Analysis of the impact of water conservation measures on the hydrological response of a medium-sized watershed

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ANALYSIS OF THE IMPACT OF WATER CONSERVATION MEASURES ON THE HYDROLOGICAL RESPONSE OF A MEDIUM-SIZED WATERSHED

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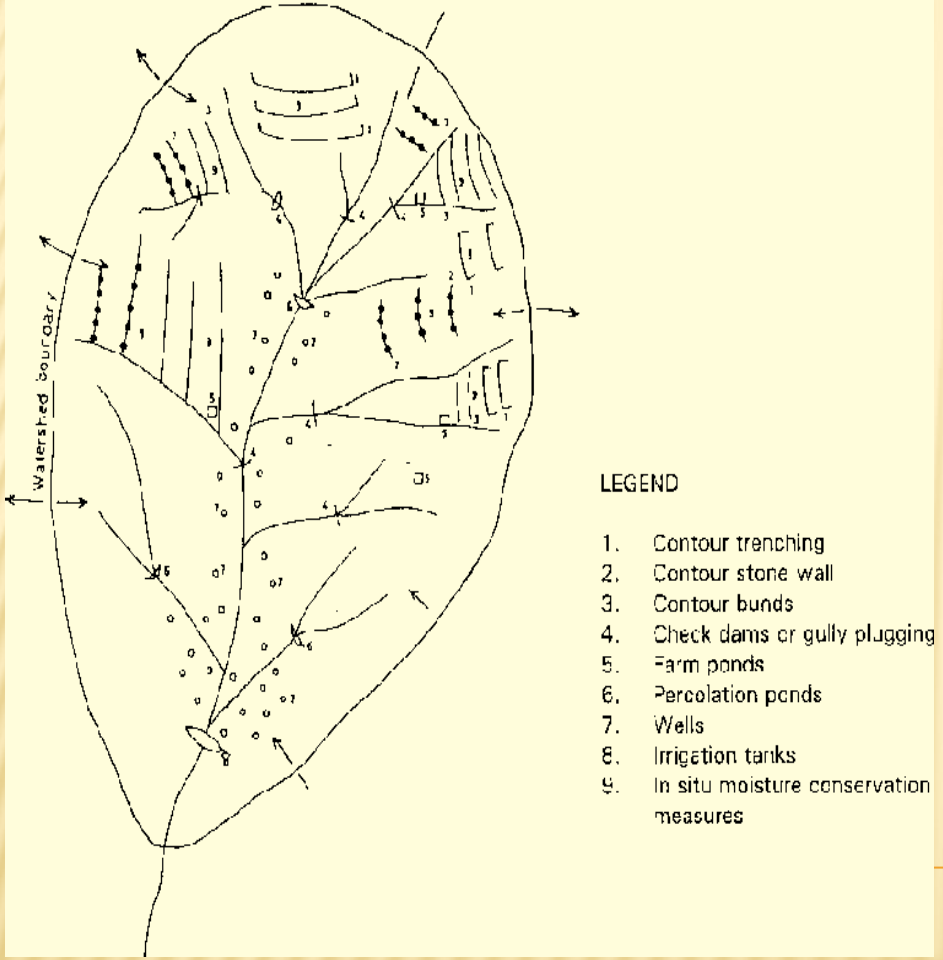
INTRODUCTION

1. North East, India receives on average 200-400 cm rainfall from which 80-90% of the rainfall occurs during monsoon months (May 15 – Sept 30)
2. Flash floods occur during rainy season and acute shortage of water for domestic and agricultural uses during winter. Rural areas are situated usually at upstream receives adequate rain, with no facilities to conserve the water for winter.
3. Average annual surface water potential of 585.6 km^3 has been assessed in this region, which is highest among all the river systems in India and fifth in the world. Out of this, 24.0 km^3 is utilizable water and is merely 4.1% of annual surface water potential.
4. People living in hills and mountains of North-eastern India have developed a number of novel practices of farming, checking soil erosion, preventing landslides and of conserving water, beneficial in retaining fertility of soil; preventing land slides and checking soil erosion and in retaining the moisture of soil and conserving water.
5. Common Structures: Check Dams, Percolation Pond, Irrigation Tanks

Field photographs showing small water conservation structures

Small water Conservation Measures in hilly watersheds



Hydrological impact of Small Water Harvesting Structures

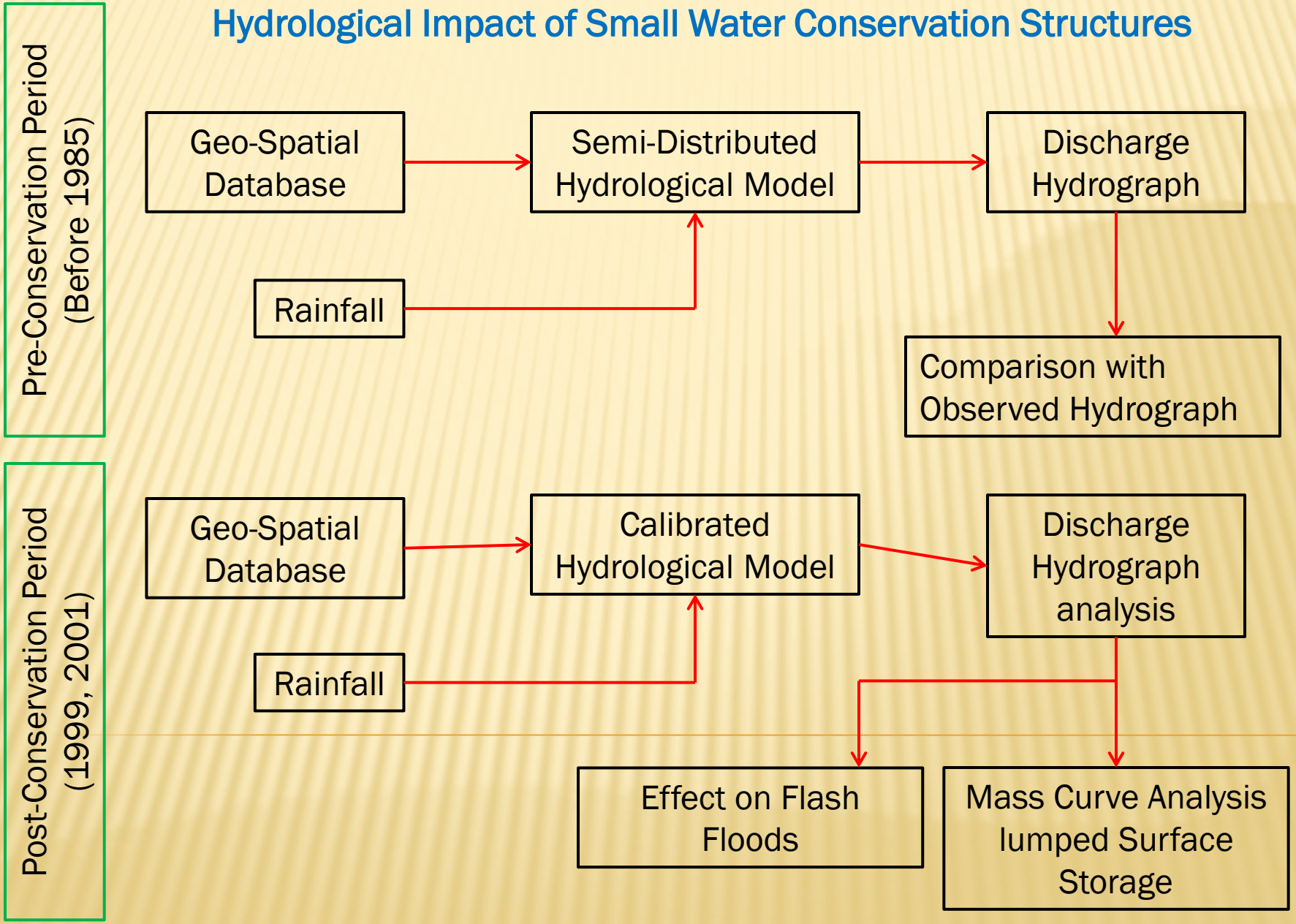
1. *Store first-order stream flow during early monsoon period*
2. *Recharge the shallow ground water*
3. *Release the stored water during non-monsoon period*
4. *Increase the flashiness due to wetness area*

