

Flux Tower

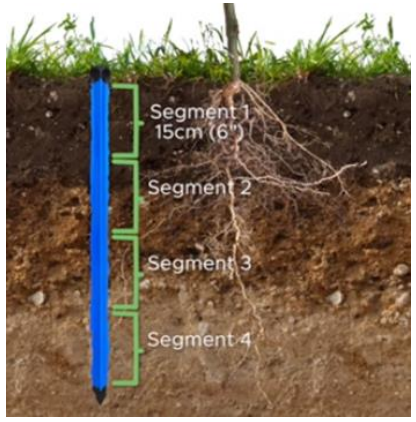
- Ground based instrumentation will be established for calibration and validation of model simulated ET
- Total of 10 flux tower stations are planned to be installed by the end of Nov, 2021



Scintillometer

- Ground based instrumentation will be established for validation of hydrological model derived soil moisture
- Comprehensive soil moisture instrumentation is planned to establish across India over varying climatological and geographical conditions (Land Cover and Soil Type …)
- Network of Time Domain Reflectometer (TDR) and COSMIC ray probes will be installed
- Permanent probes will measure soil moisture at 6 different depth along the soil column (1 m) at 10, 30, 50, 60, 80, 100 cm depths

Test Site Installed at NRSC, Hyderabad

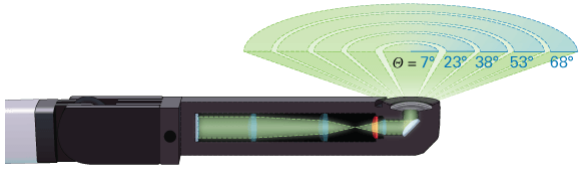


Information on description of instrument site conditions will be collected i.e.

- land use/land cover,
- crop type,
- date of sowing,
- date of harvest,
- major growing stages of the crop,
- irrigation depths applied, etc.

LAI and Portable SM

- uses a non-destructive method to easily and accurately measure Leaf Area Index (LAI)
- Accurate in most daylight conditions
- A diffuser cap is used for collecting ancillary data for applying scattering corrections when operating in direct sunlight
- Saves time — no need to wait for the sun's position to change. Measures light from five different zenith angles with one reading



Features

- Soil moisture accurate to ± 1%
- Soil temperature to ± 0.5°C over 0-40°C
- Low salinity sensitivity
- Excellent stability
- Minimal soil disturbance
- Easy installation at depth in augered holes
- Waterproof connector to IP68
- Rugged, weatherproof and can be buried.
- Good electrical immunity
- Choice of cabling system options
- Cable connector, cylindrical profile and extension tube design simplifies removal for servicing.

Input Dataset used and Timeline

Temperature

S no.	Satellite/Sensor /Project	Source	Spatial Resolution	Temporal Resolution	Latency	Availability
1.	IMD (Minimum & Maximum Temperature)	http://www.imd.gov.in/	0.25 degree	Daily (Indian)	D - 1	1971 – present

Land Use & Land Cover And LAI

S no.	Satellite/Sensor /Project	Source	Spatial Resolution	Temporal Resolution	Latency	Availability
1.	NRC-LULC	http://www.nrsc.gov.in/	56 meters	Yearly	Yearly once	2004 – 2017
2.	MODIS-LAI	https://lpdaac.usgs.gov/products/mcd15a2hv006/	500m	8 day		2002 – present

Soil Map

S no.	Satellite/Sensor /Project	Source	Spatial Resolution	Temporal Resolution	Latency	Availability
1.	NBSSLUP soil map of India	https://www.nbsslup.in/	1:50,000 scale	-	-	-

Input Dataset used and Timeline

Precipitation

S no.	Satellite/Sensor /Project	Source	Spatial Resolution	Temporal Resolution	Latency	Availability
1.	TRMM/TMPA (Rainfall)	http://trmm.gsfc.nasa.gov	0.25 X 0.25 degree	3 hourly	-	Jan 1998 – April 2015
2.	CPC (Rainfall)	www.cpc.ncep.noaa.gov	0.1 X 0.1 degree	Daily (global)	D - 2	2002 - Present
3.	IMD (Rainfall, Temperature)	http://www.imd.gov.in/	0.25 degree	Daily (Indian)	D - 1	1901 – present
4.	GPM (IMERG) (Rainfall)	http://www.nasa.gov/mission_pages/GPM/main/	0.1 X 0.1 degree	Half hourly	D - 1	April, 2015 - Present
5.	CHIRPS (Rainfall)		0.05 X 0.05 degree	Daily	D - 15	1981 – near Present

Forecast

S no.	Satellite/Sensor /Project	Source	Spatial Resolution	Temporal Resolution	Latency	Availability
1.	GEFS – Forecast (Rainfall, Temperature)	www.esrl.noaa.gov/psd/forecasts/reforecast2/download.html	~ 0.25 X 0.25 degree	3 hourly	D + 10	-
2.	IMD – WRF – Forecast (Rainfall)		3 km	Daily	D + 3	-

Daily Timeline

04:00 – 05:00 am

- ✓ Download to meteorological datasets from various sources
- ✓ Pre-processing, checks for screening, consistency, quality
- ✓ Model input data generation for all the 1,41,000 grids

05:00 – 06:00 am

- ✓ Model invoke and simulation
- ✓ Water Balance Computation

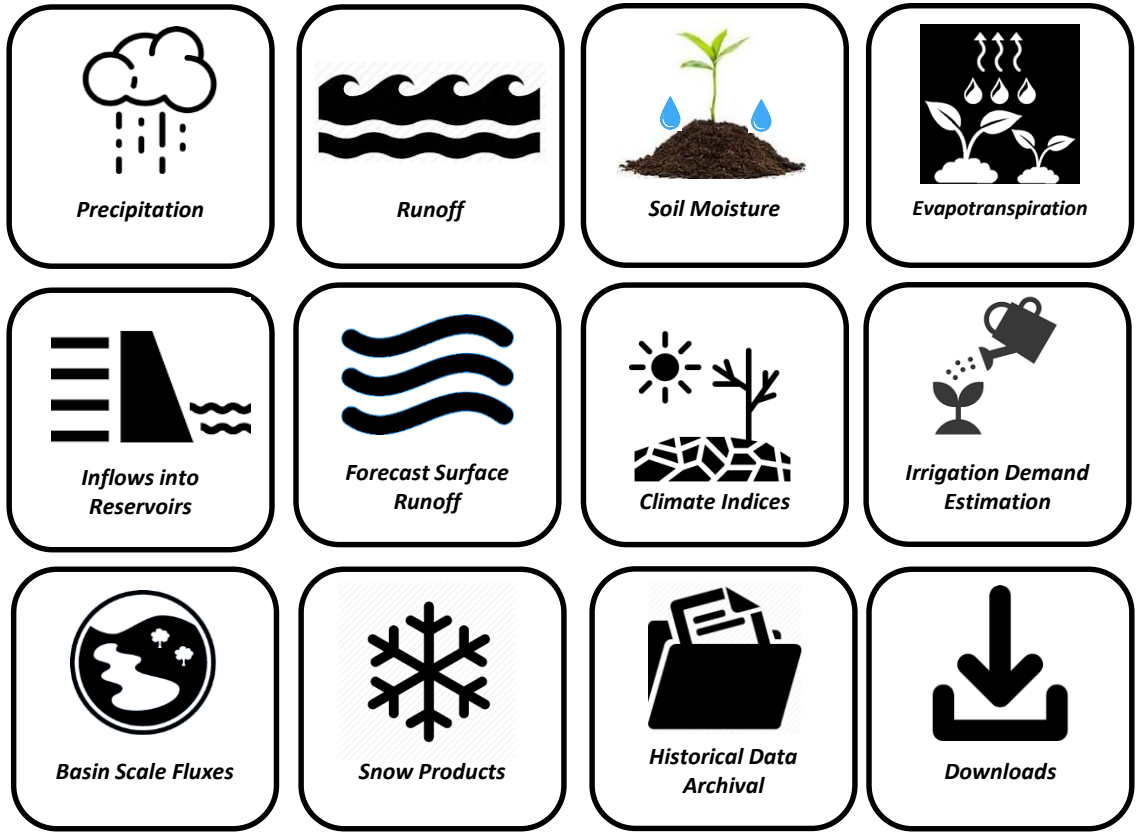
06:00 – 07:00 am

- ✓ Post-processing of model outputs
- ✓ Inflow estimation for 91 Major reservoirs of India
- ✓ Generation of Climate Indices (SPI/SRI/SMAI)

