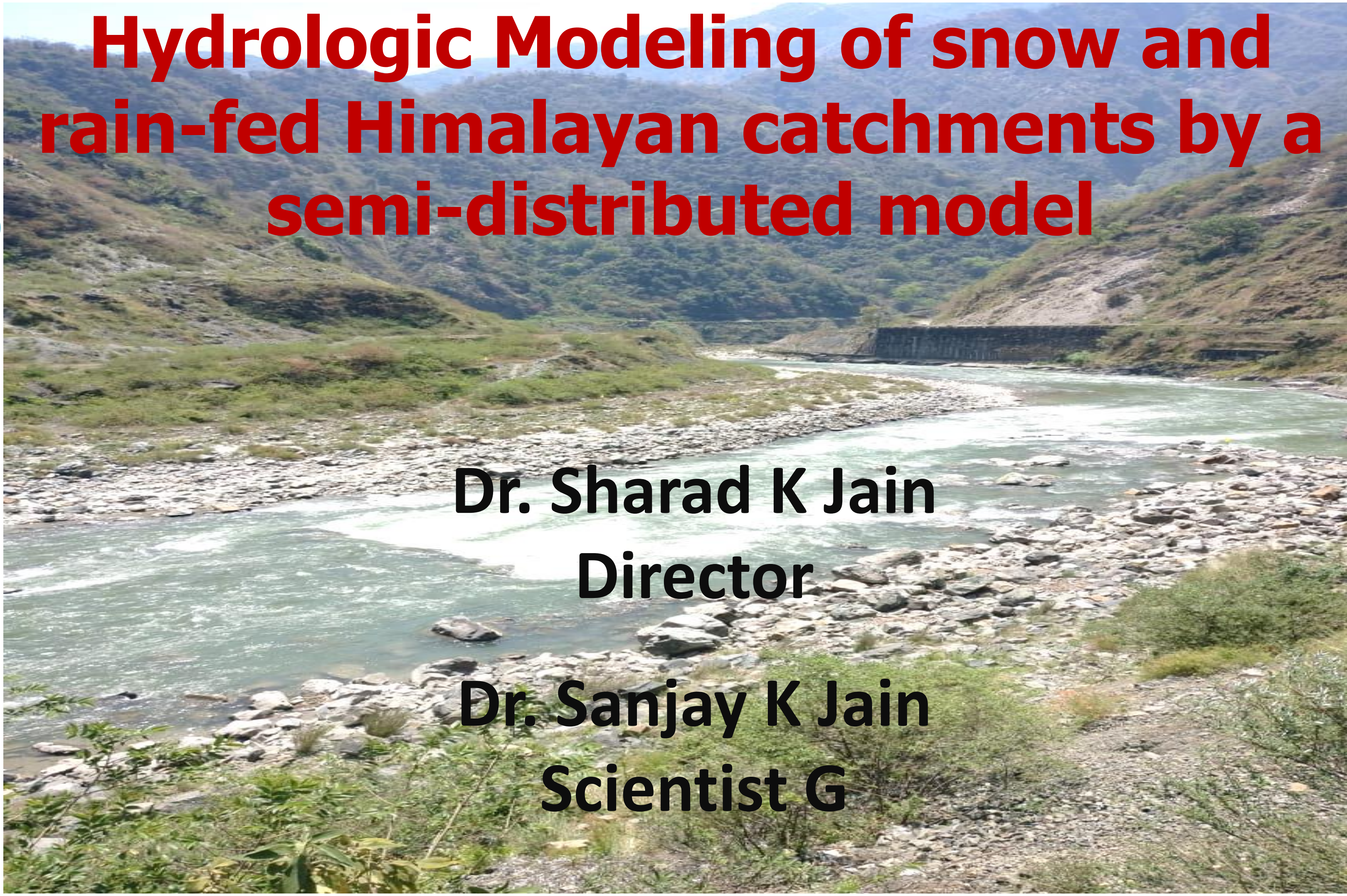
Hydrologic Modeling of snow and rain-fed Himalayan catchments by a semi-distributed model