OBJECTIVES

- To calibrate and validate a semi-distributed hydrological model for an agro-forestry dominated watershed to obtain its hydrological response for pre-conservation period
- To obtain the hydrological response of the watershed without water harvesting structures for post-conservation period by model simulation
- To quantify the change in hydrological response due to water harvesting structures by conducting mass curve analysis and peak flow analysis for post-conservation period
- To quantify the change in hydrological response of the watershed under best-guess land use change conditions

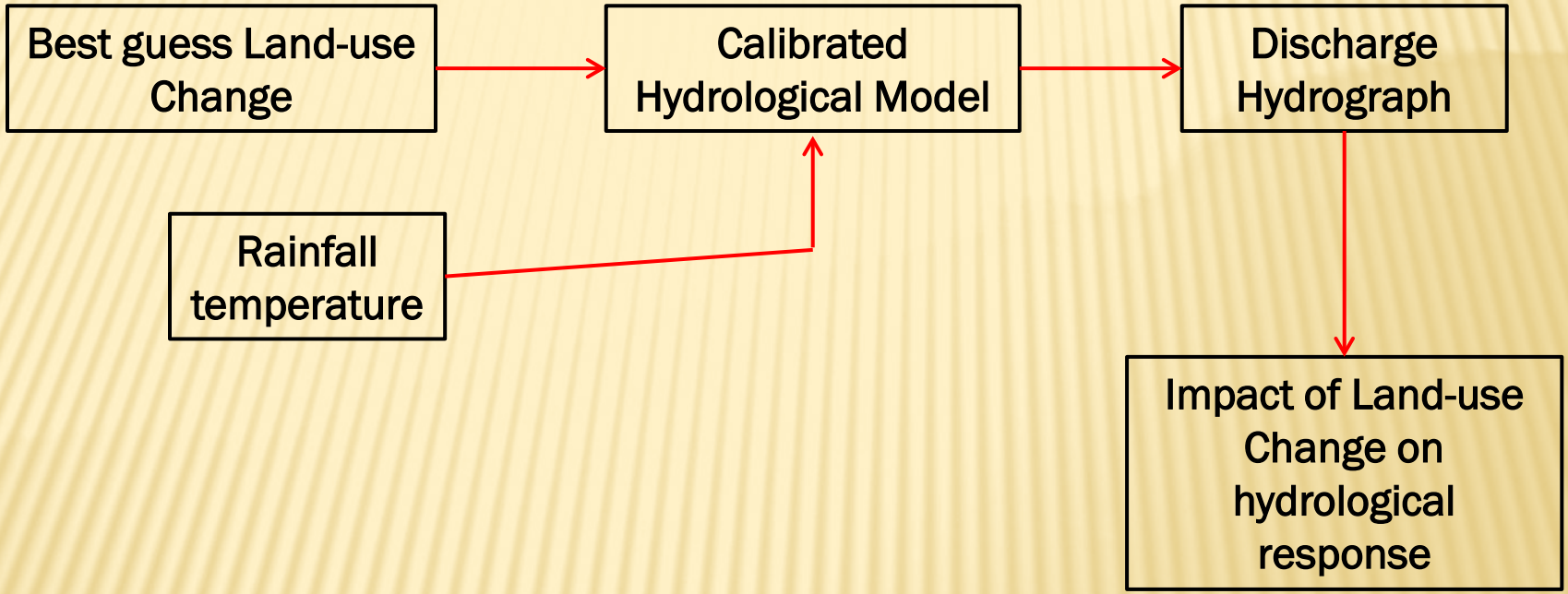
METHODOLOGY

Hydrological Impact of Small Water Conservation Structures



Methodology

Impact of Land-use Change on hydrological response



Introduction to RISE Model*

A semi-distributed hydrological model defining the hydrological processes in Sub-tropical hilly region with paddy fields

Runoff Generation

- *Macropore dominated vegetated hillslope*
- *Paddy cultivation dominated agricultural lands*
- *Semi-impervious urban areas*
- *Wet lands as permanent sinks*

Subsurface flow component

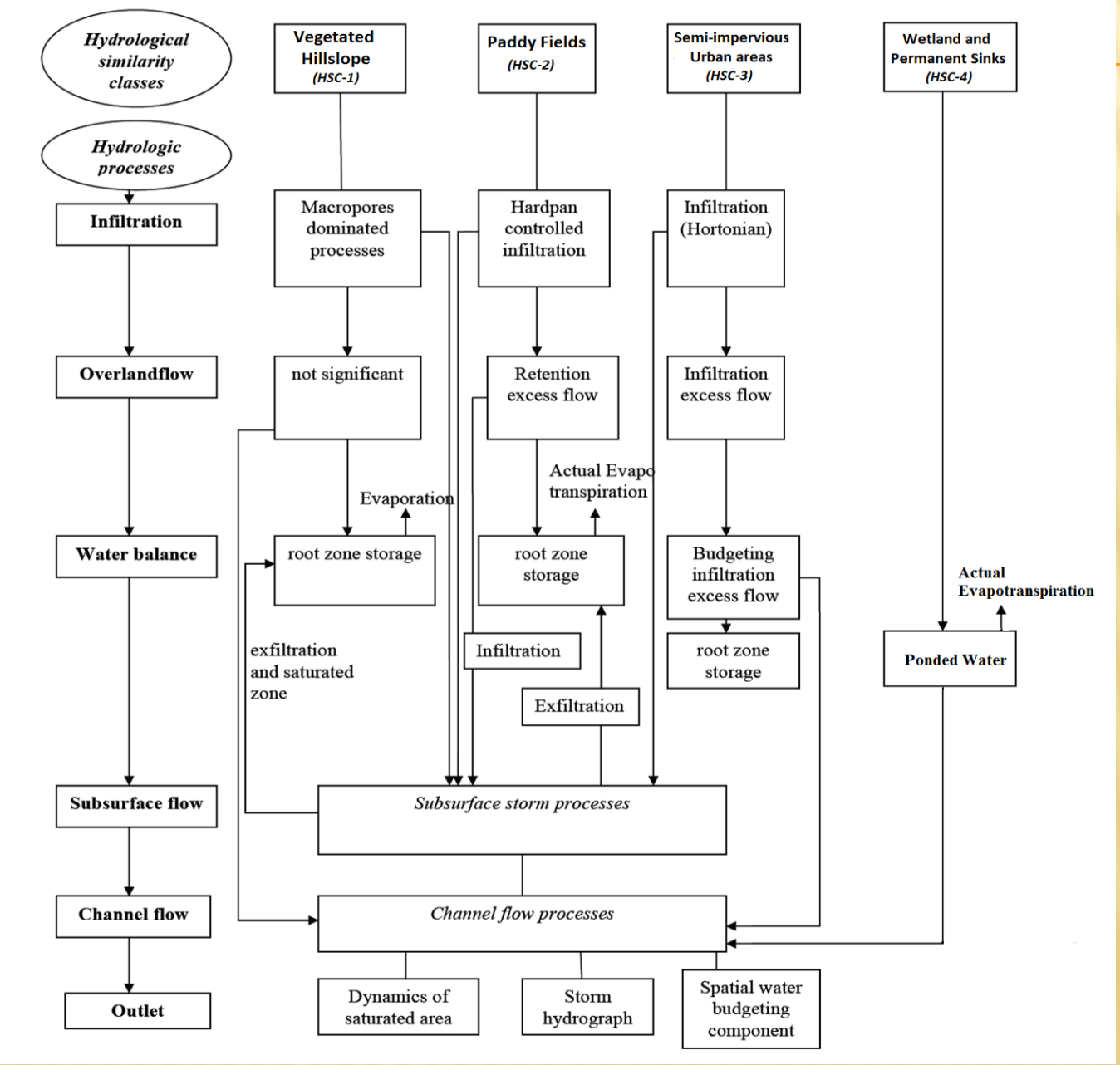
Channel routing

- *Lateral flow to the channel segments*
- *Linearized channel routing*

Only 5 calibration parameters and required spatial input data can be obtained from international/national sources

* Sudipta Kumar Mishra, Rupak Sarkar, Subashisa Dutta and Sushma Panigrahy (2008). "A Physically process Based Hydrological Model for Paddy Agriculture Dominated Hilly Watersheds in Tropical Region". Journal of Hydrology, Vol. 357, 389-404.

Conceptual diagram of the model



Model Components

Rice Irrigation System Evaluation (RISE) model (Dutta and Zade 2003): Semi-Distributed physically based hydrological model

- Dominant hydrological processes based on different distinct hydrological similarity classes (HSC).:

Infiltration Process

- ***Macropore dominated vegetated hill-slopes***

$R = 0,\ when\ i \leq f_{max}$ (1-a)

$R = i - f_{max}\ ,\ when\ i \geq f_{max}$ (1-b)

where *i* is the rainfall intensity.