07:00 – 08:00 am

- ✓ Product dissemination and web-hosting onto Bhuvan-NHP portal and India WRIS

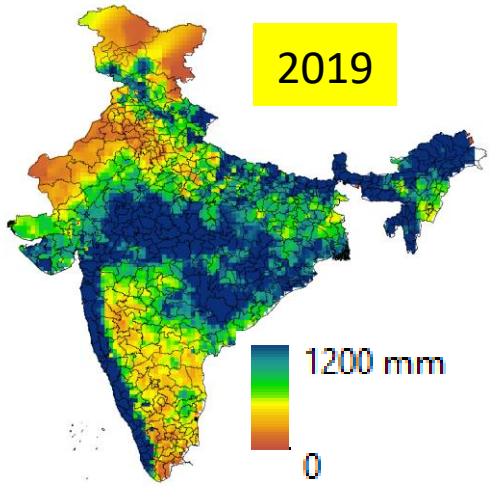
Hydrological Products

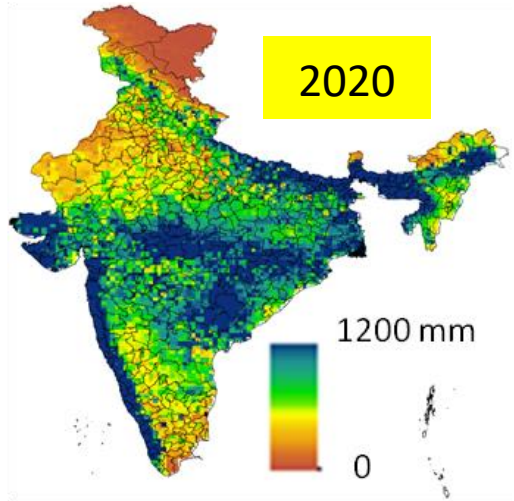


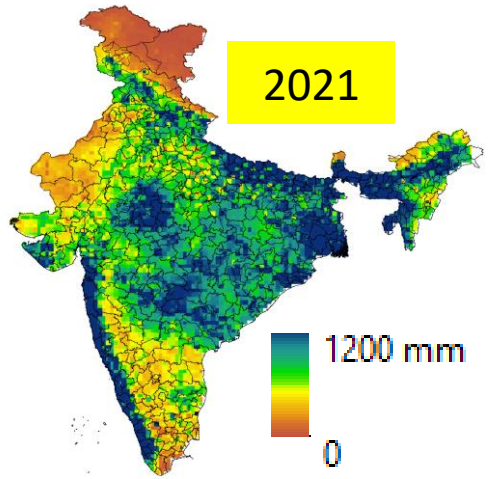
Precipitation

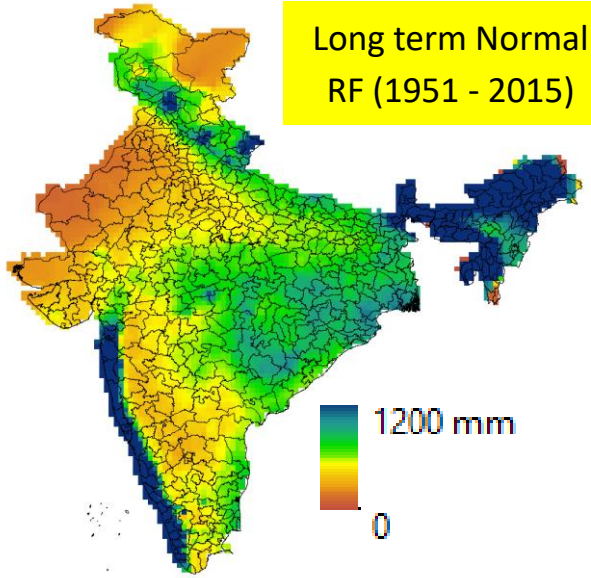
Precipitation

1. Dataset

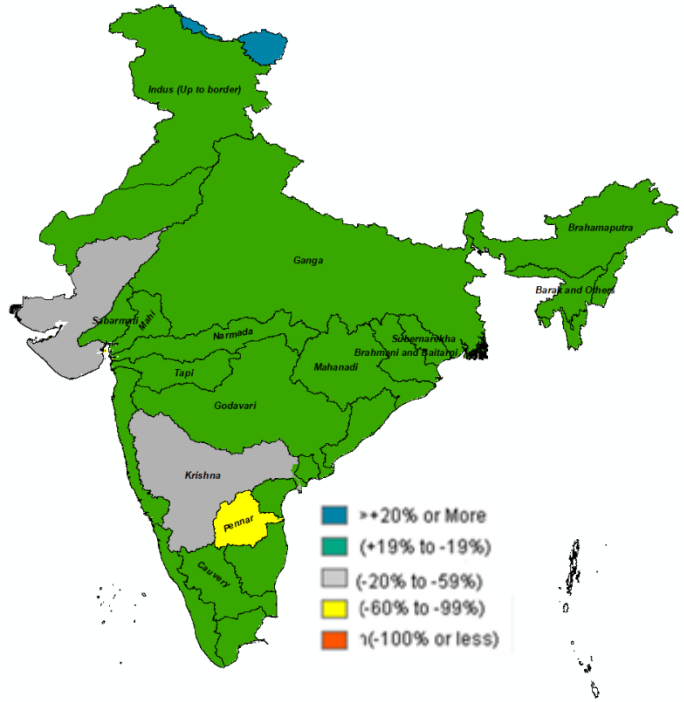






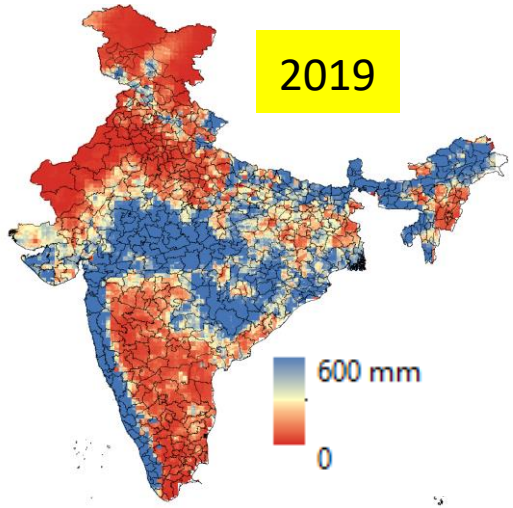


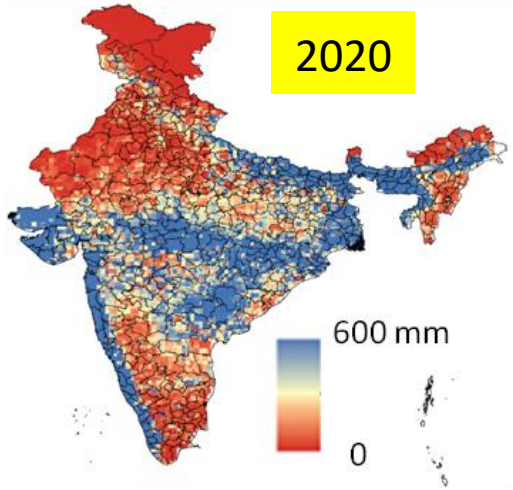
RF (2021) Deviation from Normal RF

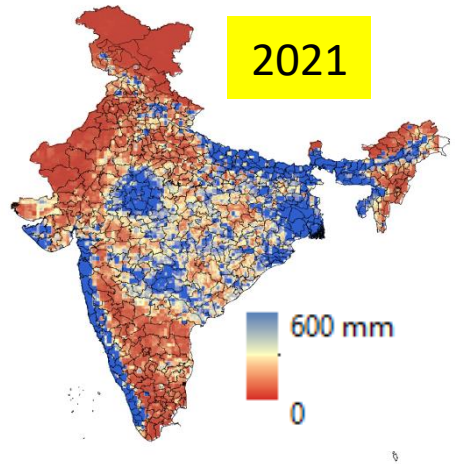


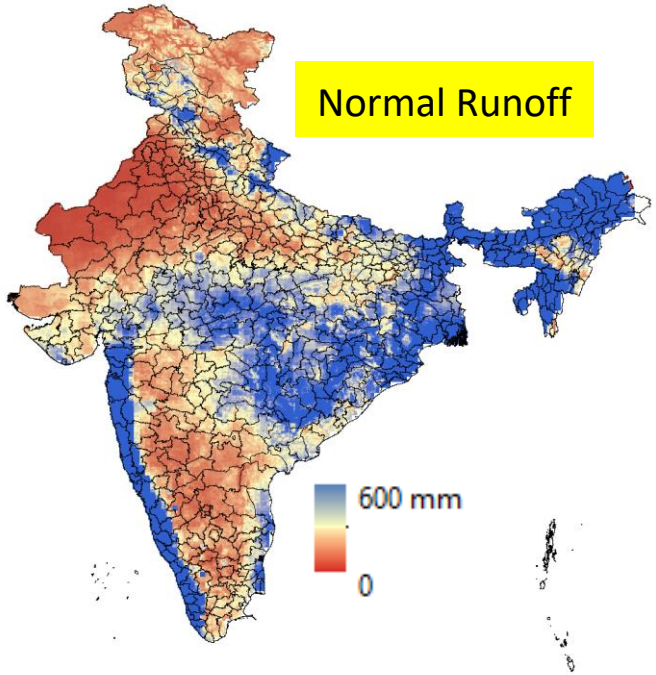
Surface Runoff

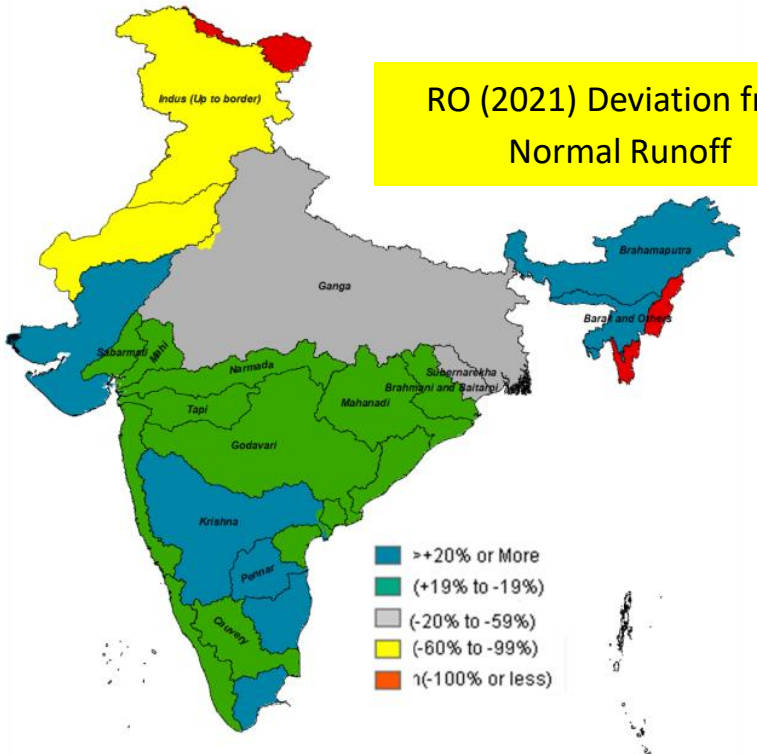
Runoff







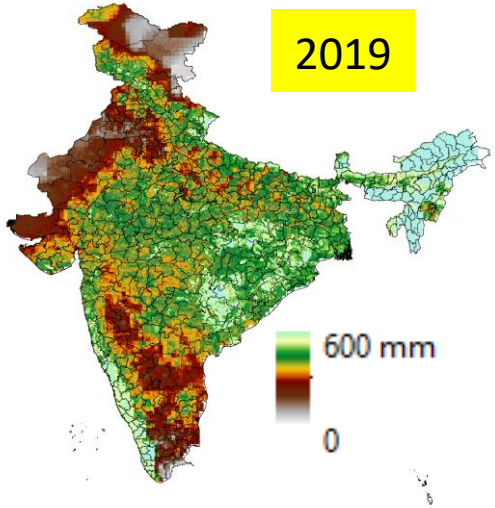


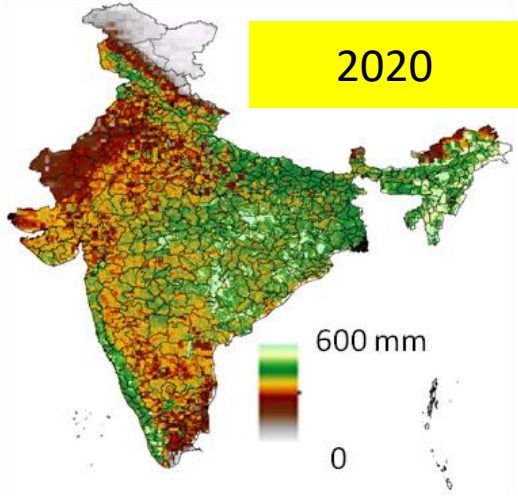


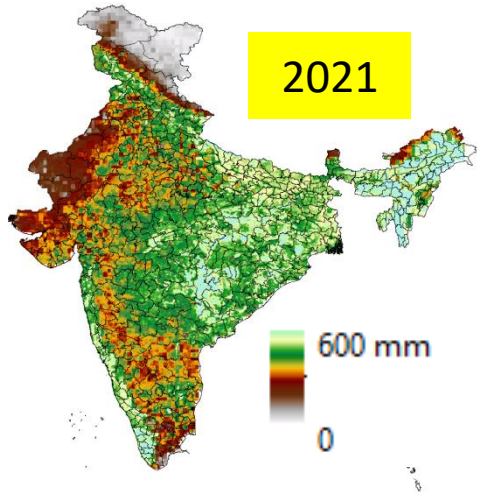
Basin-wise runoff deviation for the year 2021 from long term mean condition

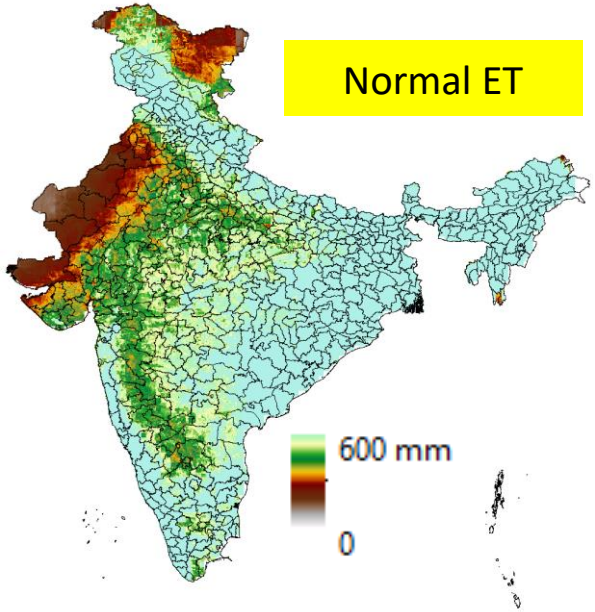
Evapotranspiration

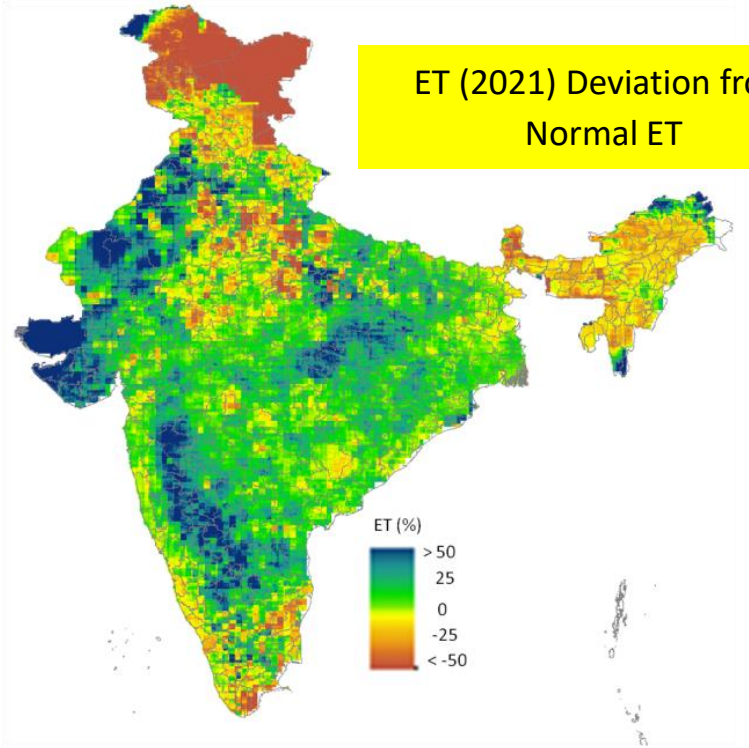
Evapotranspiration









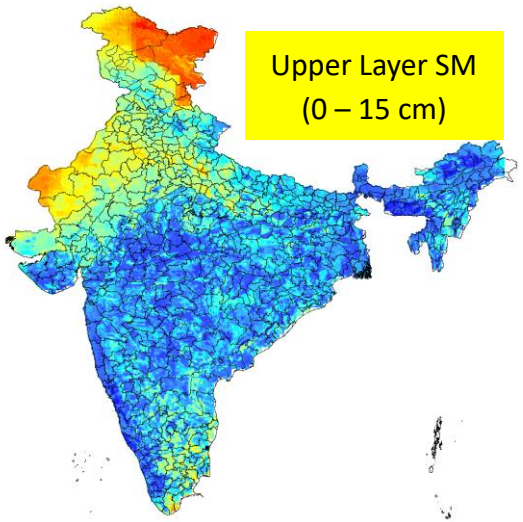


Note: Rainfall driven ET

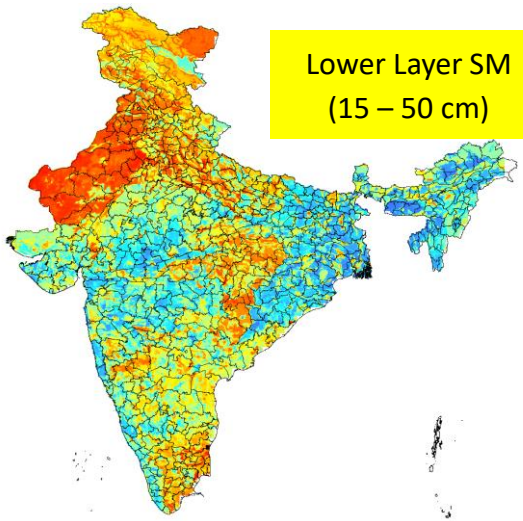
ET deviation for the year 2021 from long term mean condition

Soil Moisture

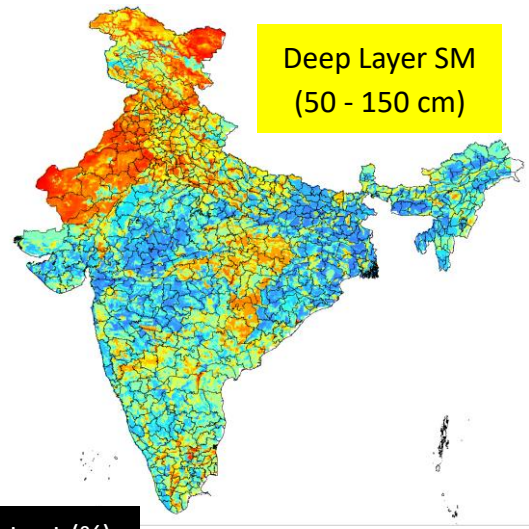
Soil Moisture



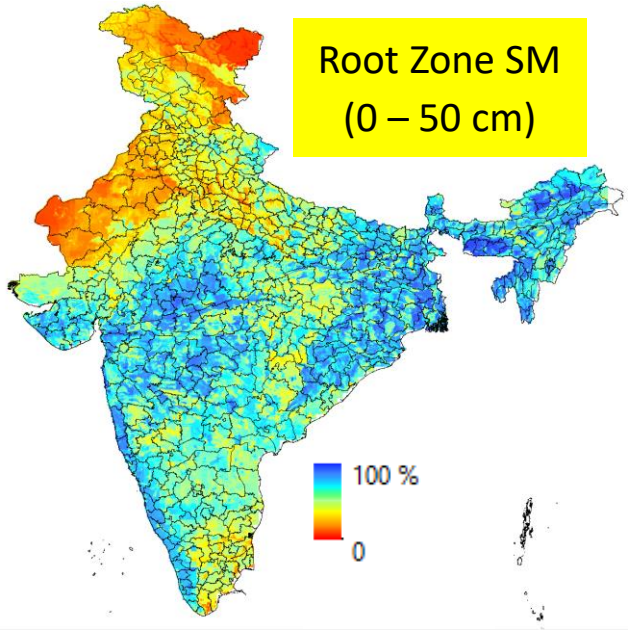
Upper Layer SM
(0 – 15 cm)