Dr. Sharad K Jain
Director

Dr. Sanjay K Jain
Scientist G

NATIONAL INSTITUTE OF HYDROLOGY
ROORKEE

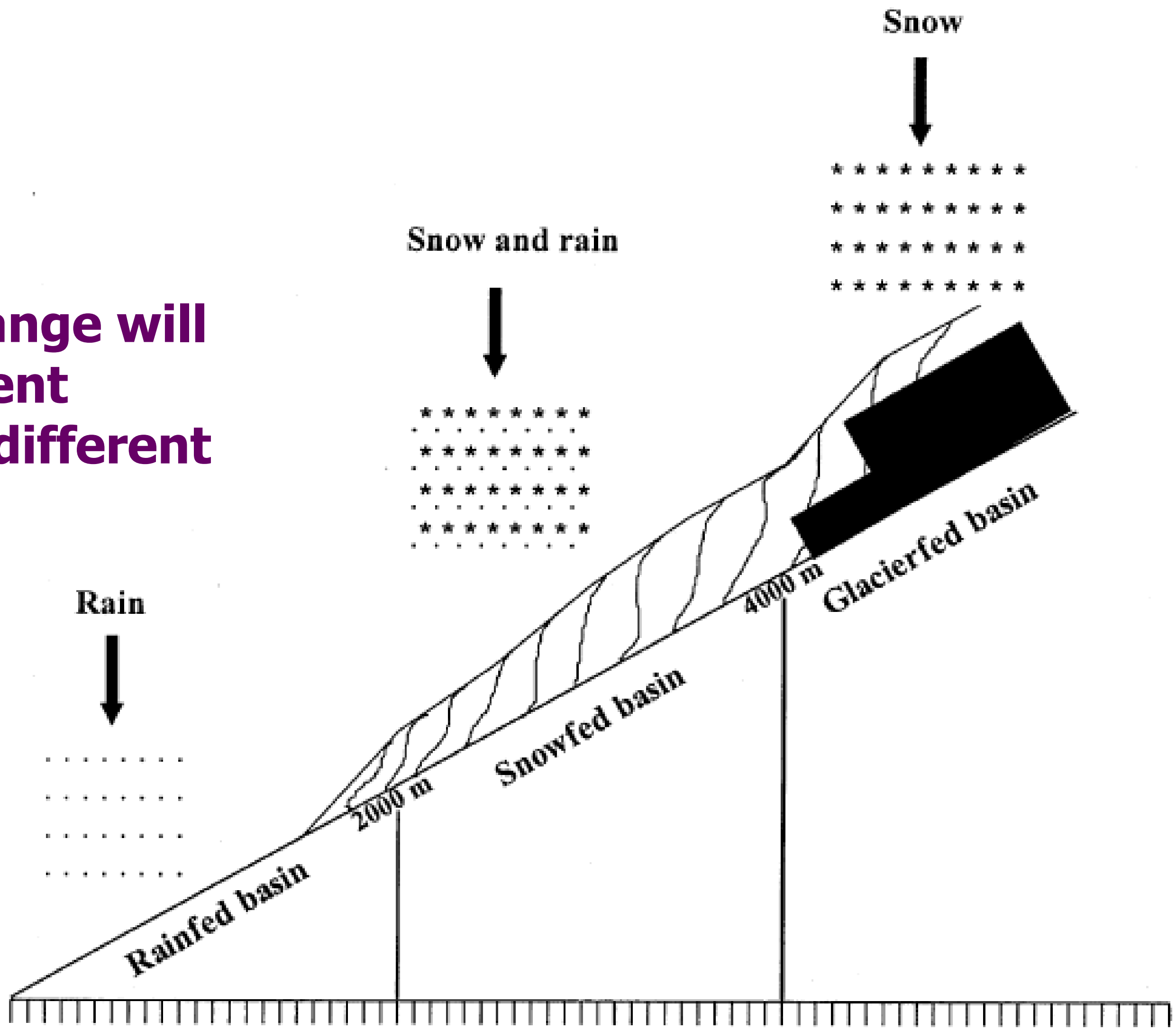
New Delhi, 25 April 2019

Himalaya Mountains

- Himalayas are "Water towers".
- Source of many major rivers – Indus, Ganga, Brahmputra, Yangtse, Amu Darya, Mekong …
- Flow is contributed by snow/glacier melt as well as rainfall.
- Large hydropower and irrigation potential.
- Large disaster risk – flash floods, floods, water scarcity.
- Helpful to understand hydrologic response mechanism.
- Develop ability to predict /forecast flows by using a hydrologic/statistical model.