- ***Paddy cultivation dominated agricultural lands***

$$f = \frac{k_1 k_2 (h_1 + h_2 + h + \Psi_1)}{h_1 k_2 + h_2 k_1} \quad (2)$$

where Ψ_1 is the suction pressure of the saturated plow layer; k_1 and k_2 are saturated hydraulic conductivities of plow layer and hard pan formations respectively. Value of k_2 can be obtained from the relation: $k_2 = (k_1/r)$where *r* is the degree of soil impermeability (dimensionless) due to the formation of hard pan layer

- ***Semi-impervious urban area***

$f_c(t) = 0.5St^{-0.5} + A_0$ (3)

where $f_c(t)$ is the potential infiltration rate (mm/h), *S* is the sorptivity, and A_0 is the gravitational infiltration rate (mm/ h

Model Components

- **Water Budgeting**

Paddy field

$$\frac{dh}{dt} = \left(i - f - ET_{actual} - h_{ov} + f_{ex}\right)$$

- **Subsurface flow**

1. $q_i = T_o \tan\beta \exp\left(-S_i/m\right)$
2. $S_i = \overline{S} + m\left[\left(\lambda - \ln\frac{a}{\tan\beta}\right) - \left(\ln T_o - \delta\right)\right]$
3. $\overline{S_t} = \overline{S_{t-1}} + (q_{t-1} - f)\Delta t$

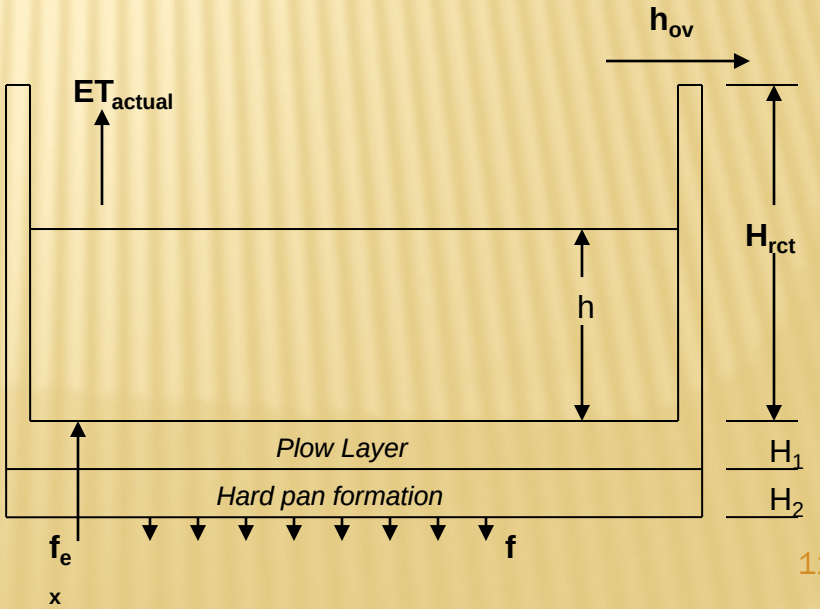
- **Semi-distributed channel routing**

$$\frac{\partial y}{\partial t} + \frac{1}{b}\frac{\partial (UA)}{\partial x} = 0$$

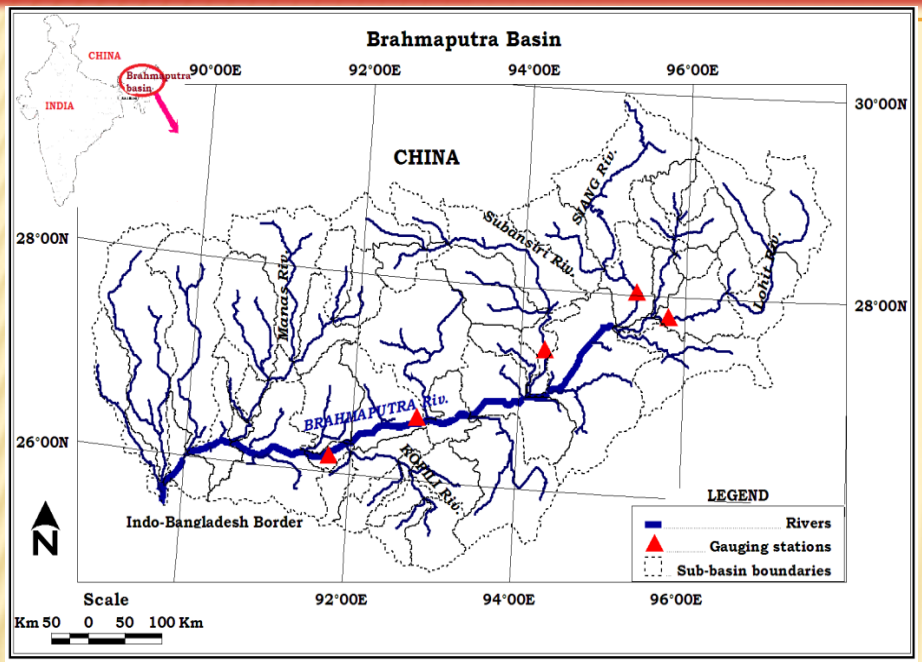
$$\frac{1}{g}\frac{\partial U}{\partial t} + \frac{U}{g}\frac{\partial U}{\partial x} + \frac{\partial y}{\partial x} + S_f = 0$$

$$\frac{\partial Q}{\partial t} = D\frac{\partial^2 Q}{\partial x^2} - C\frac{\partial Q}{\partial x}$$

$$Q_i(x,t) = \frac{x}{2(\pi D t^3)^{1/2}} \exp\left[-\frac{(x - Ct)^2}{4Dt}\right]$$

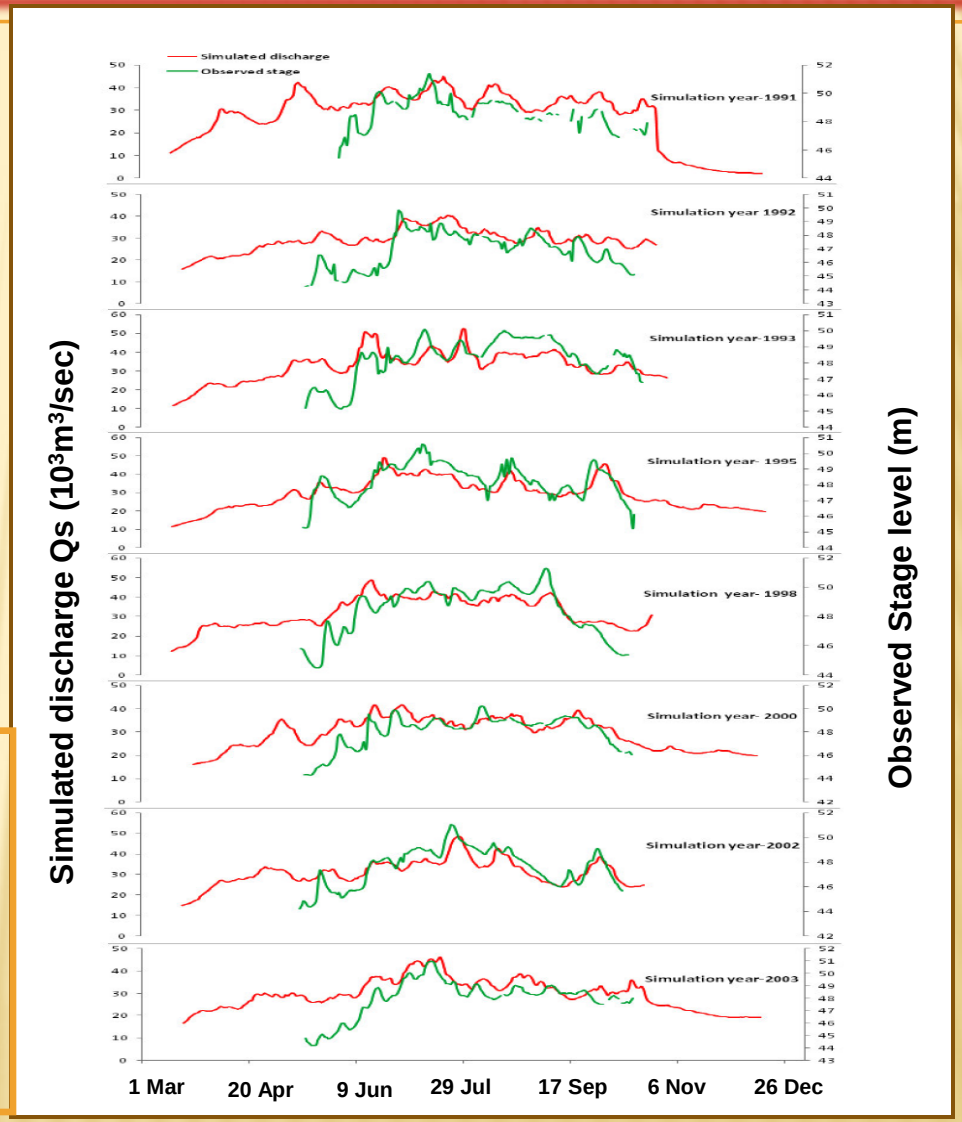


Performance of the Model for Predicting Flow variation in Brahmaputra*



Index map showing gauging stations

- Two gauging stations - Tezpur, Guwahati
- 25 years period from 1978 to 2003
- Eight wet years of highest flood lift (Karmaker and Dutta, 2010).