Lower Layer SM
(15 – 50 cm)

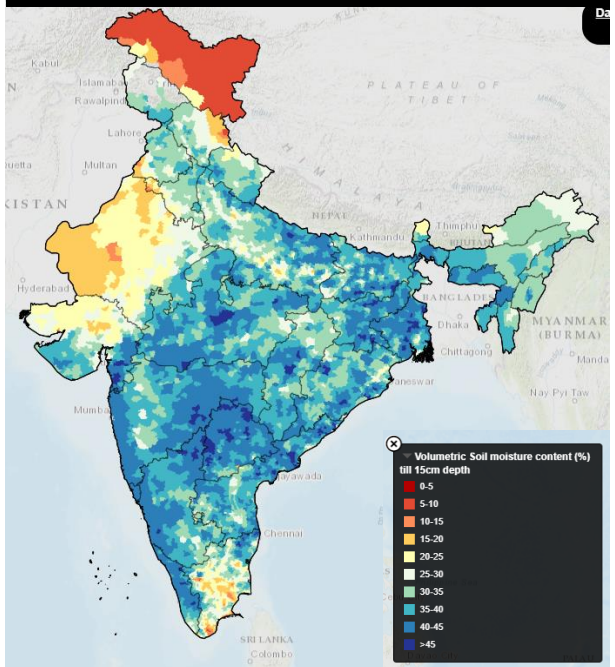


Deep Layer SM
(50 - 150 cm)



Root Zone SM
(0 – 50 cm)

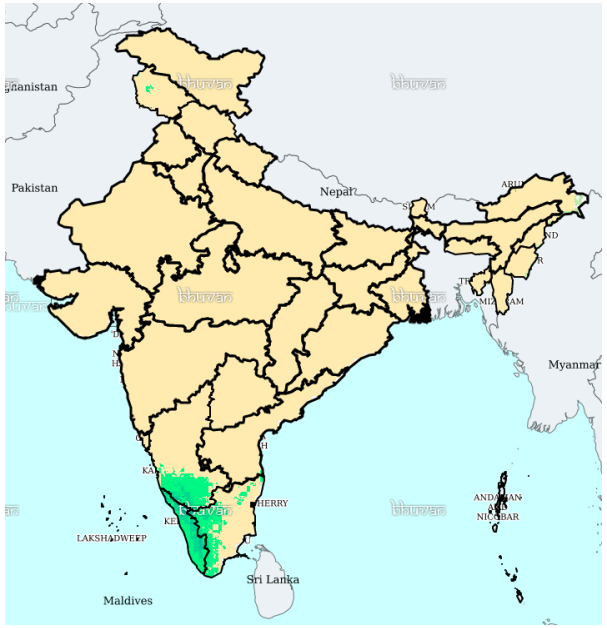
Daily Volumetric Soil Moisture content (%) till 15cm depth



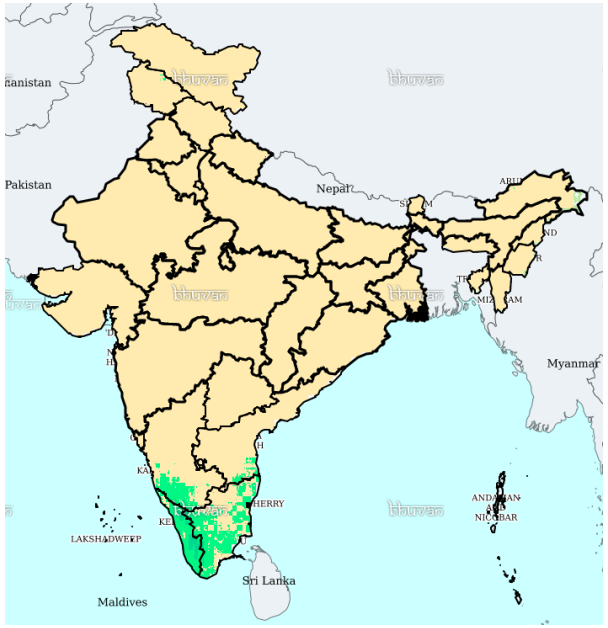
Forecast Surface Runoff

Forecast Surface Runoff

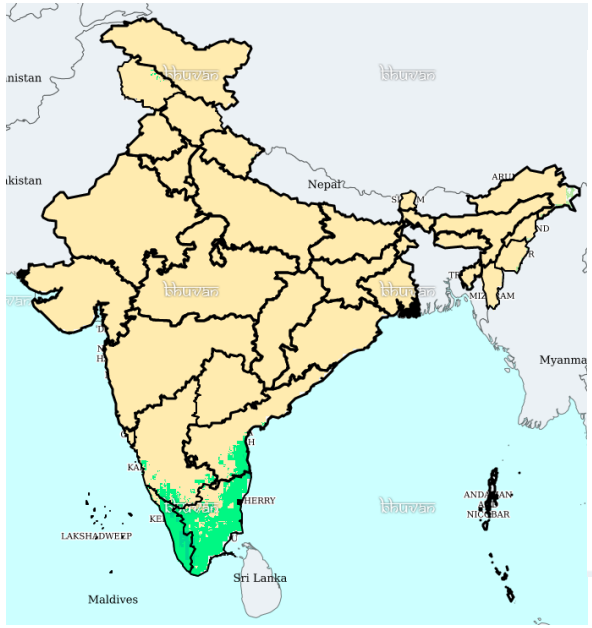
26th Oct 2021

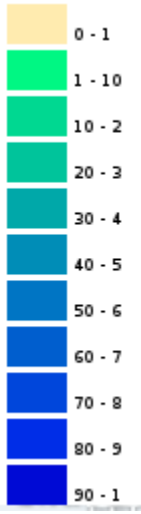


27th Oct 2021



28th Oct 2021



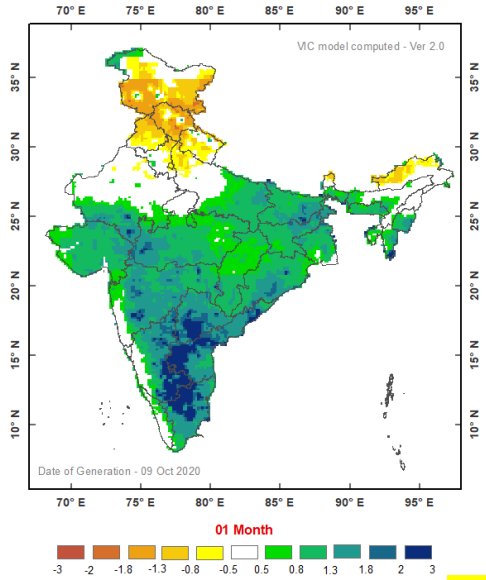


Climate Indices

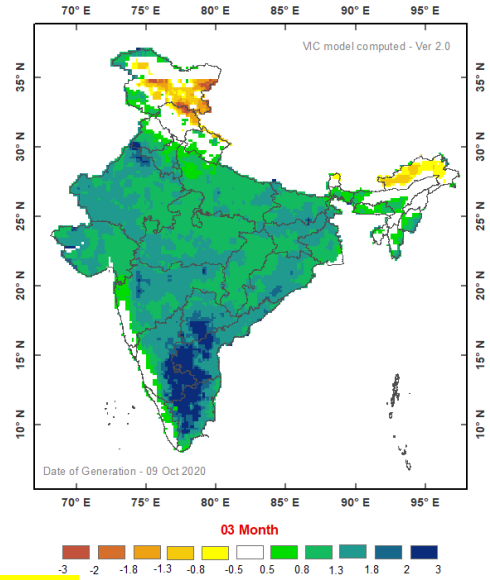
Climate Indices

- Standardized Precipitation Index
- Standardized Runoff Index
- Soil Moisture Availability Index

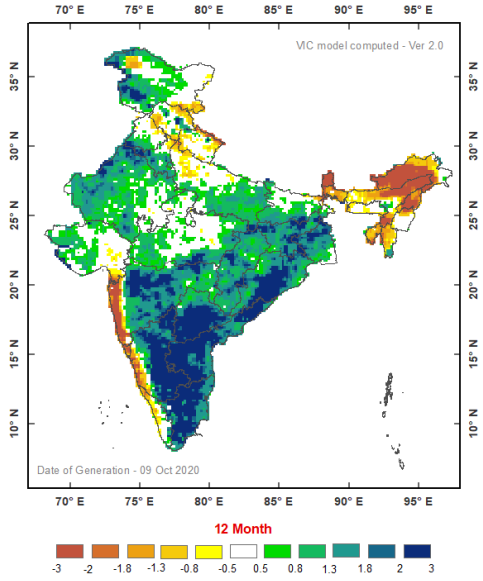
1 Month



3 Month



12 Month



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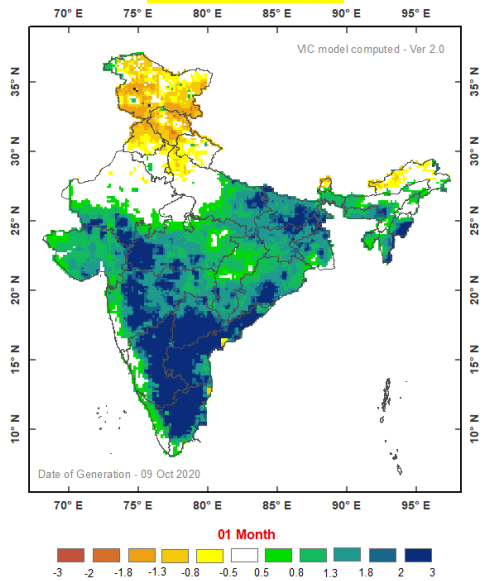
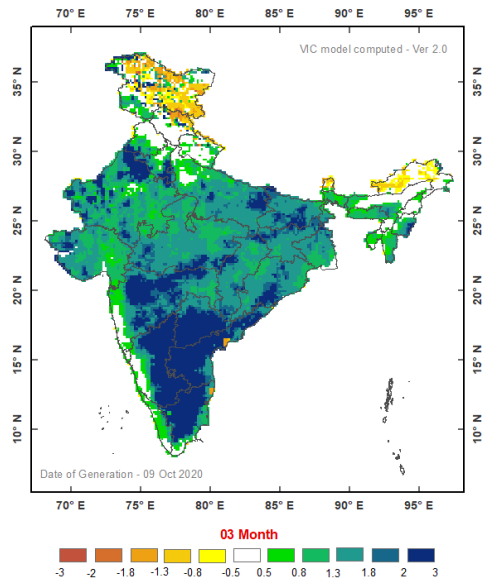
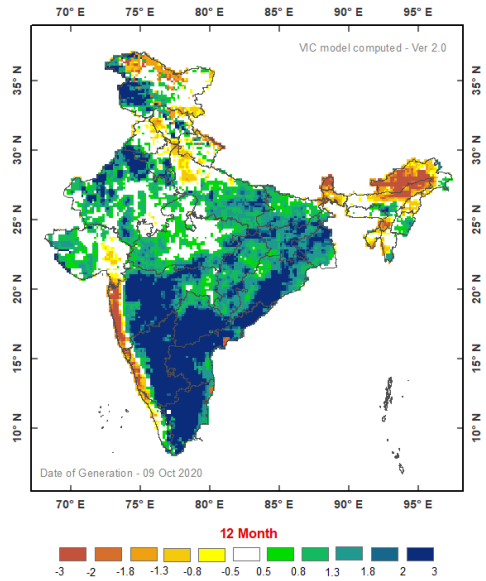