A Typical Himalayan Watershed

Climate change will have different impacts at different elevations



SNOWMELT RUNOFF MODELLING APPROACHES

Model Approach	Input Parameters	Output	Remarks
Temperature Index method	Air Temperature, Precipitation, Snow covered area. Rainfall runoff coefficient, Critical Temperature, Temperature lapse rate, Time lag	Daily stream flow, Seasonal volume of runoff	Does not consider spatial variability of physical processes for model input and calibration. Can be applied with limited amount of available observed data set.
Energy Balance Method	Air temperature, Radiation (SW, LW), Precipitation, Wind speed, Relative Humidity, Snow surface temperature, Albedo, Snow cover area, Cloud cover, Pressure, Elevation.	Snow melt depth, evaporation	Requires large amount of input data for model simulations

SWAT (Soil & Water Assessment Tool) Model

- SWAT is a spatially distributed, continuous time, watershed scale model.
- It was developed to predict the impact of land management practices on water, sediment and agricultural chemical.
- Weather, soil properties, topography, vegetation and land management practices are the most important inputs for SWAT to model hydrologic and water quality in a watershed.

Uncertainties in Hydrologic Modeling

- **Natural uncertainties: associated with random temporal and spatial fluctuations inherent in natural processes.**
- **Model structure uncertainty**
- **Model parameter uncertainties: due to use of inadequate parameter estimation technique, inaccurate data used, or both.**
- **Data uncertainties due to: (i) measurement inaccuracy and errors, (ii) inadequacy of gaging network, and (iii) data handling errors.**
- **Computational uncertainties: due to incorrect algorithm, truncation and rounding off errors.**

Uncertainty in Hydrologic Modeling - SWAT CUP (Sufi-2 Algorithm)

- **Operational uncertainties: associated with construction, manufacturing, maintenance, and human factors.**

- **Important to account for uncertainties.**
- **Sequential Uncertainty Fitting (SUFI2) algorithm developed by Abbaspour et al. (2004; 2007) is a multi-site, semi-automated global search procedure for model calibration and uncertainty analysis.**
- **All sources of uncertainties are accounted for in SUFI2.**

Model Input

- **Spatial input data for SWAT model include**
  - **Digital Elevation Model (DEM)**
  - **Land use/ cover map**
  - **Soil layers**

- **DEM can be utilized to delineate basin and subbasin boundaries, calculate subbasin areas, and delineate stream network.**

- **Land use, soil and slope layers are used to create and define Hydrological response units (HRU's).**