* Shyamal Ghosh, Subashisa Dutta (2012). "Impact of climate change on flood characteristics in Brahmaputra basin using a macro-scale distributed hydrological model". Journal of Earth System Science, Vol. 121, No. 3, 637.

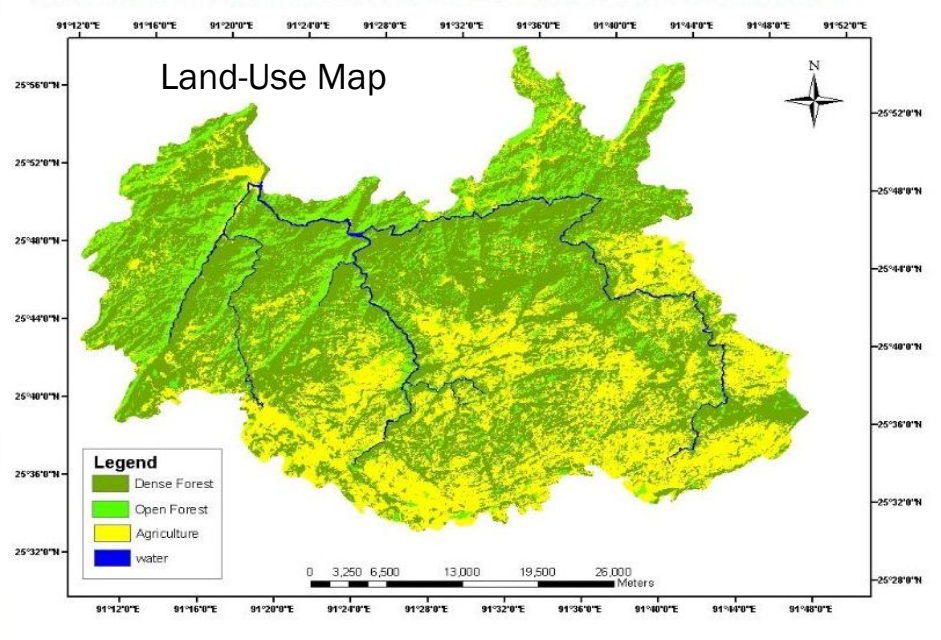
INPUT DATA AND PARAMETERS OF THE MODEL

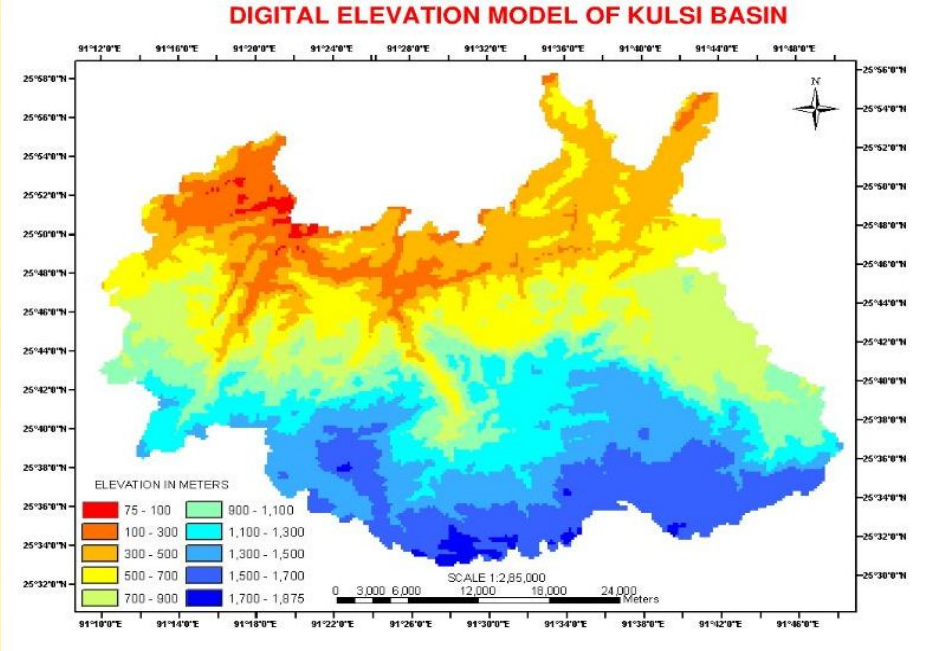
Parameter/ Data type	Name	Source
Static	Topography and Basin Characteristics	SRTM
	Soil type distribution	NBSS&LUP, India
	Soil parameters	NBSS&LUP, India
	Land use classes	ETM Imagery (Classified)
	Average surface storage in paddy field (h)	Calibration parameter
	Degree of impermeability of hardpan formation (r)	Calibration parameter
	Minimum storing depth in macropores (S_{max})	Calibration parameter
Dynamic	Exponential transmissivity decay function (m)	Calibration parameter
	Natural logarithm of transmissivity of just saturated soil profile ($\ln T_0$)	Calibration parameter
	Initial saturated topographic index (TI)	SRTM
	Variable advection, diffusion constants (a, b, α ,β)	Computed model parameters
Time Series	Daily observed stage data	Water Resources Department, Assam
	Rainfall distribution	Aprohdite

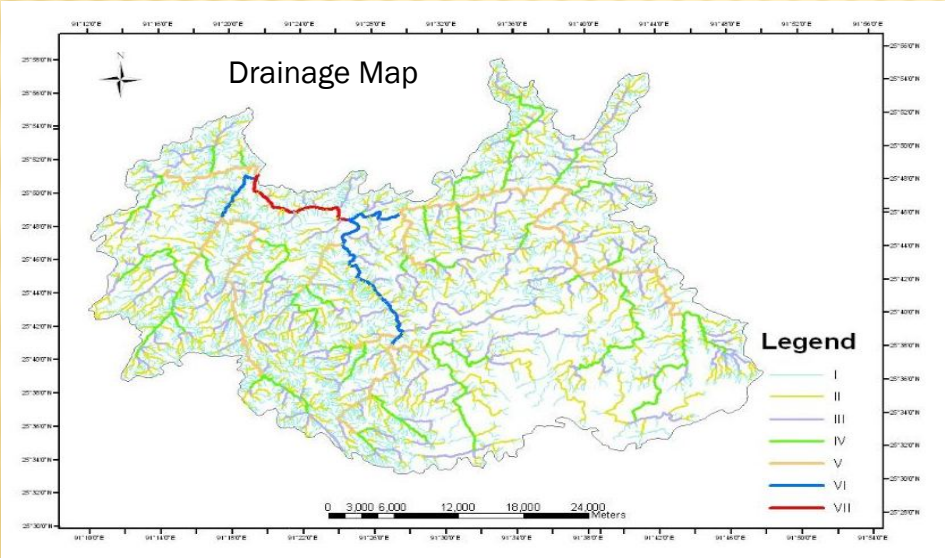
Study watershed: Kulsi river, Southern Tributary of Brahmaputra river