3 Month



12 Month



Climate Indices

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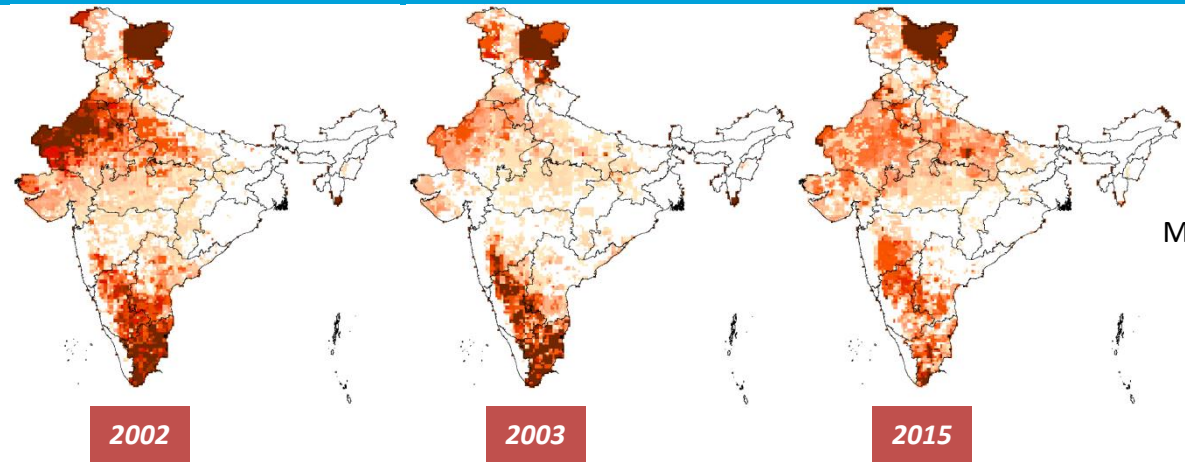
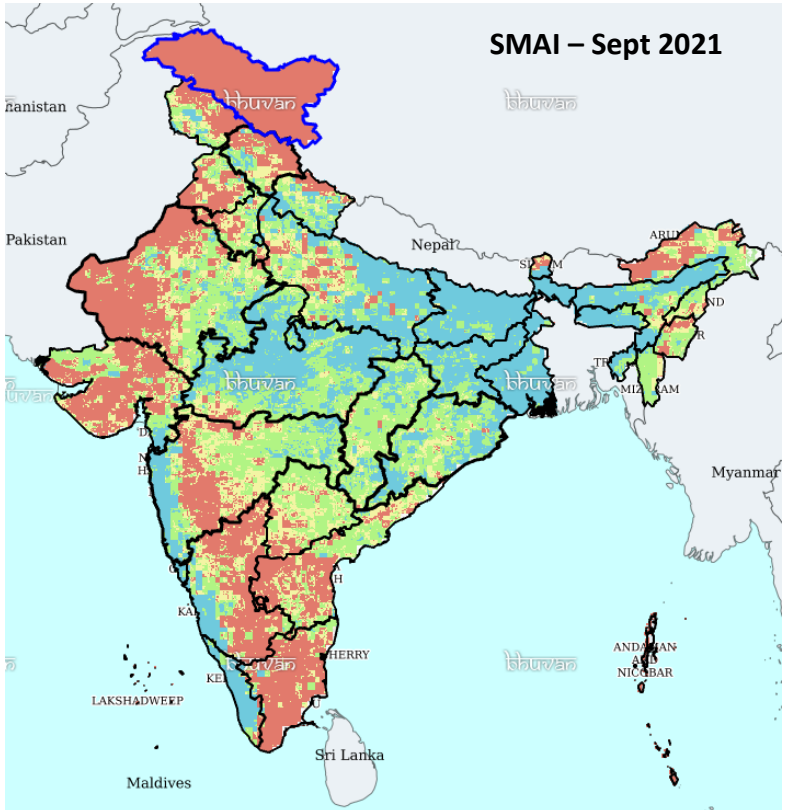
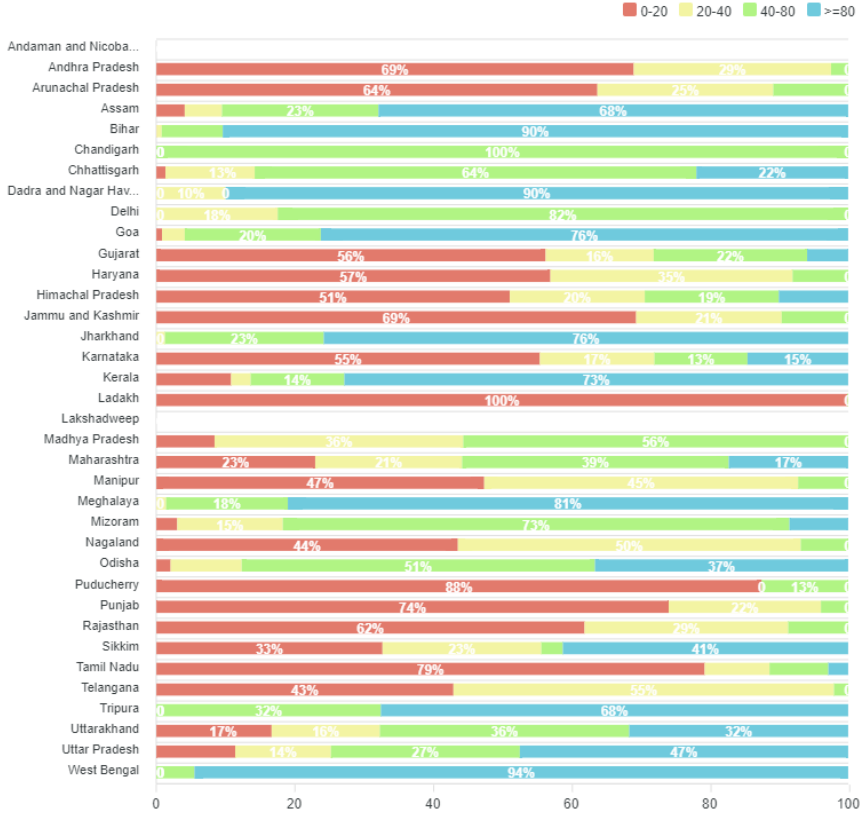
- Standardized Runoff Index
- Soil Moisture Availability Index



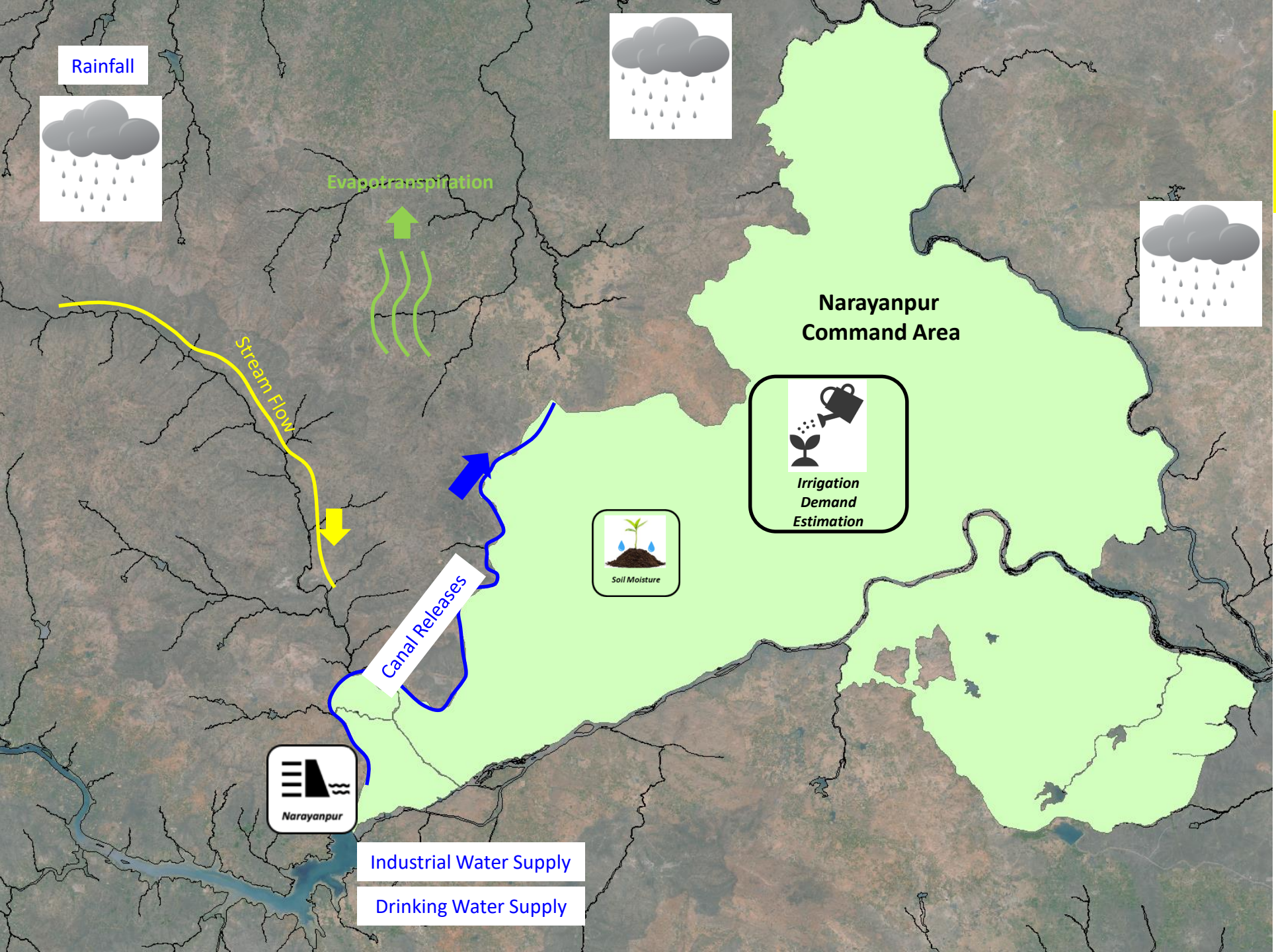
Severe SM deficit --
Moderate SM deficit --
Mild SM deficit--
No SM deficit --

Worst Drought Years in India (1986, 1987, 2002, 2009, 2015) – Reported in IMD Drought Manual 2016

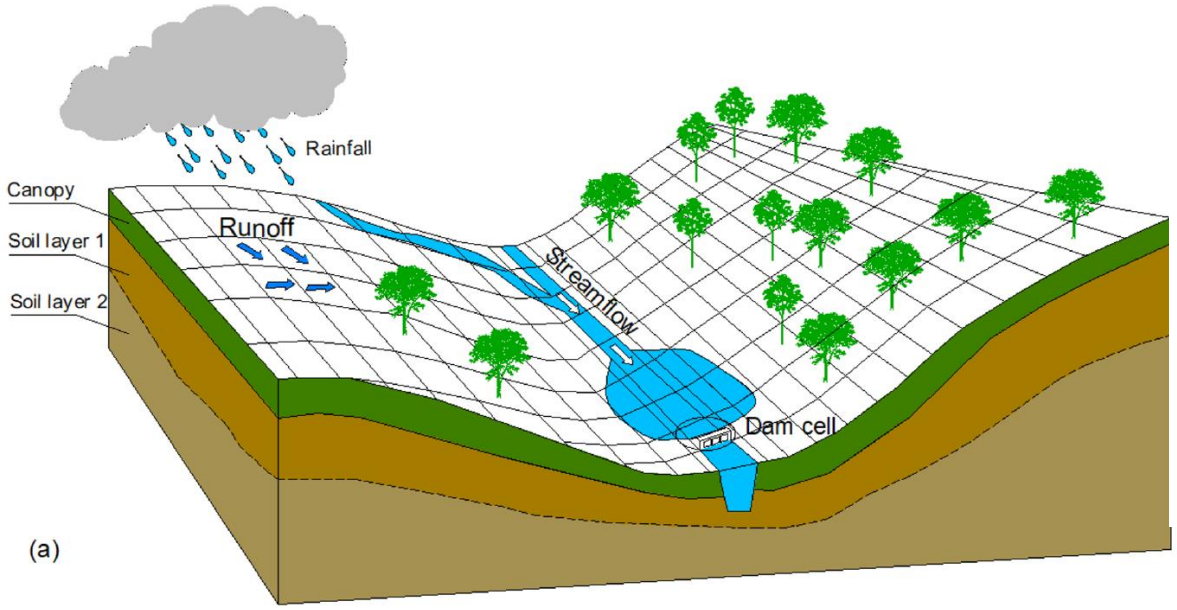


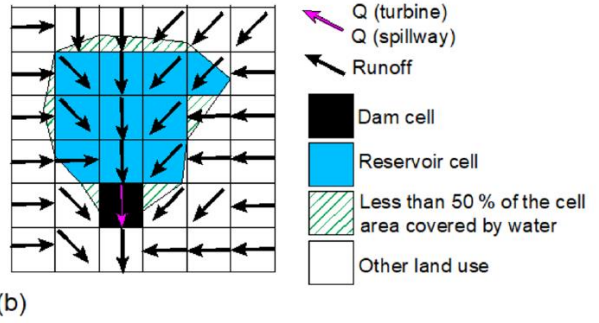


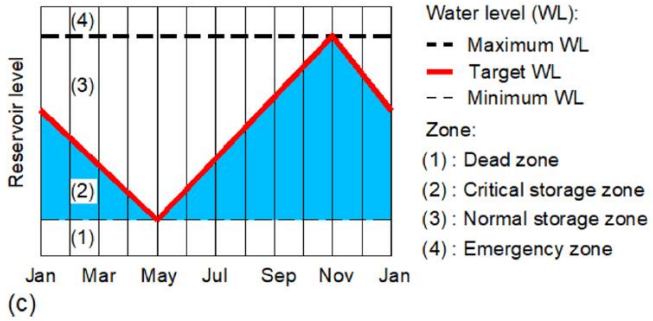
Overview of Hydrological Processes



Reservoir Representation Module







Subplot (a) Graphical representation of VIC's spatial domain; (b) selection of dam cell (black), reservoir cells (blue), and cells with other land use (white and white with green lines). The arrows indicating direction of the flow routing and discharge from the reservoir; (c) Typical reservoir operating rule curve