Meteorological Data

Weather data used for modelling include

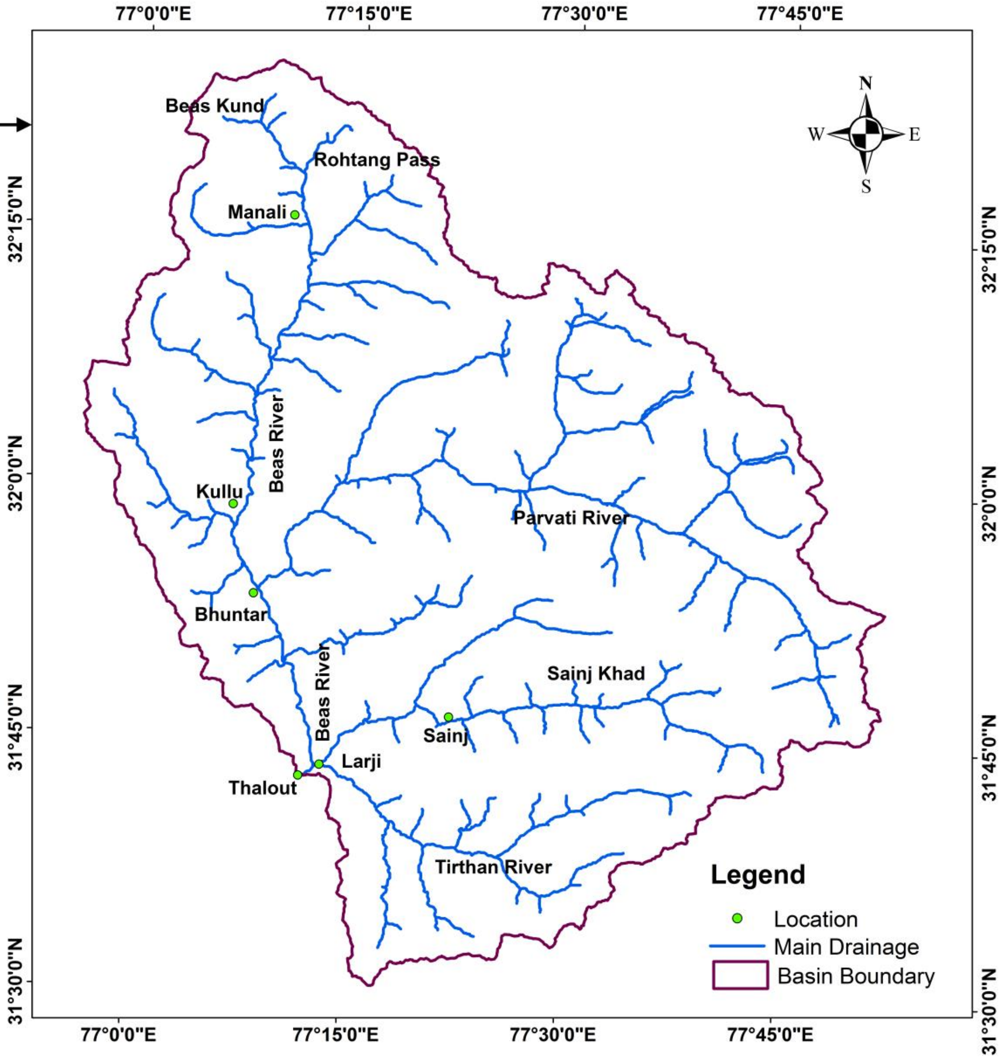
- Precipitation
- Temperature – maximum and minimum
- Solar radiation
- Wind speed
- Relative Humidity

STUDY AREAS AND DATA USED

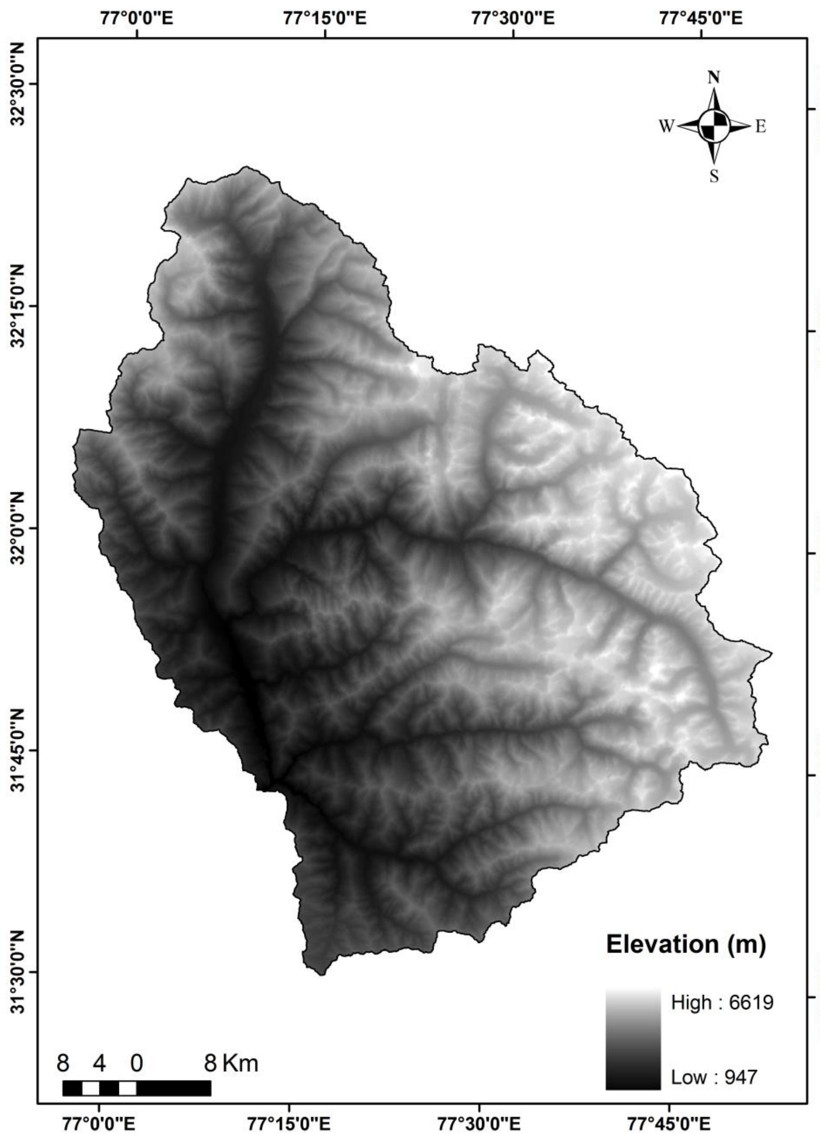
Beas River basin up to Thalout site and Ganga Basin up to Devprayag