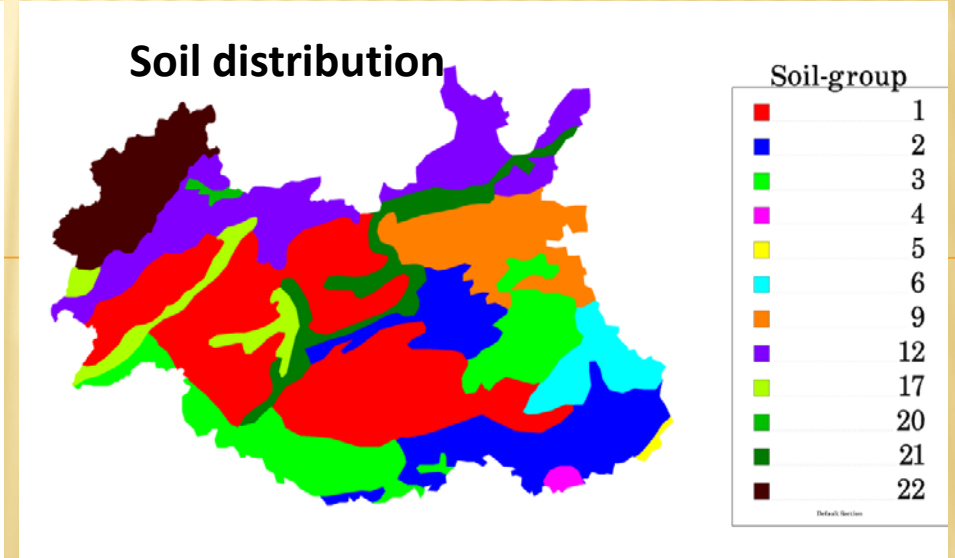
- the Kulsi watershed in the state of Meghalaya, India, a part of the Brahmaputra basin
- originates from the West Khasi hills and flows north, finally joining the Brahmaputra River.
- The catchment area : 1660 km square
- mostly hilly terrain, the average altitude and slope is 1400m above msl and 39.22 % respectively.
- **Humid, sub-tropical and monsoonal climate zone receiving high monsoonal rainfall**.
- The average annual rainfall : about 2395 mm.
- Under saturated condition, such a formation is highly conducive to rapid subsurface storm flow.
- The land use /land cover: Evergreen forest, semi-evergreen forest, moist-deciduous forest, bamboo-thickets, Jhum and rolling grasslands.

Geospatial dataset : Kulsi Catchment



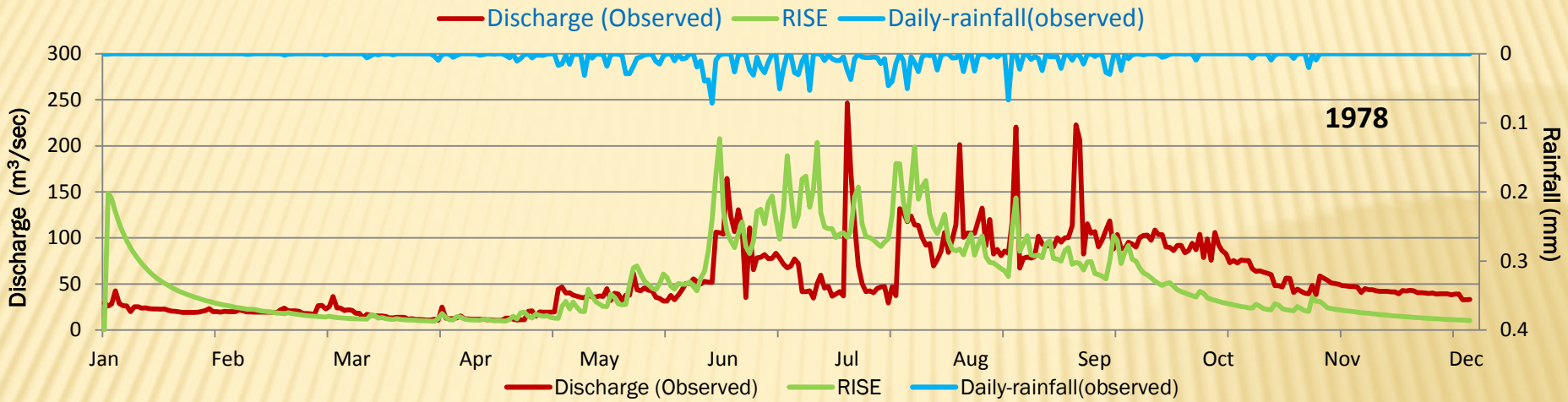


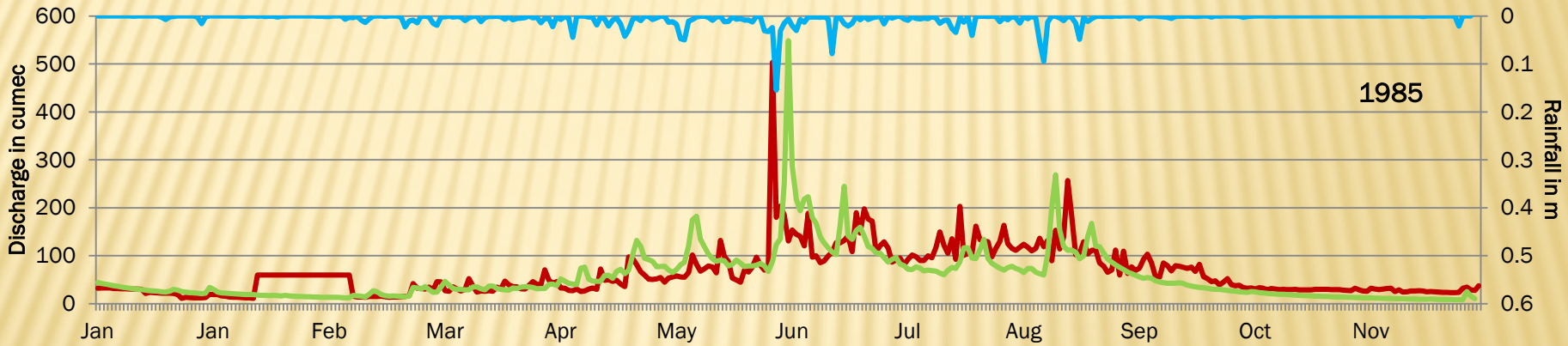




Model Calibration and Validation

(Pre-soil water conservation measures: Before 1985)

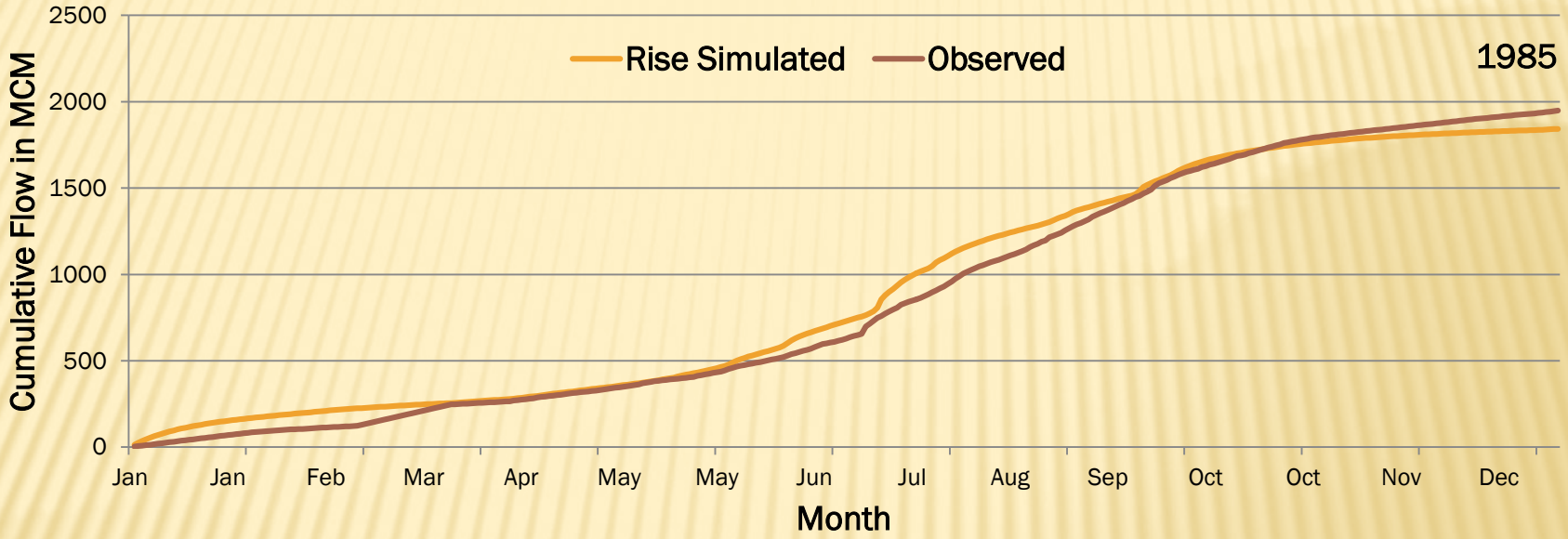




Peak Observed Discharge: 246, Peak Simulated Discharge: 210, Performance Index: 0.03