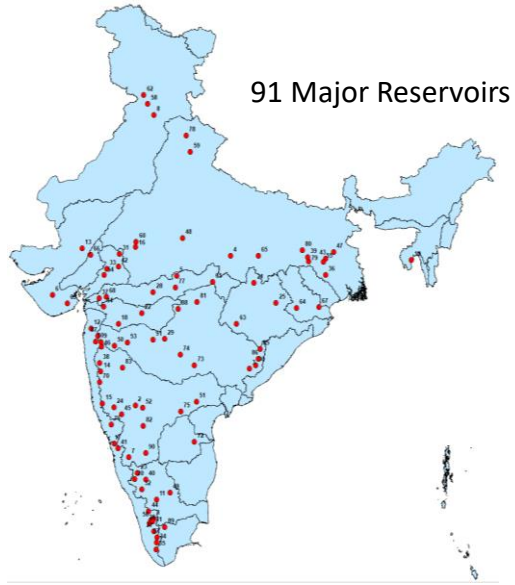
Methodology

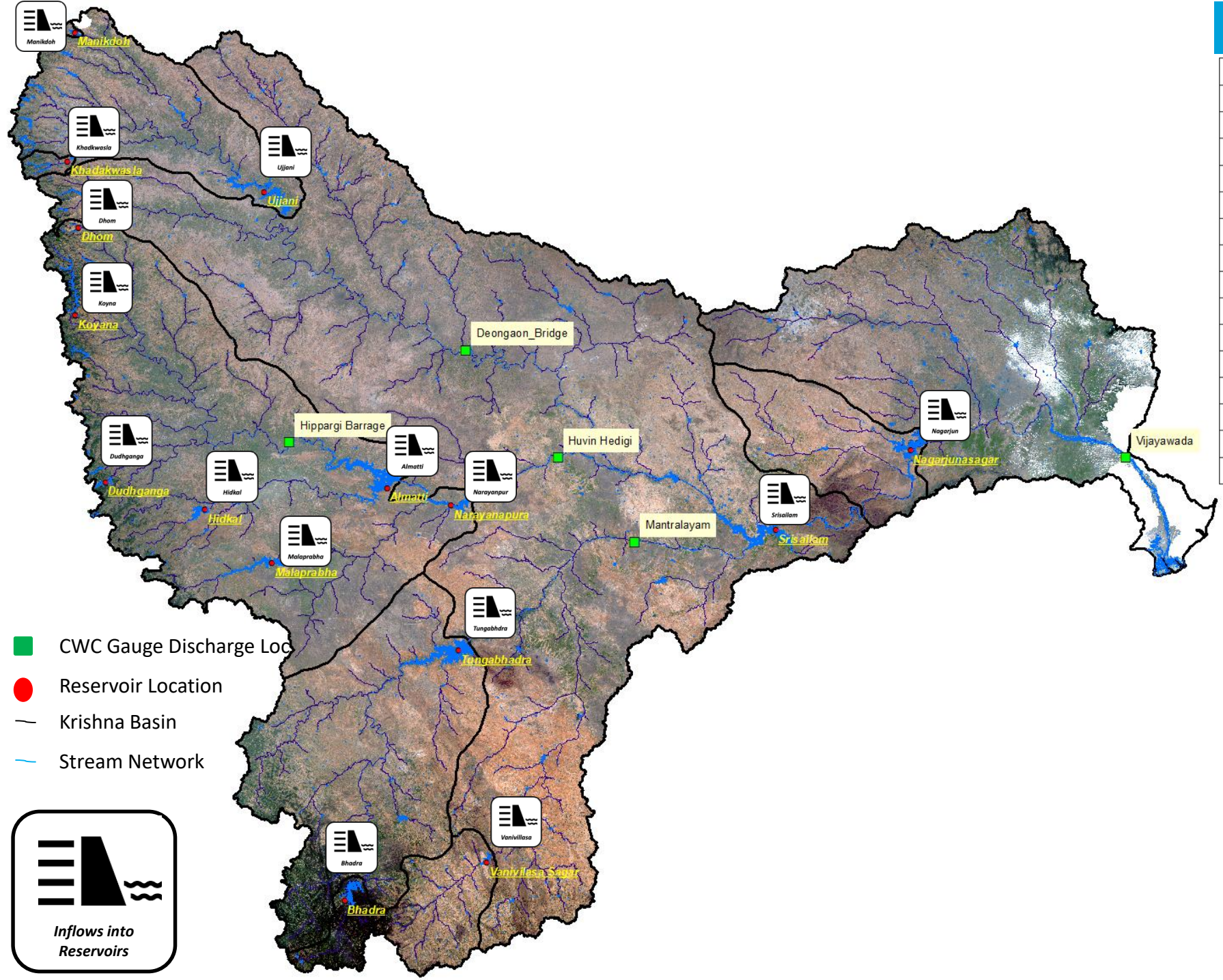
$$S_{t+1} = S_t + Q_t - E_t - R_t$$

$$R_t = \begin{cases} 0, & if\ S_t \le S_d & (Zone\ 1) \\ 0, & if\ S_d \le S_t \le S_T\ and\ S_t + Q_t - E_t \le S_T & (Zone\ 2; Case\ 1) \\ S_T - (S_t + Q_t - E_t), & if\ S_d \le S_t \le S_T\ and\ S_t + Q_t - E_t > S_T & (Zone\ 2; Case\ 2) \\ (S_t + Q_t - E_t) - S_T, & if\ S_T \le S_t \le S_{cap}\ and\ S_t + Q_t - E_t - R_m \le S_T & (Zone\ 3; Case\ 1) \\ R_{max}, & if\ S_d \le S_t \le S_T\ and\ S_t + Q_t - E_t - R_m > S_T & (Zone\ 3; Case\ 2) \end{cases}$$

$$Spill_t = \max(0, S_t + Q_t - E_t - R_m - S_{cap}) \quad (\text{Zone } 4)$$

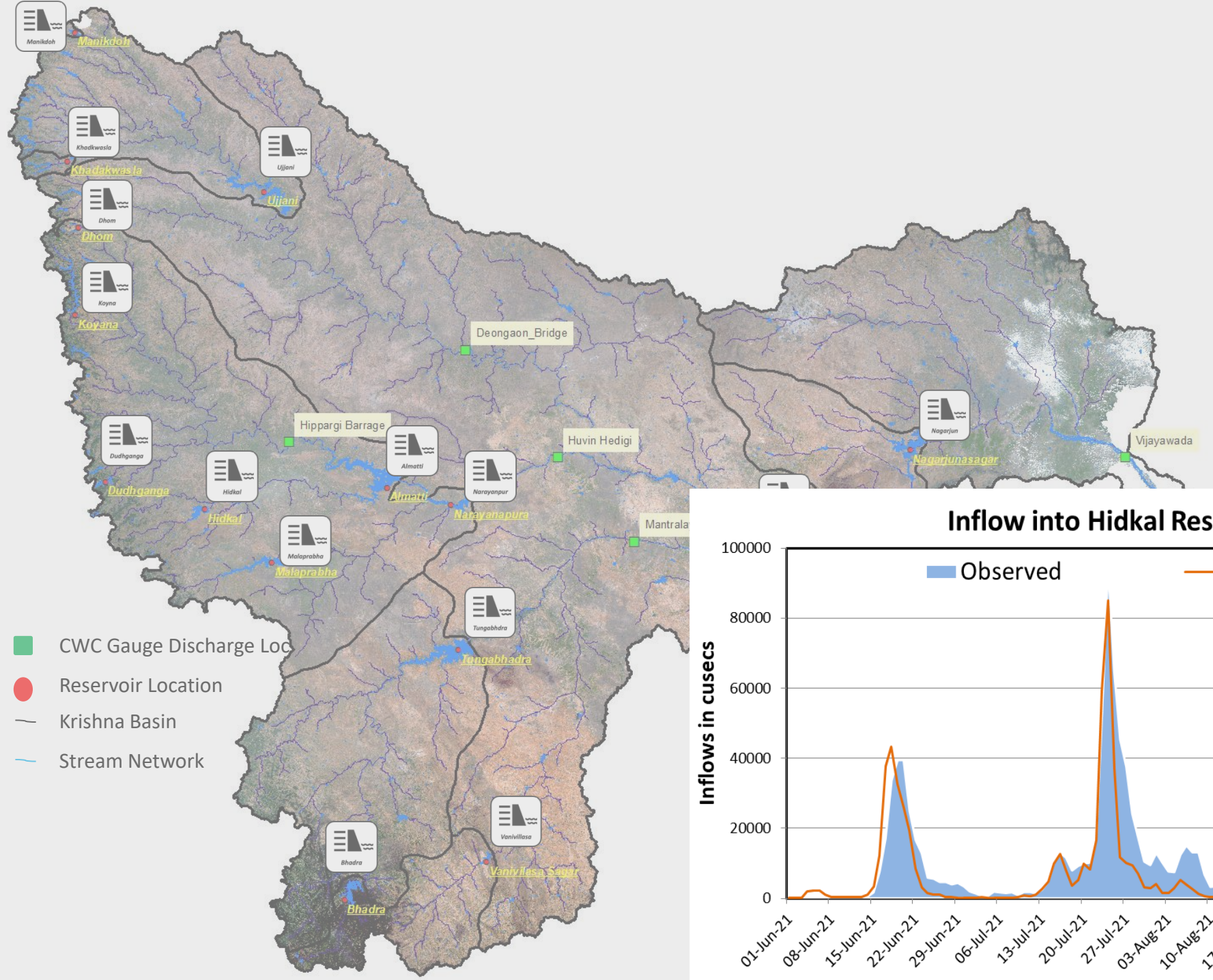
where, S_d is the storage corresponding to the dead water level, and S_T the target storage





Krishna Basin

Res ID	NAME
1	MANIKDOH
2	KHADAKWASALA
3	UJJANI
4	DHOM
5	KOYNA
6	DUDHGANGA
7	HIDKAL
8	ALMATTI
9	MALAPRABHA
10	NARAYANPUR
11	BHADRA
12	TUNGABHADRA
13	VANIVILASA
14	SRISAILAM
15	NAGARJUNA SAGAR



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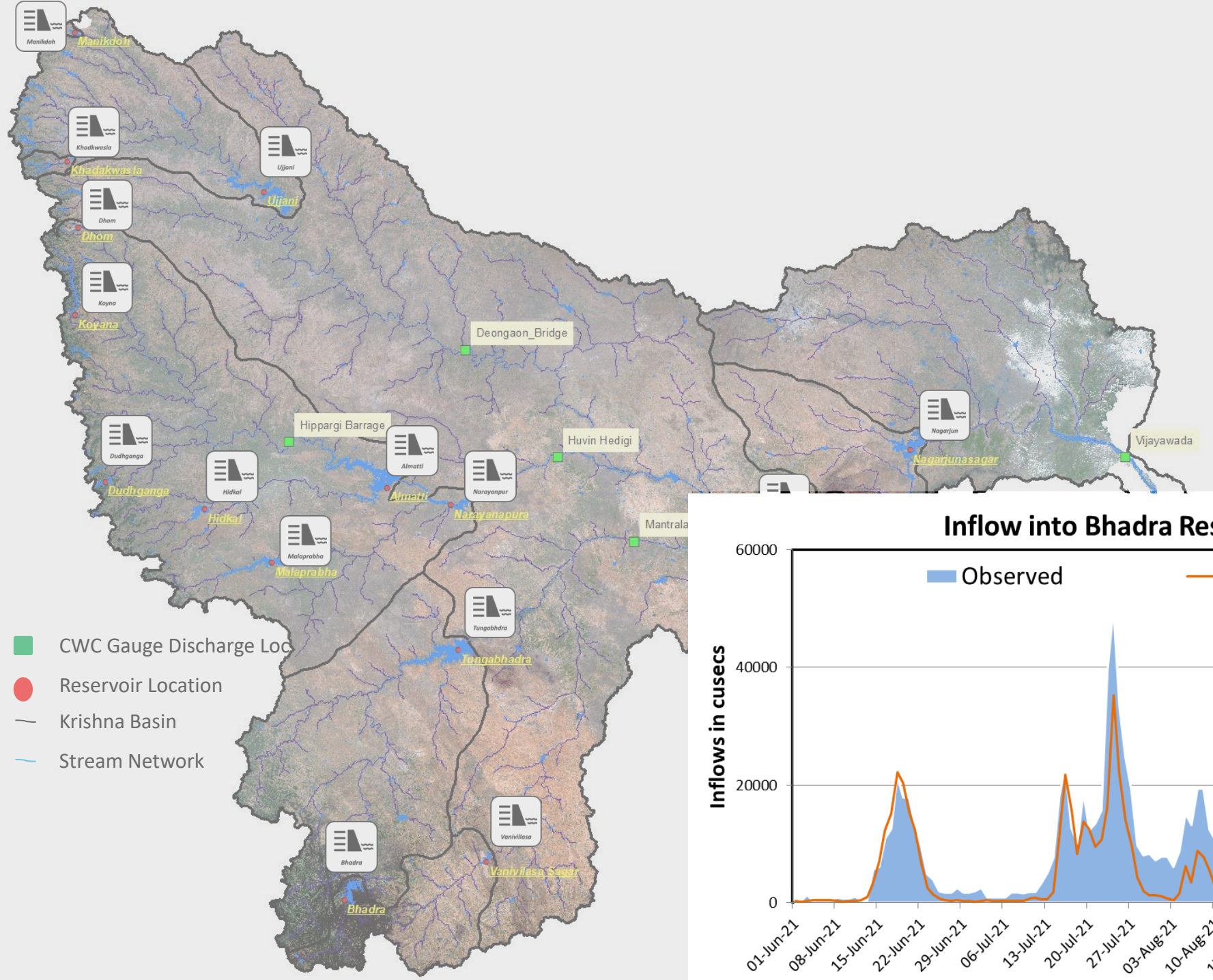

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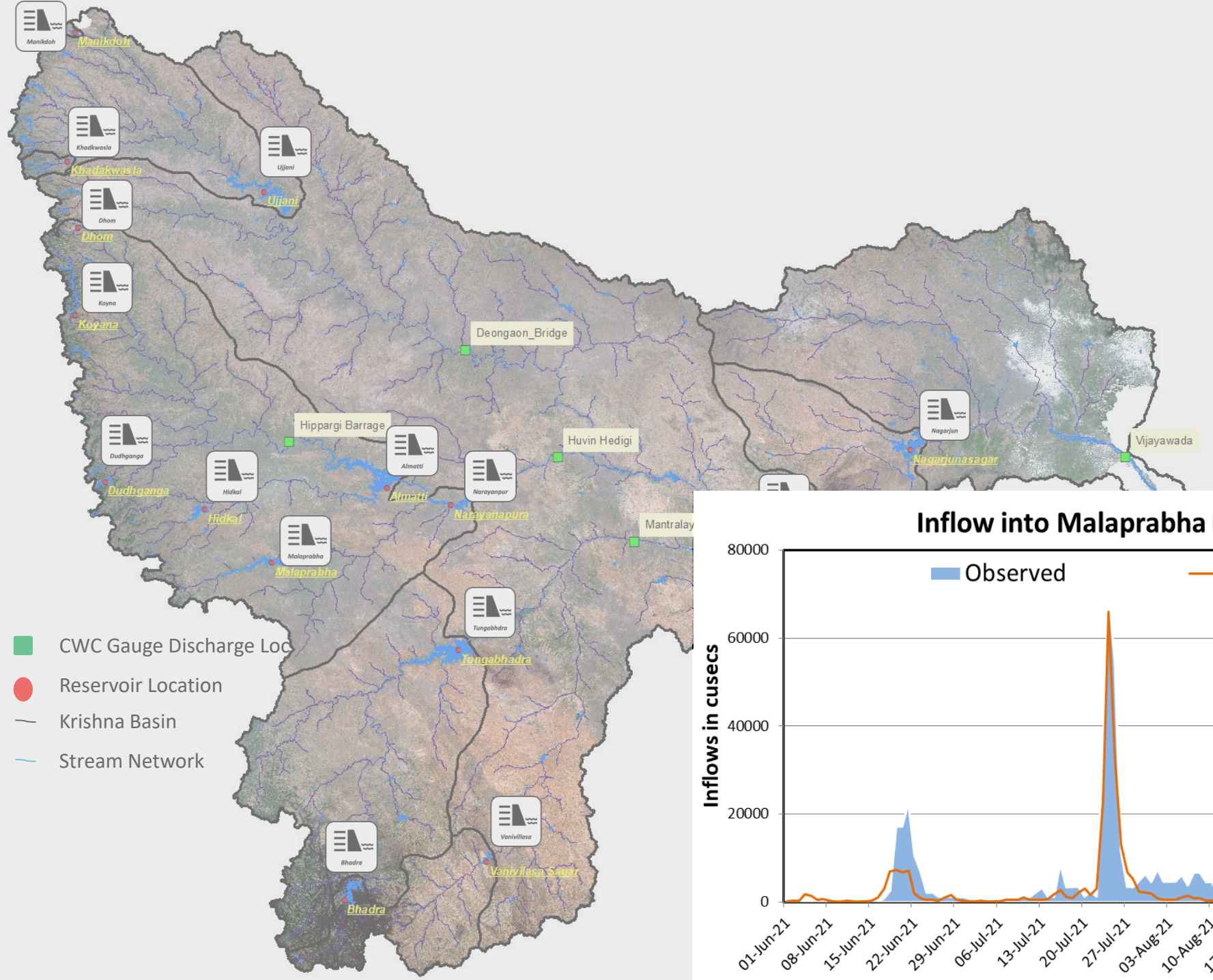

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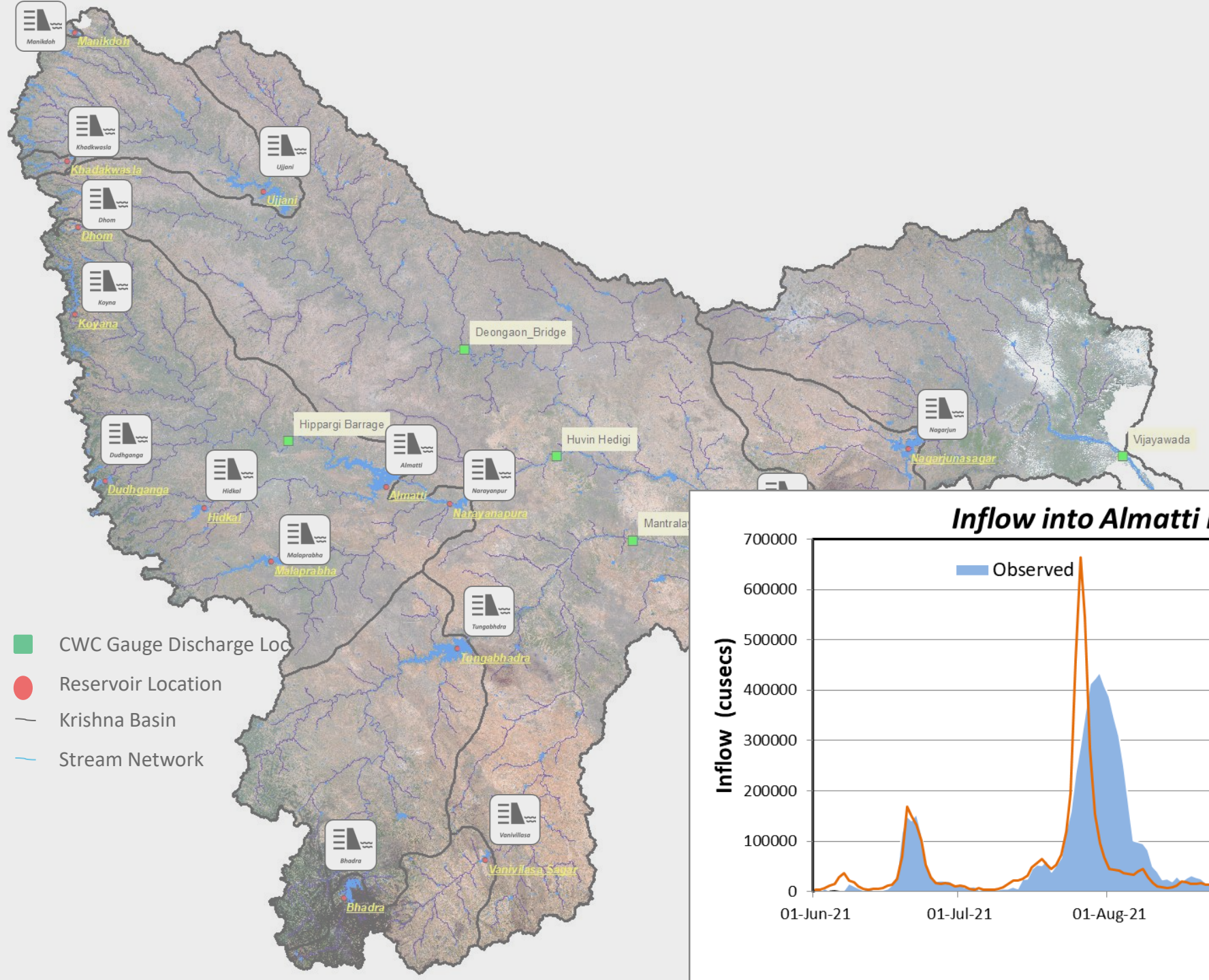

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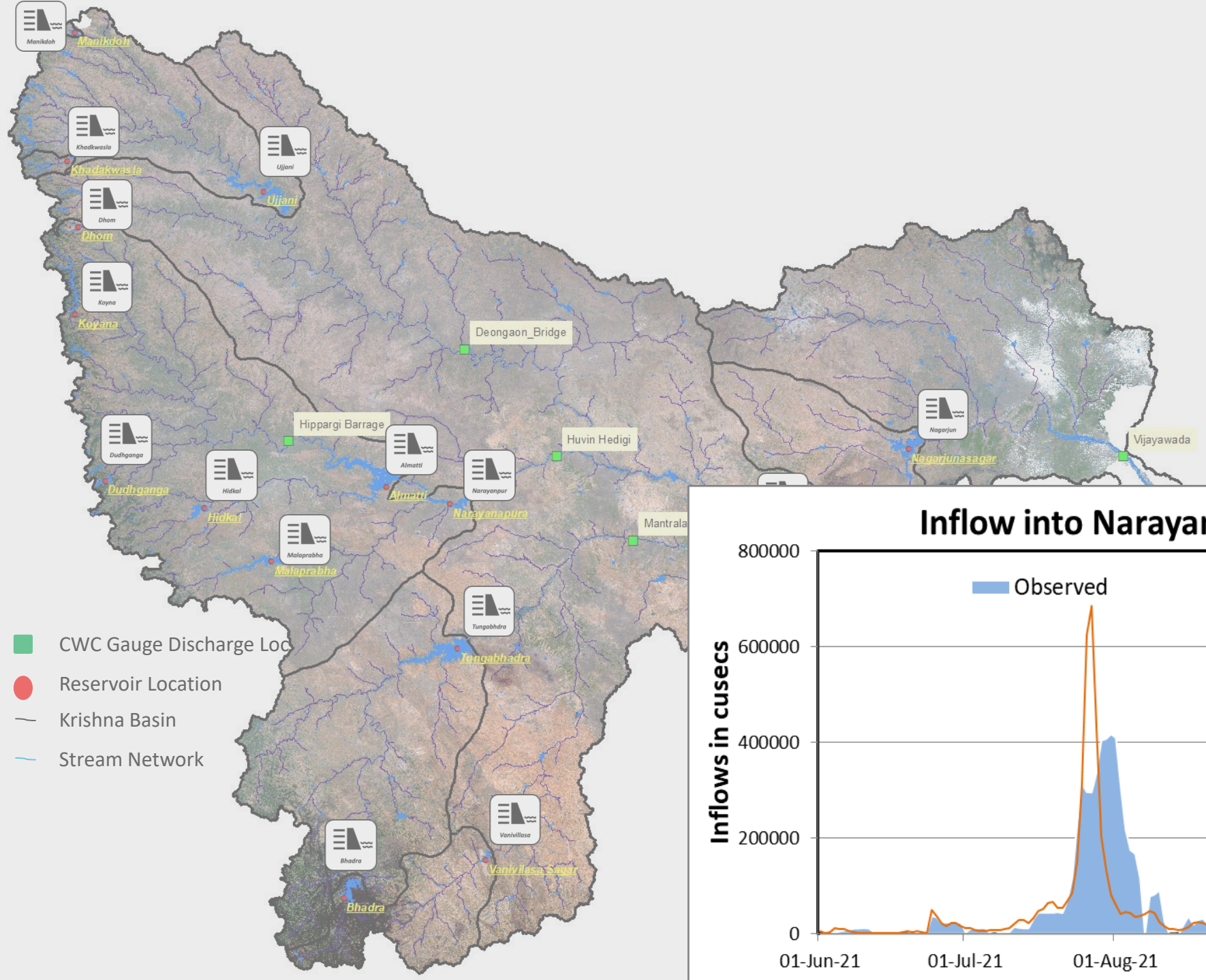

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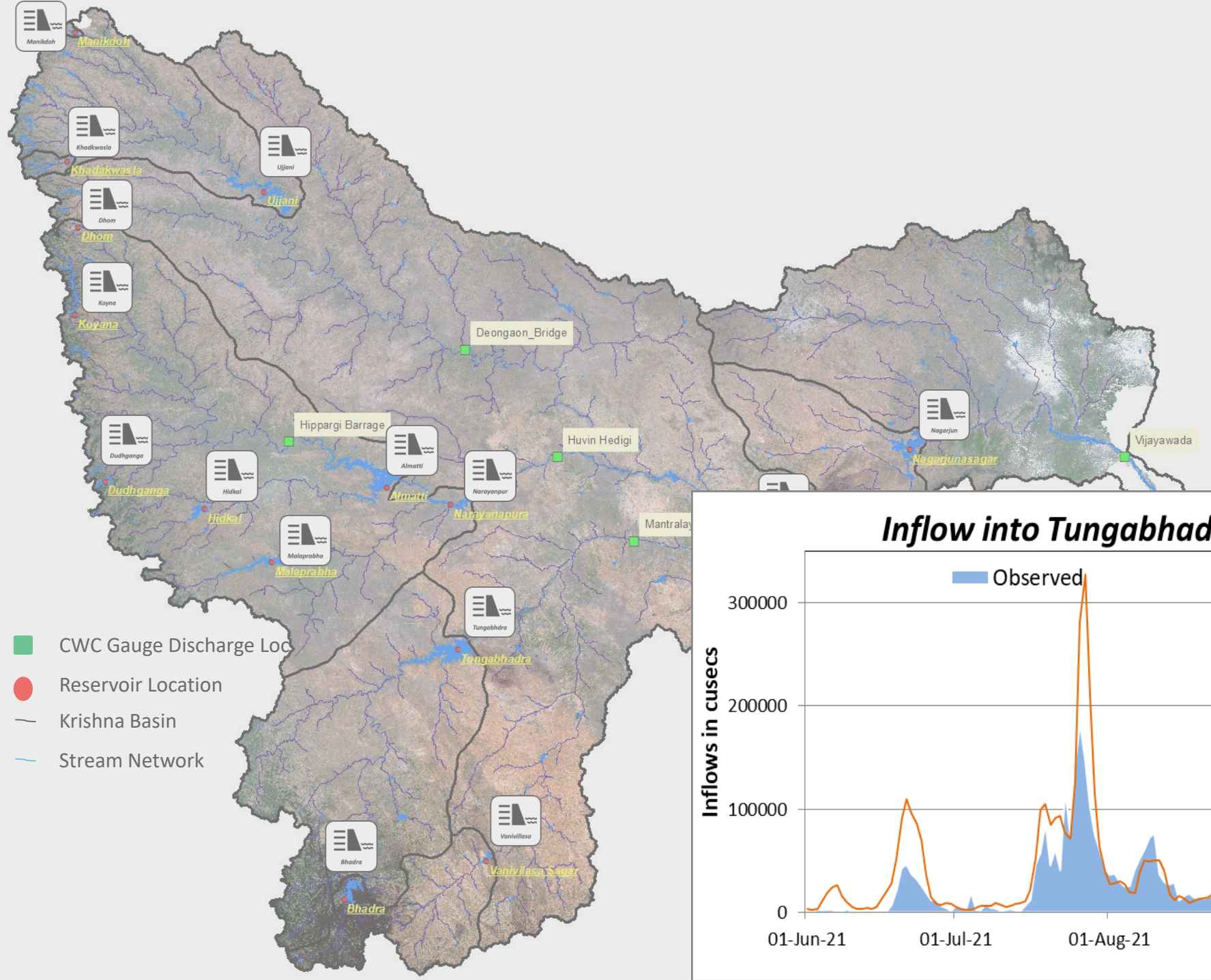

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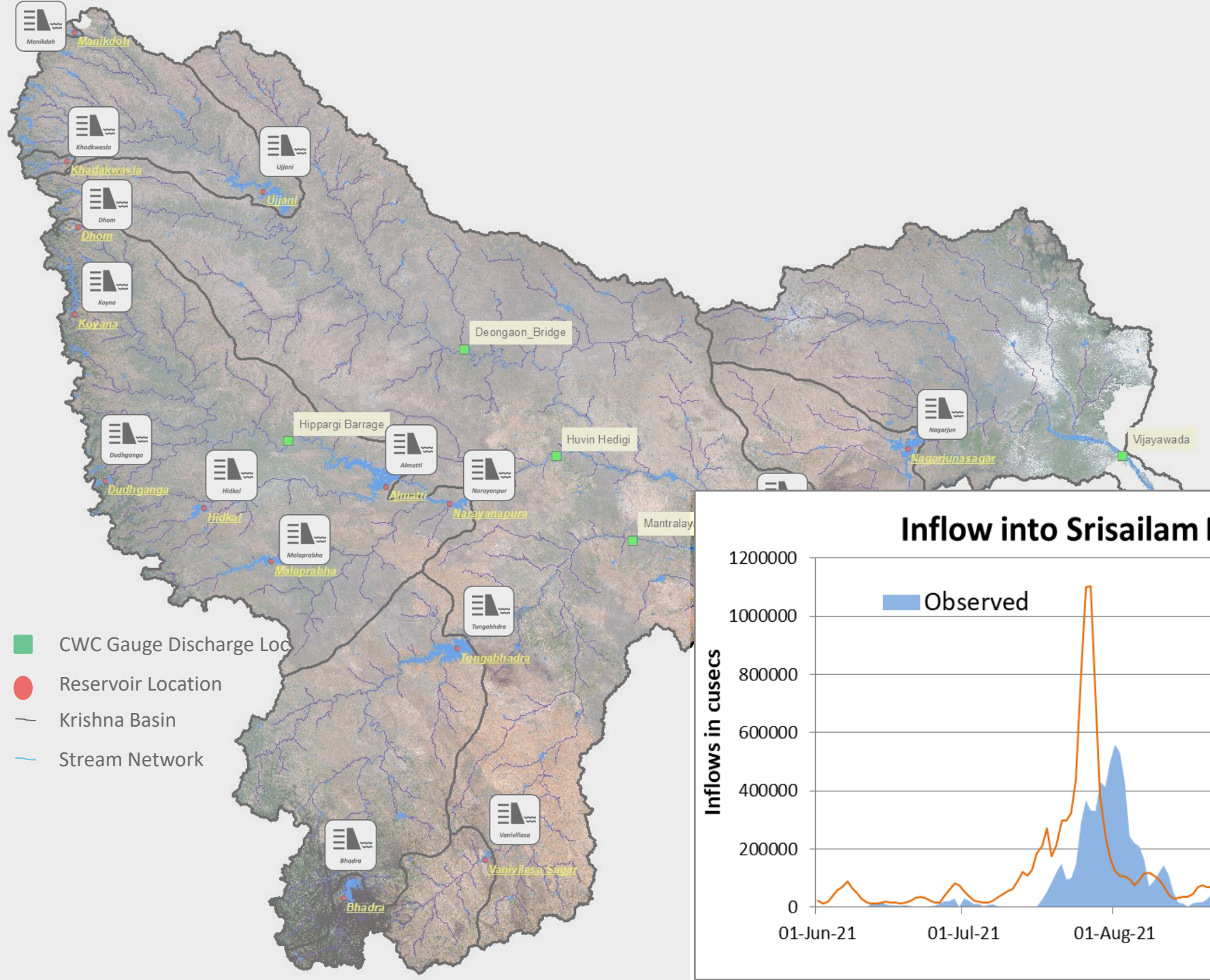