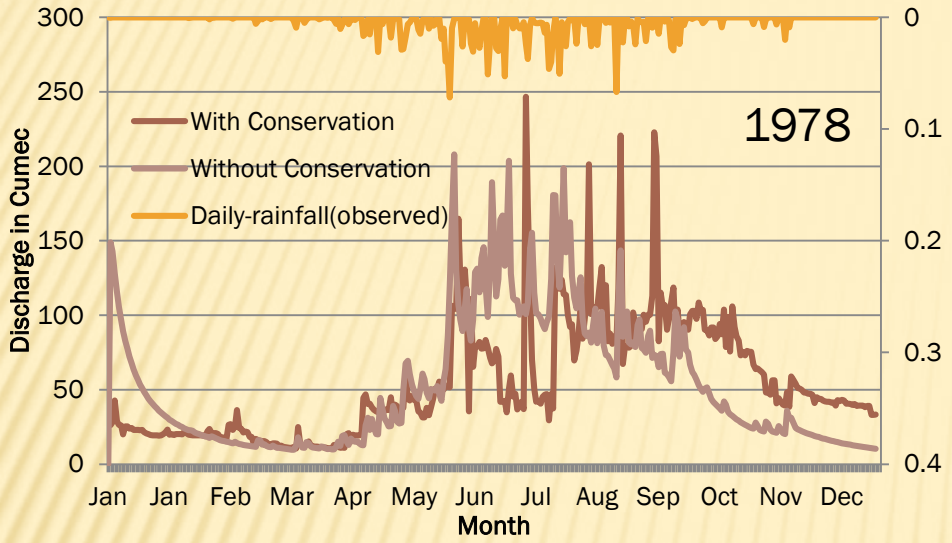
Calibration parameters	Calibrated value	Range
Average surface storage in paddy field (h_{ret})	0.3 m	0-0.5 m
Degree of impermeability of hardpan formation (r)	1000	700-2000
Maximum storing depth in macropores (S_{max})	0.1 m	0.03-0.9 m
Exponential transmissivity decay function (m)	0.035	0.002-0.05
Natural logarithm of transmissivity of just saturated soil (lnT_0)	0.01	0-1.6

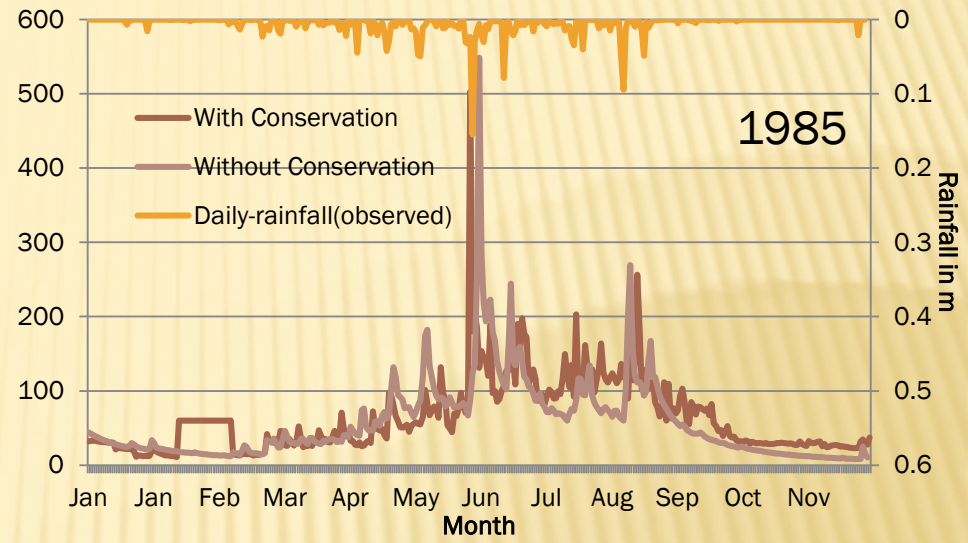
Mass curve analysis for Cumulative Flow during Pre-Conservation Period

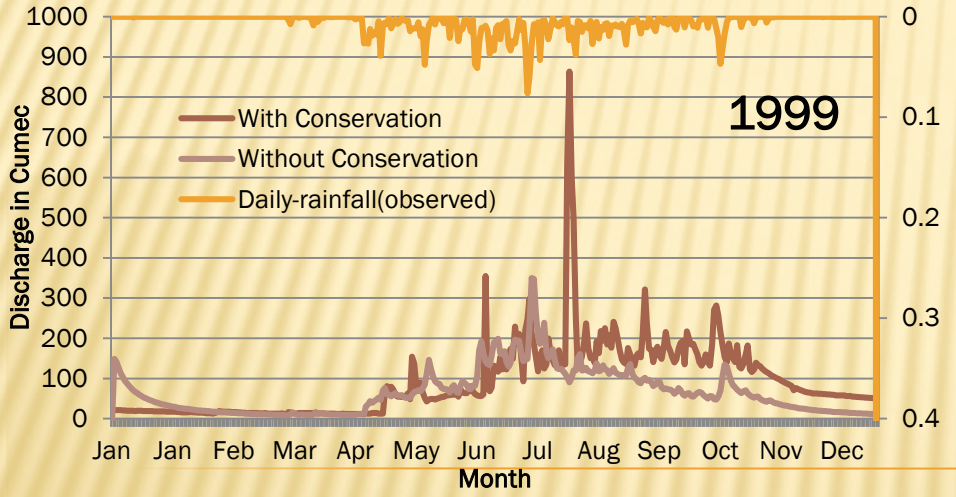


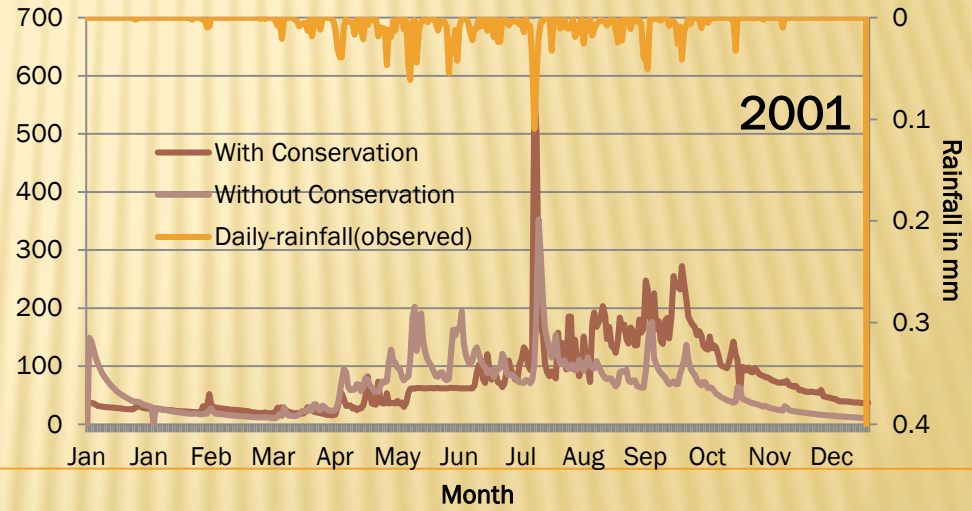
No Significant deviation between observed and simulated cumulative flow