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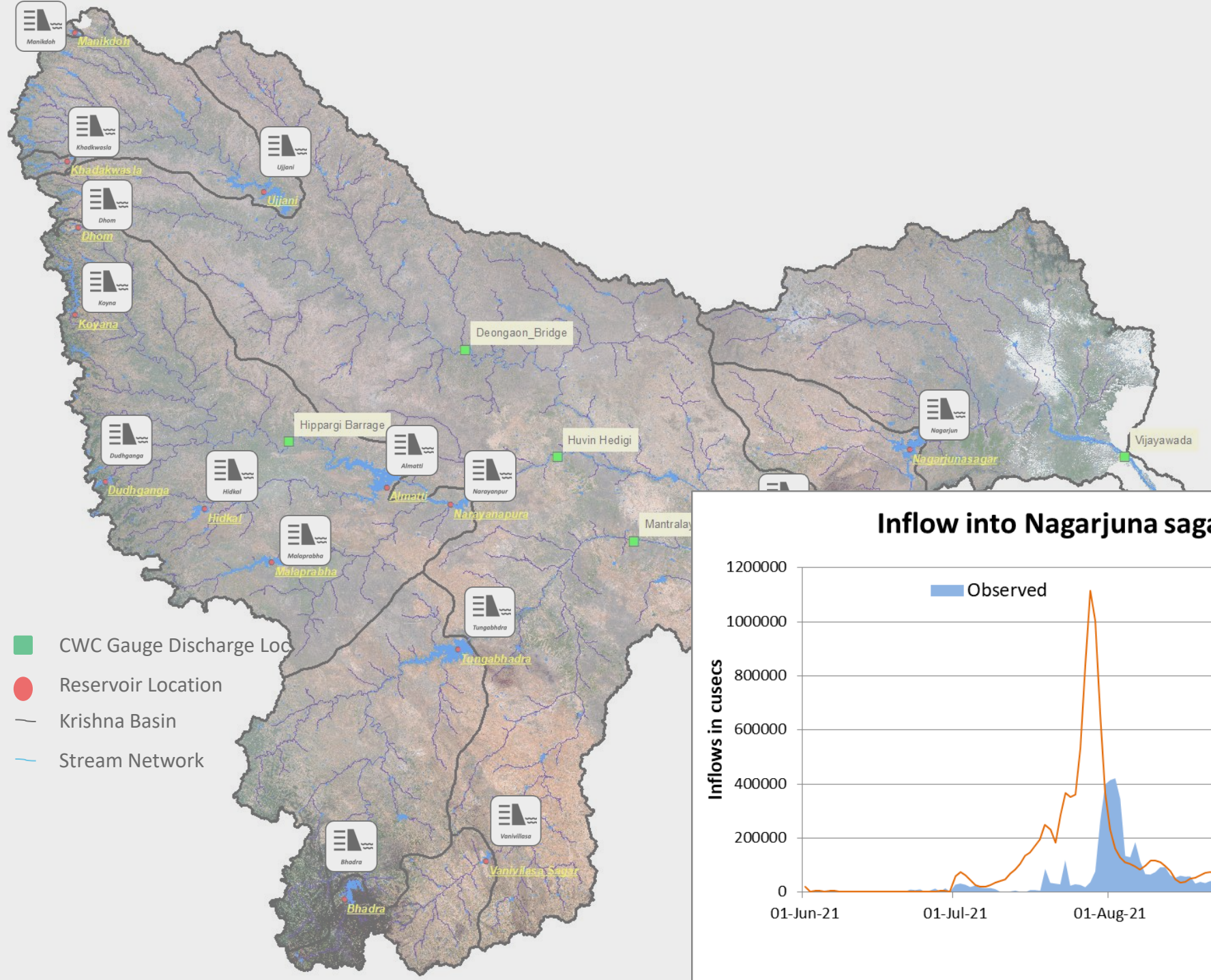

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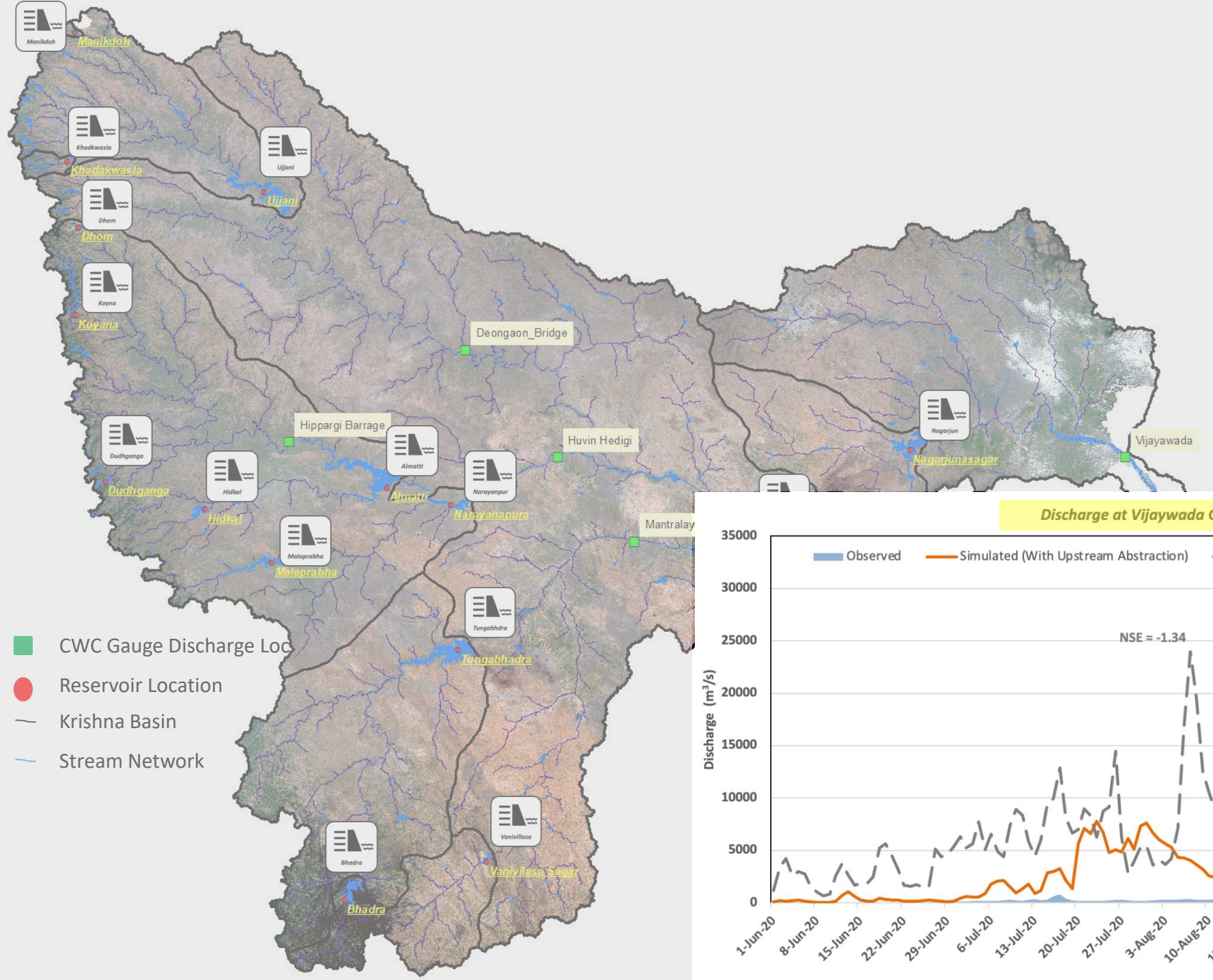

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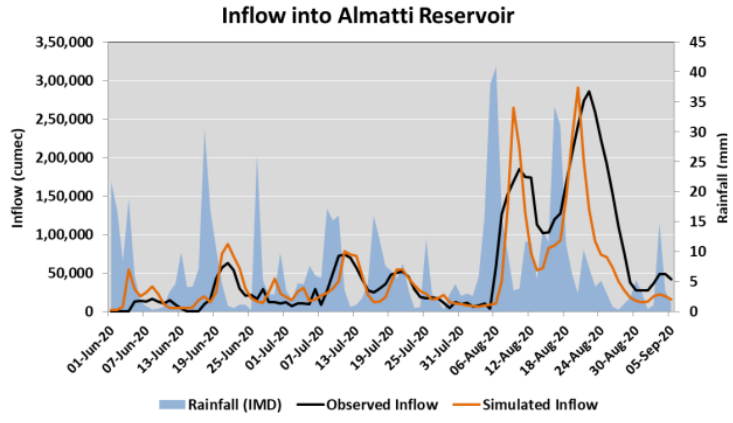
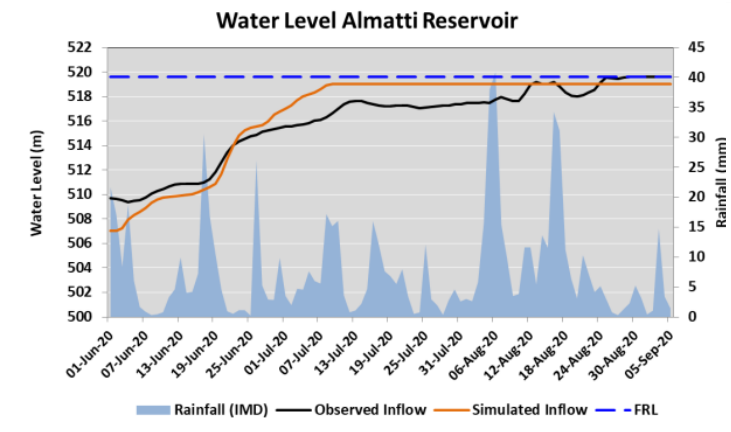
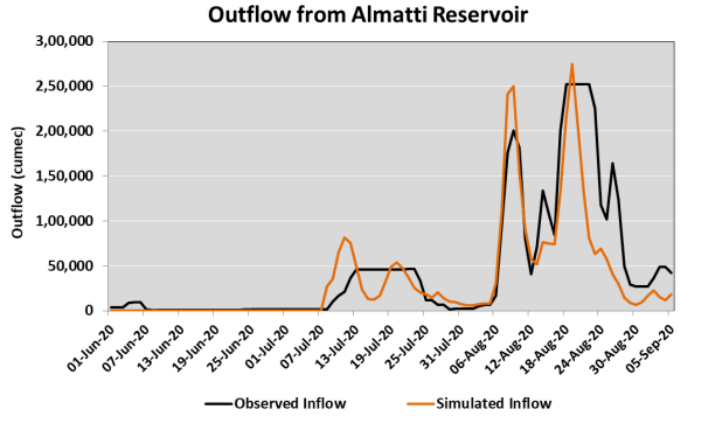
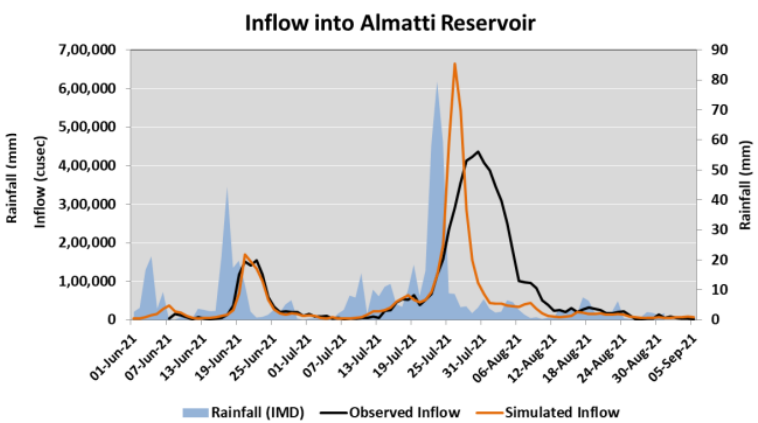
2020


Inflow into Almatti Reservoir
Inflow (cumec)
Rainfall (mm)
Rainfall (IMD)
Observed Inflow
Simulated Inflow


Water Level Almatti Reservoir
Water Level (m)
Rainfall (mm)
Rainfall (IMD)
Observed Inflow
Simulated Inflow
FRL


Outflow from Almatti Reservoir
Outflow (cumec)
Observed Inflow
Simulated Inflow

2021


Inflow into Almatti Reservoir
Inflow (cusec)
Rainfall (mm)
Rainfall (IMD)
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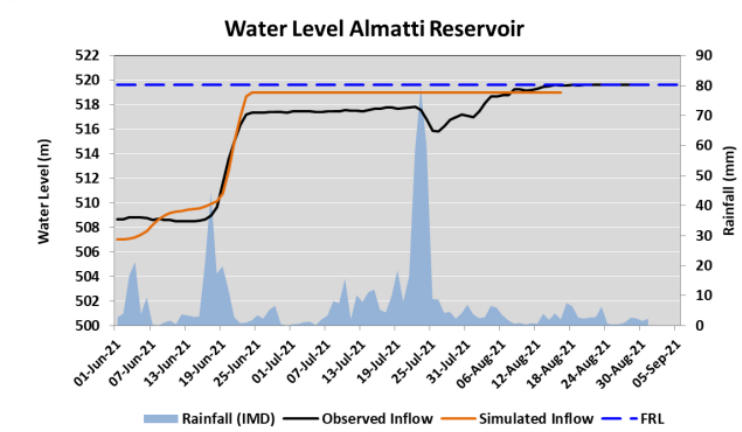
Water Level Almatti Reservoir
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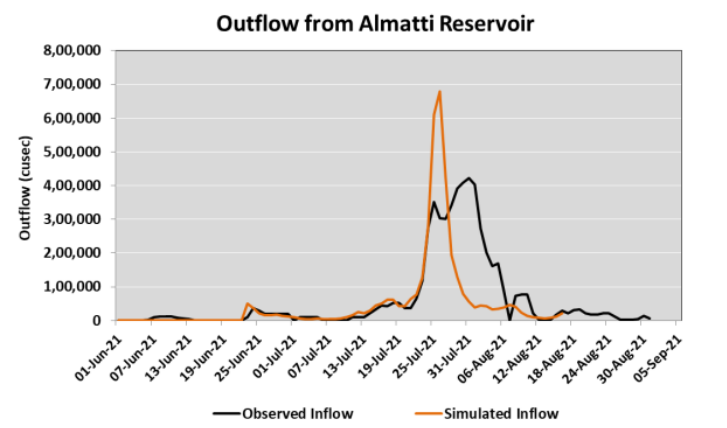
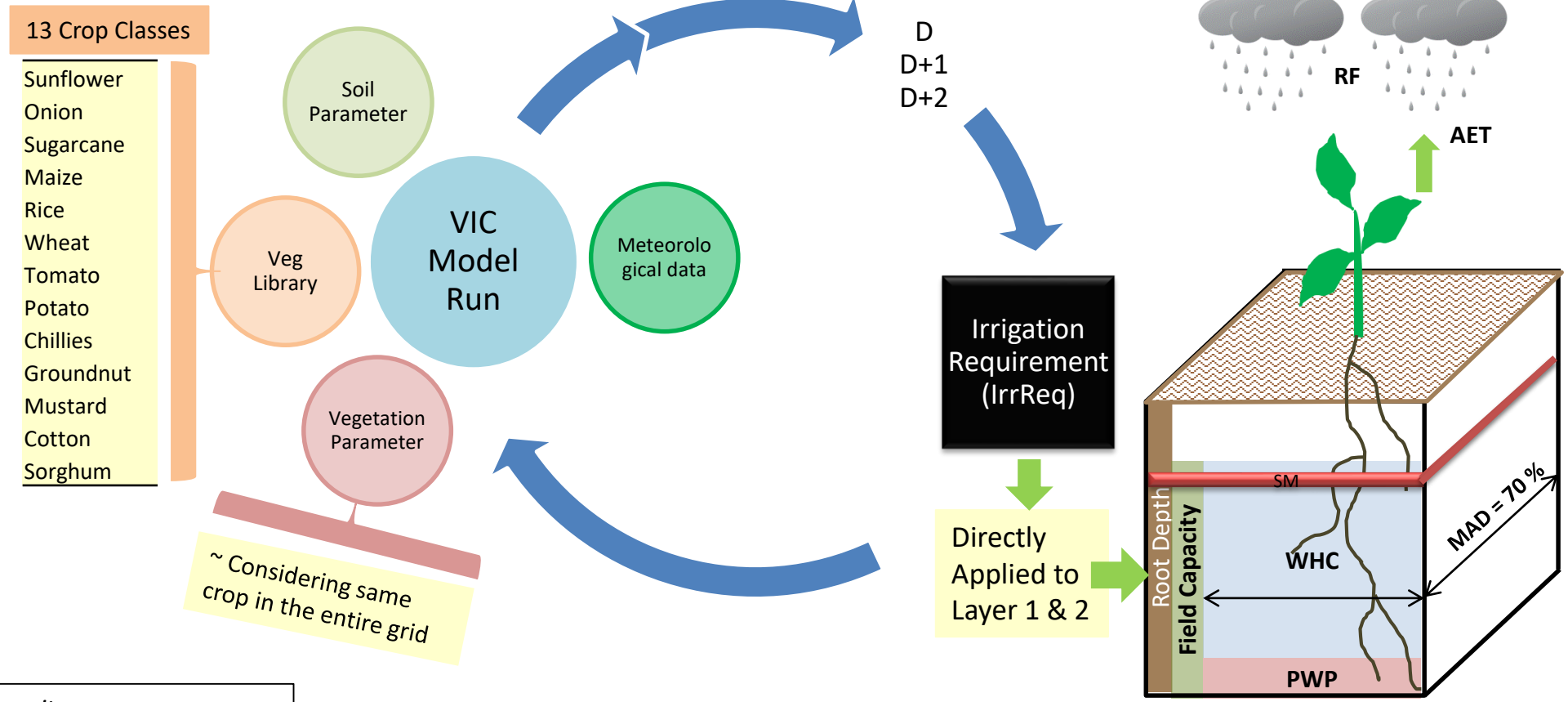

Outflow from Almatti Reservoir
Outflow (cusec)
Observed Inflow
Simulated Inflow

Irrigation Requirement Methodology

User Input:
- Selection of Command Area
- Crop Type
- Crop Sowing Date

~ Irrigation is provided so that the water requirement of crop is satisfied
~ Irrigation Requirement = Field Capacity – SM
~ Irrigation is provided when SM reaches MAD value. SM is allowed to deplete till MAD value and Irrigation is applied till FC.

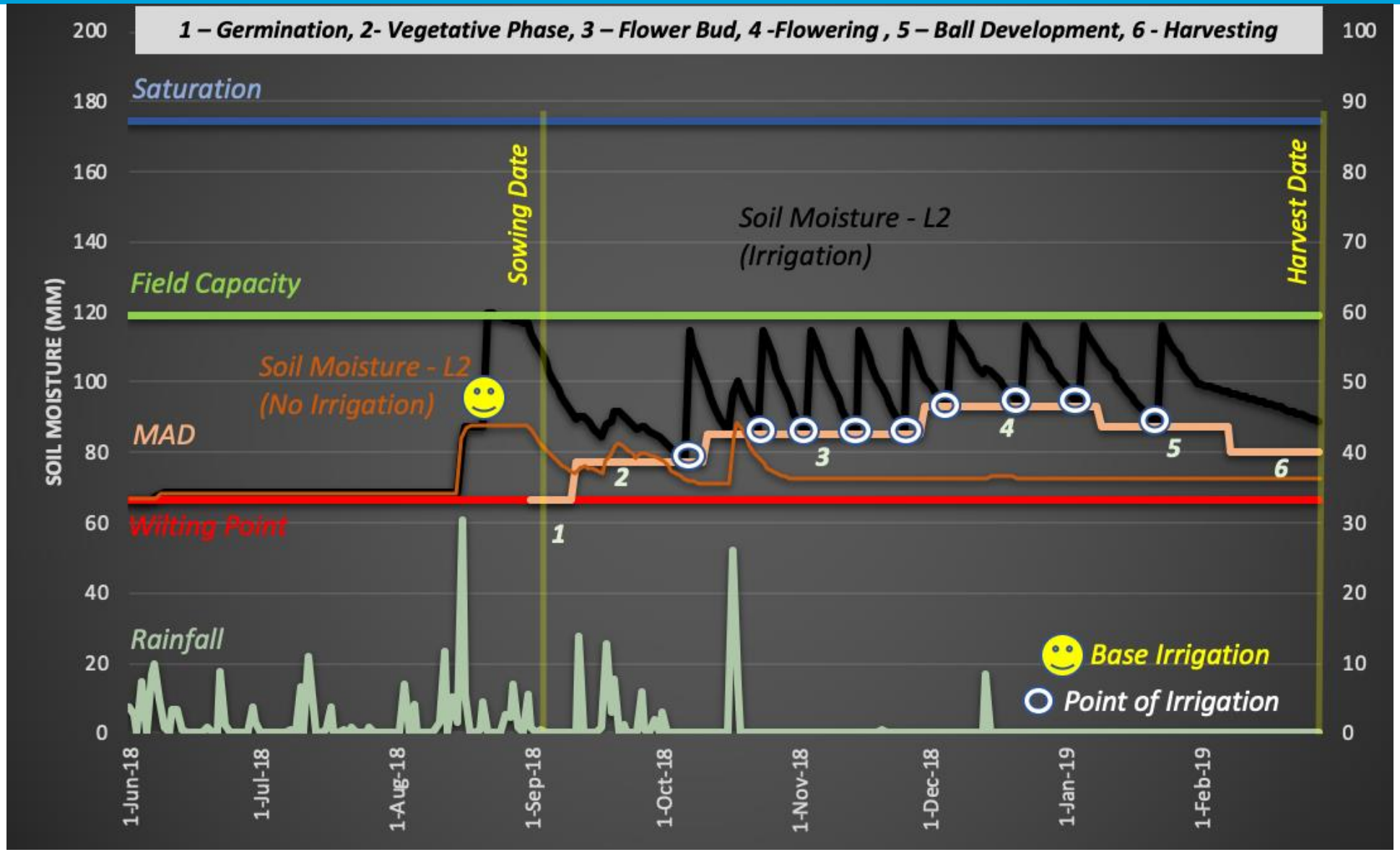


FC: Field Capacity
PWP: Permanent Wilting Point
AW: Available Water
EW: Extractable Water
WHC: Water Holding Capacity
MAD: Maximum Allowable Depletion

For Non-Rice Crop only

- Base Irrigation = SAT(L1) – SM_d(L1) + FC(L2) – SM_d(L2)
- Irrigation is applied when SM(L2) < MAD
- IrrReq = FC(L1) – SM_d(L1) + FC(L2) – SM_d(L2)

Layer 2 - Base Irrigation (Before Sowing), Applied Irrigation and Stage Wise MAD Values



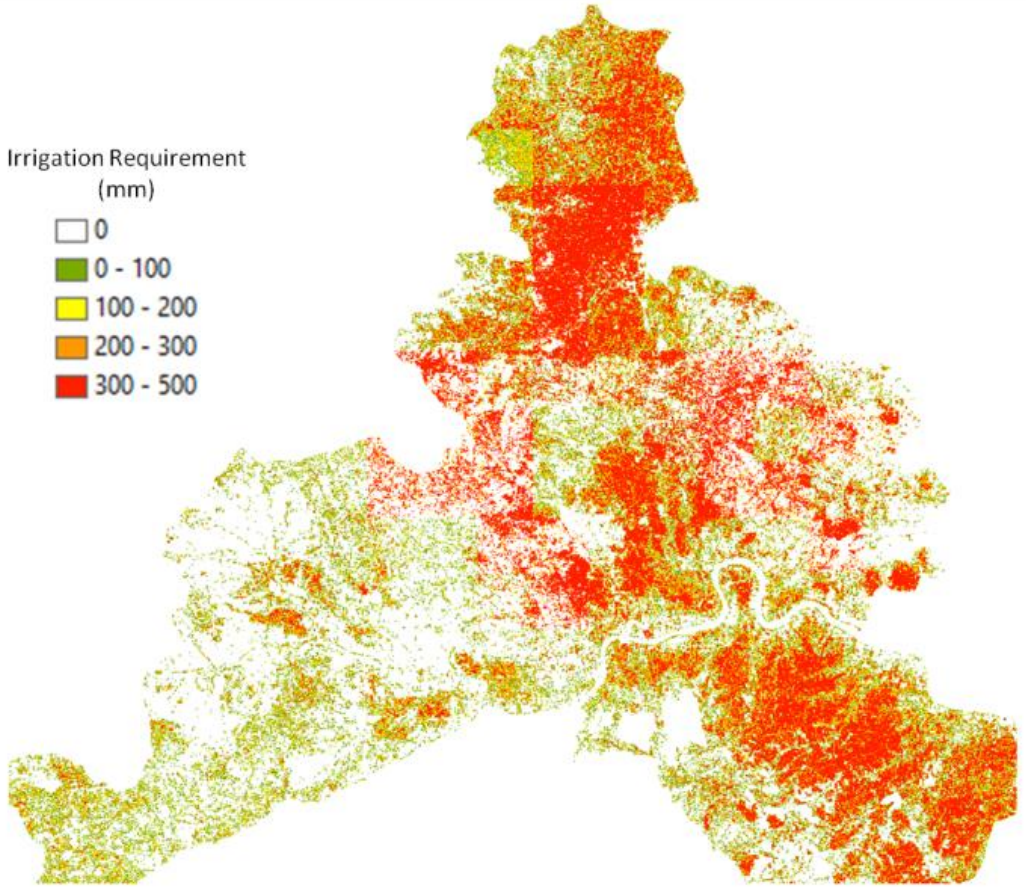
- Change in Layer 2 Soil Moisture When "***No Irrigation***" Vs When "***Irrigation***" was supplied
- Base Irrigation is applied to FC for Layer 2; 10 days prior sowing (22nd Aug 2018)
- Stage-Wise MAD values with respect to Yield Response Factor

Statistics

	Dates	IrrReq (mm)
Base Irrigation	22-Aug	51.02
Sowing Date	1-Sep	0.00
	7-Oct	54.8
	24-Oct	44.3
	4-Nov	48.03
	15-Nov	48.15
Irrigation points	26-Nov	46.42
	6-Dec	37.28
	23-Dec	36.75
	5-Jan	37.09
	23-Jan	44.34
Harvest Date	28-Feb	0.00
	Total Irrigation Estimated	448.18

Crop Stages	EstIrrReq (mm)
Base Irrigation	51.02
Germination	0
Vegetative Phase	54.8
Flower Bud	186.9
Flowering	111.1
Ball Development	44.3
Harvesting	0
Total	448.18

Field level Irrigation Requirement for Cotton crop in Narayanpur Command Area



Downloads

S no.	Product	Source	Spatial Resolution	Temporal Resolution	Latency	Data Available for Download
1.	Surface Runoff	https://bhuvan.nrsc.gov.in/nhp/nhp-data-download	0.05 degree	Daily (Indian)	D - 2	2020 – present
2.	Upper Layer Soil Moisture	https://bhuvan.nrsc.gov.in/nhp/nhp-data-download	0.05 degree	Daily (Indian)	D - 2	2020 – present
3.	Root Zone Soil Moisture	https://bhuvan.nrsc.gov.in/nhp/nhp-data-download	0.05 degree	Daily (Indian)	D - 2	2020 – present

Pre-Requisite

- ✓ ***User should have a login credential in Bhuvan portal***
- ✓ ***Max of 10 downloads allowable at a time***
- ✓ ***Downloadable products are in .tiff format***
- ✓ ***Each Download has its information in metadata sheet***

Historical Data Archival

S no.	Product	Spatial Resolution	Temporal Resolution	Data Available for Download
1.	Surface Runoff	0.05 degree	Daily (Indian)	1971 – present
2.	Upper Layer Soil Moisture	0.05 degree	Daily (Indian)	1971 – present
3.	Root Zone Soil Moisture	0.05 degree	Daily (Indian)	1971 – present
4	Evapotranspiration	0.05 degree	Daily (Indian)	1971 – present

Limitation/Future Scope

Land Surface Models (LSM) simulates water balance components (WBC) and can estimate discharge at various location over a stream network over a **natural system**.

Major limitation in hydrological models:-

1. Interventional Flow (Medium Reservoirs/WB/Lakes/Farm Ponds)
2. Runoff generated from other than rainfall due to supplies from irrigation is not accounted
3. Crop type information not incorporated
4. Different resolution of the input meteorological datasets

Future Scope

1. Validation of model simulated SM and ET using data measured from flux tower and Soil Moisture Probes.
2. Reservoir optimization towards maximizing irrigation benefits/crop yield
3. Water resources availability assessment at sub-basin, administrative unit etc.

Datasets requirement for improved hydrological predictions

Datasets requirement for improved hydrological predictions

1. Meteorological datasets (AWS) under state agency
2. Daily reservoir information consists of Inflow, Outflow, Canal Releases, operational rule curves, Water level for major and medium size reservoirs (Min recent 10 years data)
3. Observed discharge at river basin points
4. Command Area details (.shp file)