Effect on Flashiness Behavior due to Conservation Structures







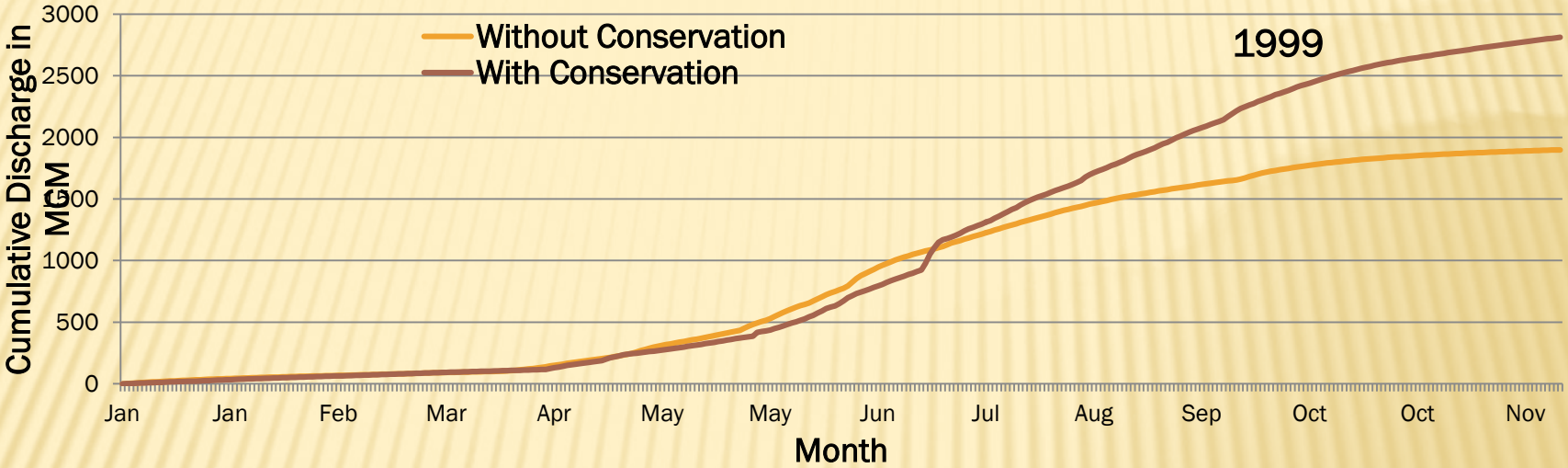


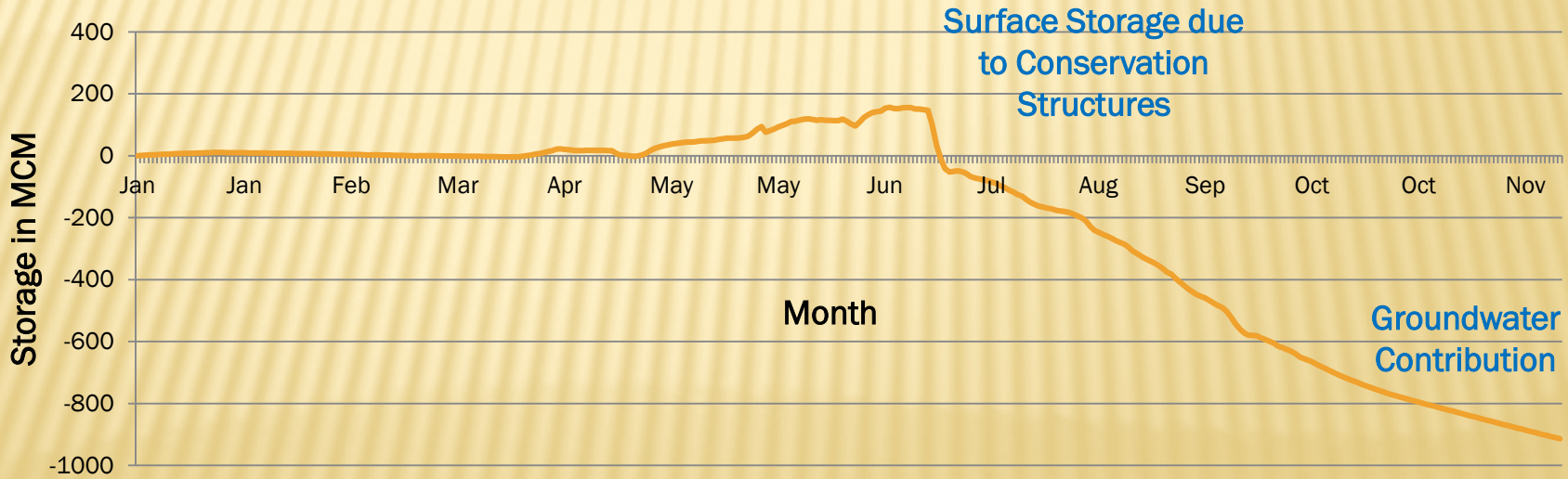
Period	Year	Peak Discharge	Peak Discharge
Pre-Conservation Period	1978	250	225
	1985	425	550

Period	Year	Peak Discharge Without Conservation	Peak Discharge With Conservation
Post-Conservation Period	1999	**450`**	**850**
	2001	**400**	**600**

Mass curve analysis :Cumulative Flow during Post-Conservation Period

Total Rainfall: 2100 mm

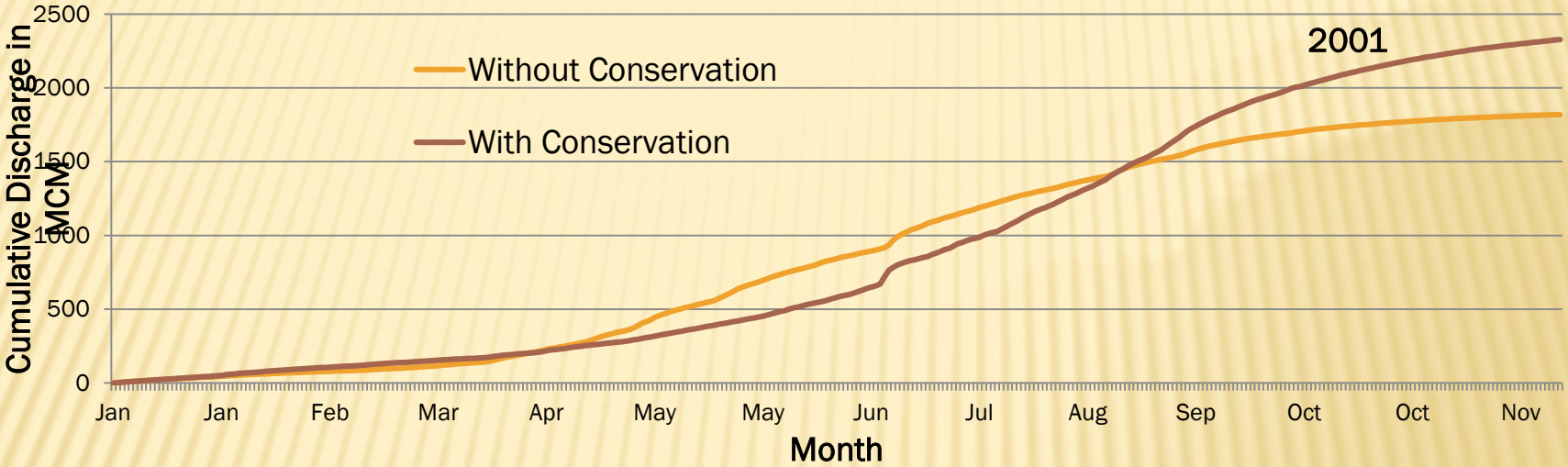


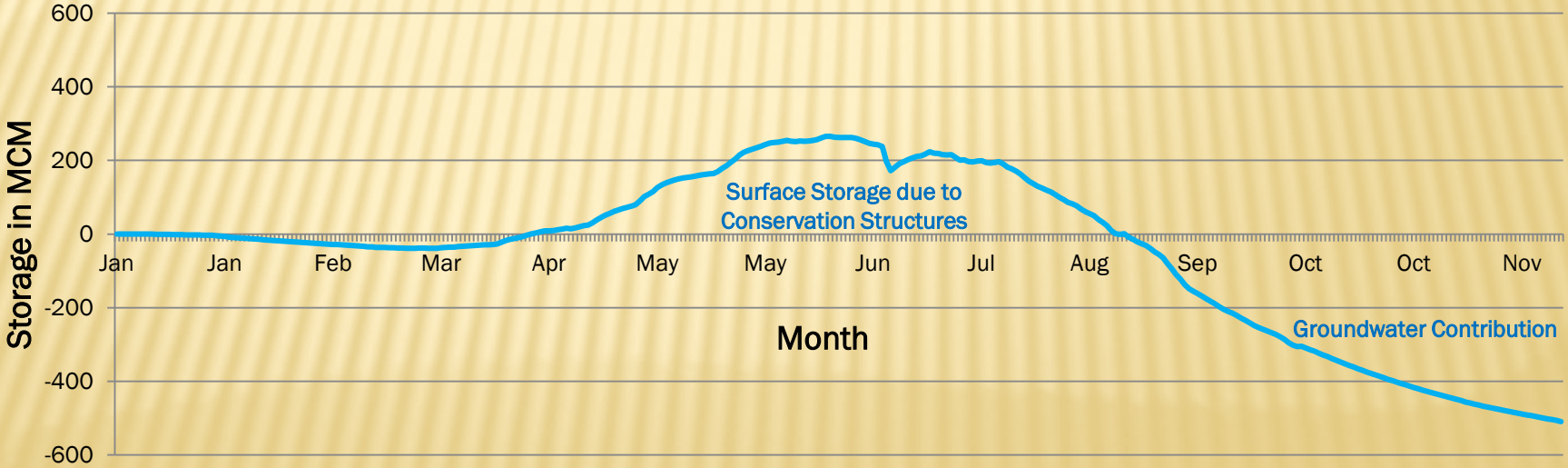


Lumped Storage by Conservation Structures: 156 MCM (about 5% of Total Flow)
Groundwater Recharge : 913 MCM (about 30% of Total Flow)

Mass curve analysis :Cumulative Flow during Post-Conservation Period

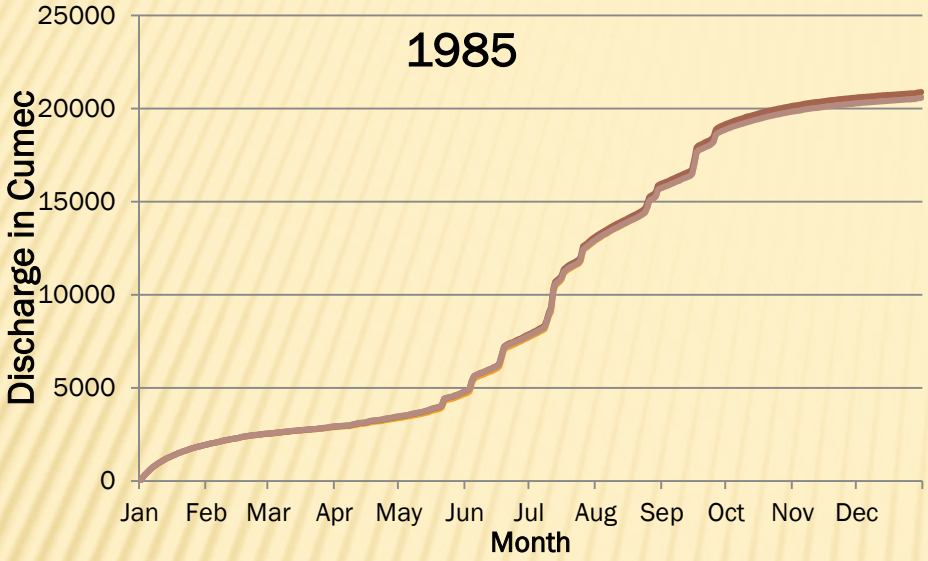
Total Rainfall: 2000 mm

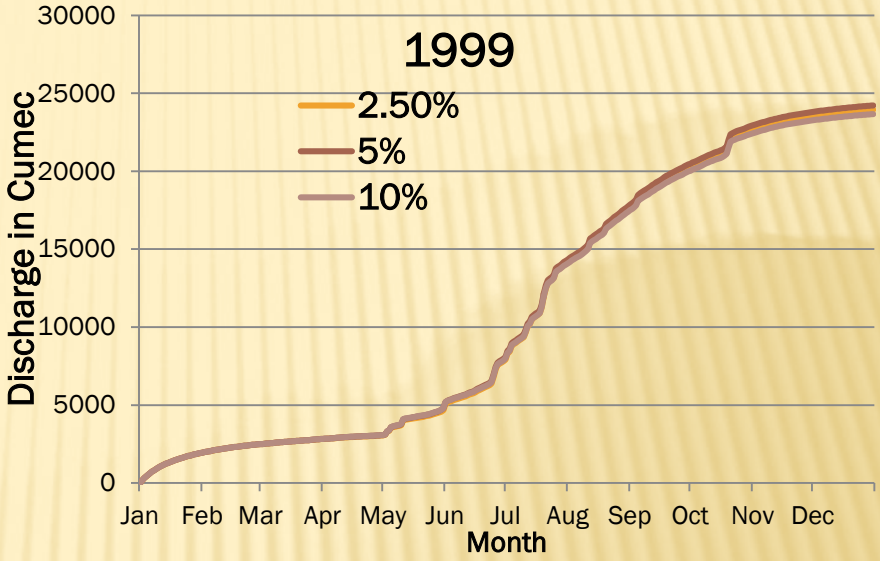


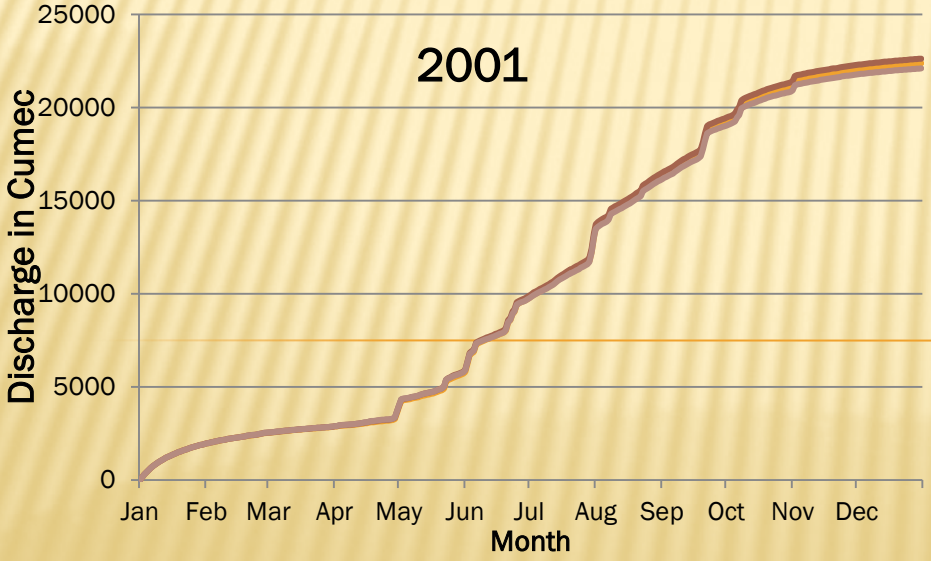


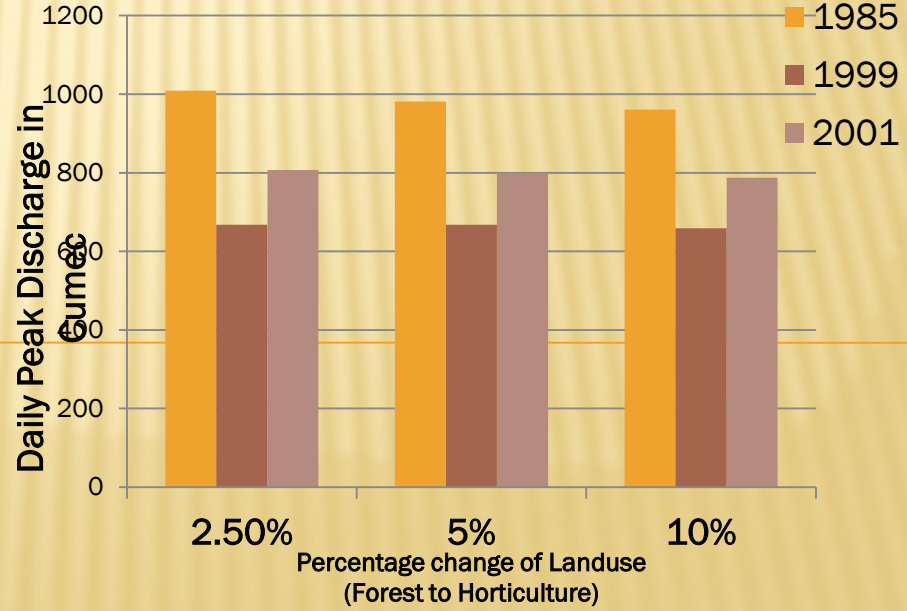
Lumped Storage by Conservation Structures: 265 MCM (about 10% of Total Flow)
Groundwater Recharge : 509 MCM (about 20% of Total Flow)

Evaluation of Land-use Change (Forest to Horticulture)









CONCLUSIONS

- *With limited hydrological input dataset, a semi-distributed hydrological is able to predict the hydrological response of agro-forestry watersheds*

- *Change in hydrological response due to water harvesting structures: less flow during early monsoon period, lumped storage varies year to year, significant increase in dry month flow, however, flashiness increased by 2 times*

- *Hydrological impact of land use change: no significant change in both cumulative flow and flashiness*

- *Long -period hydrological database can help to quantify the hydrologic response with its temporal component.*

THANK YOU A LOT