- **Beas, a tributary of Indus River, takes off from Rothang Pass (Himachal Pradesh) at elevation 3900m.**
- **Major tributaries of Beas River u/s of Thalout: Parvati, Tirthan, Sainj, and Sabari Nala.**
- **Basin is located between latitudes 31° 30′ to 32° 25′ North and longitudes 76° 50′ to 78° East,**
- **CA is about 4866 km^2, elevation from 947 to 6619 m.**
- **Extensive portion of basin comes under snow in winters; Beas River is mainly fed by snowmelt in summers.**
- **Beas basin was delineated from ASTER DEM.**
- **Landuse/cover map was generated from Resourcesat-1 LISS III imagery (4 spectral bands), downloaded from BHUVAN portal (*www.bhuvan.nrsc.gov.in)* of ISRO.**

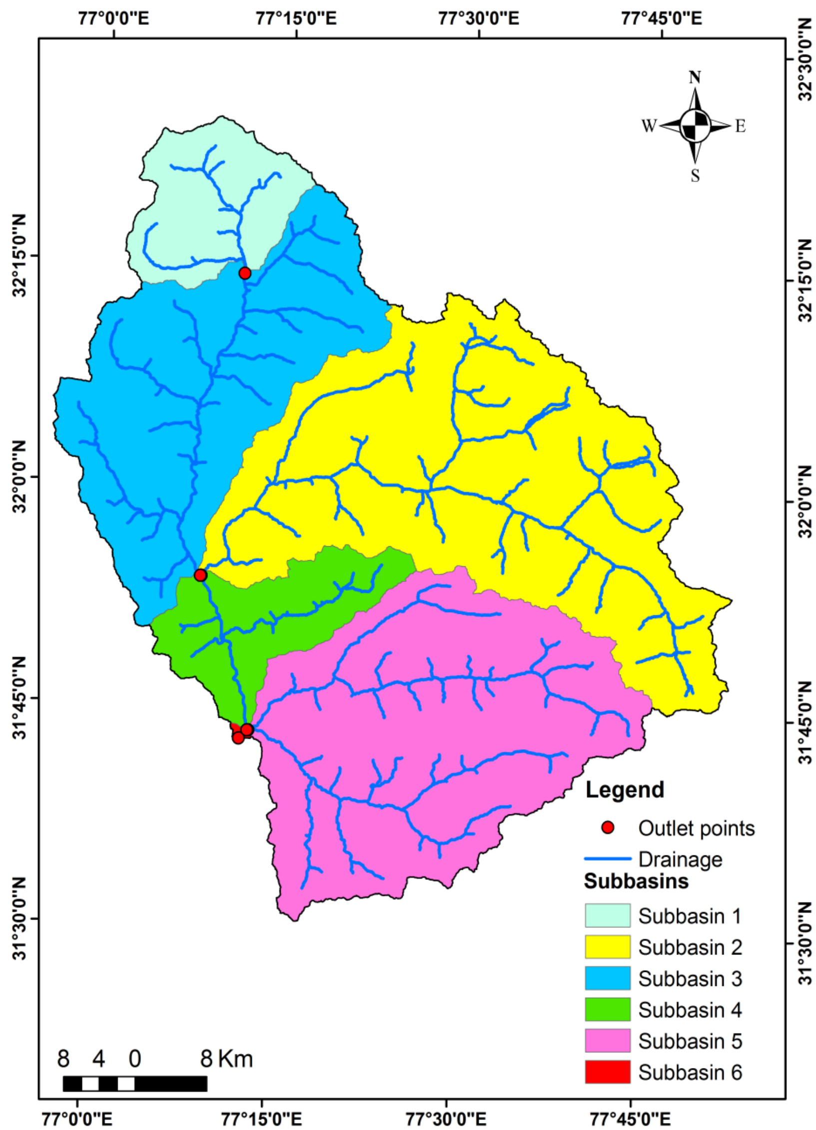
Index map of Beas Basin



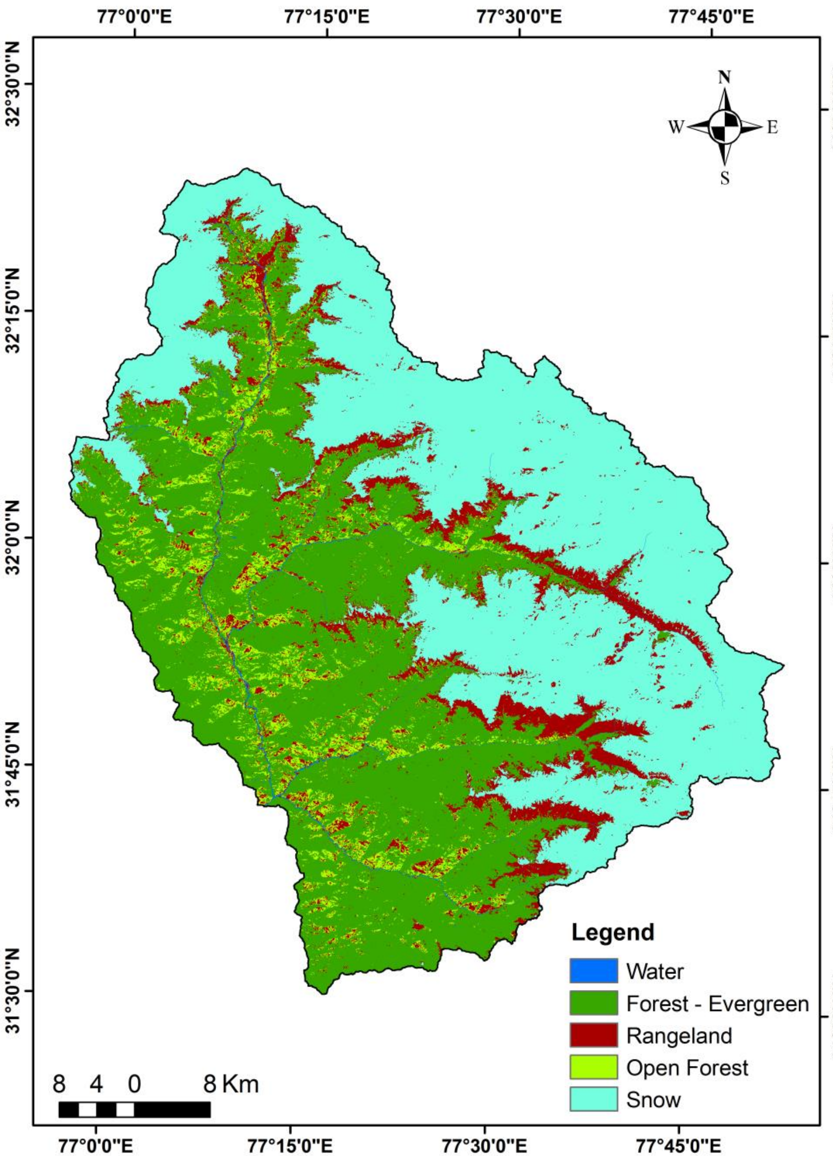
DEM of Beas Basin



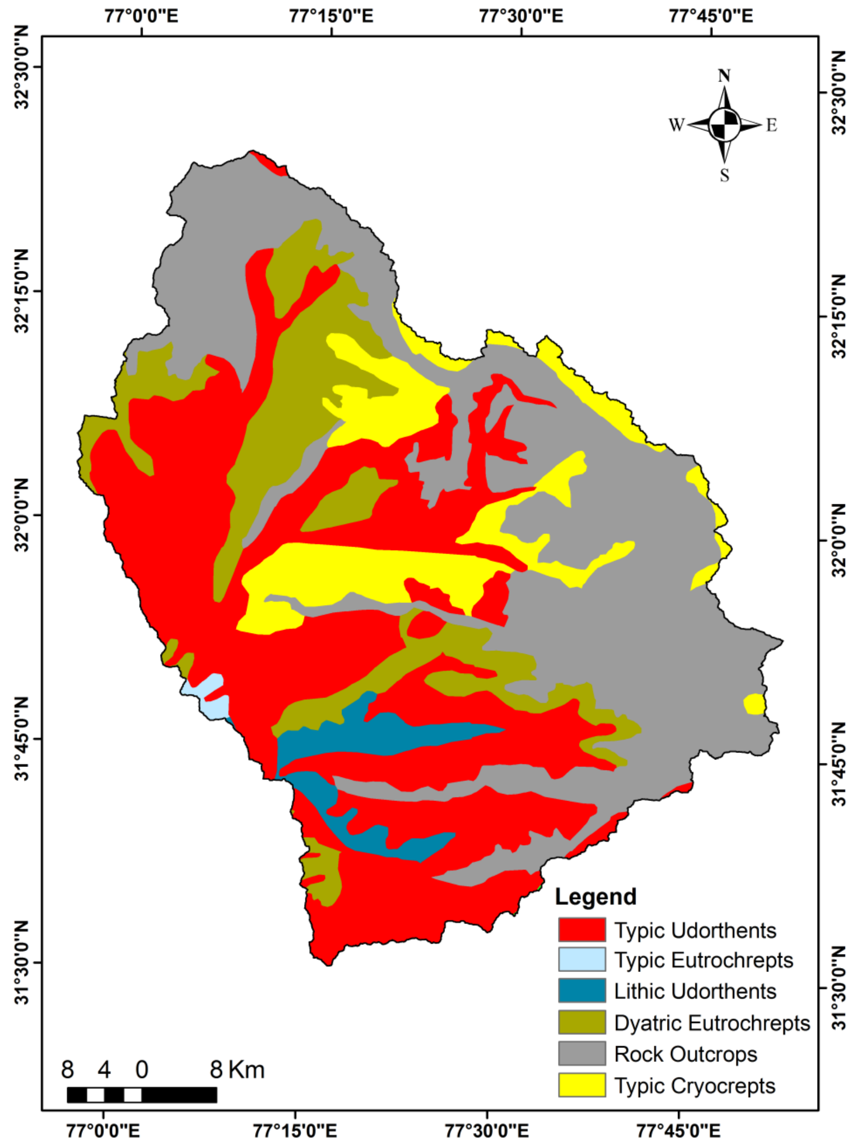
Subbasins of Beas Basin



LULC map of Beas basin



Soil map of Beas basin



Beas River basin (Contd.)

- **Soils map was digitized from map of NBSS&LUP.**
- **All spatial data processed at 30 m resolution.**
- **Time series (1990-2005) of daily RF, Min and Max Temp, solar radiation, RH and wind speed data for subbasins were used.**
- **RF, temp and RH were obtained from BBMB, India.**
- **Solar radiation and wind speed data were downloaded from http://globalweather.tamu.edu/.**
- **Daily flow data (1990-2005) for Thalout gauging station was obtained from BBMB.**

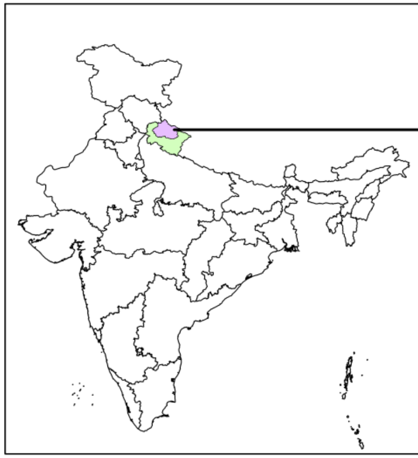
Upper Ganga Basin

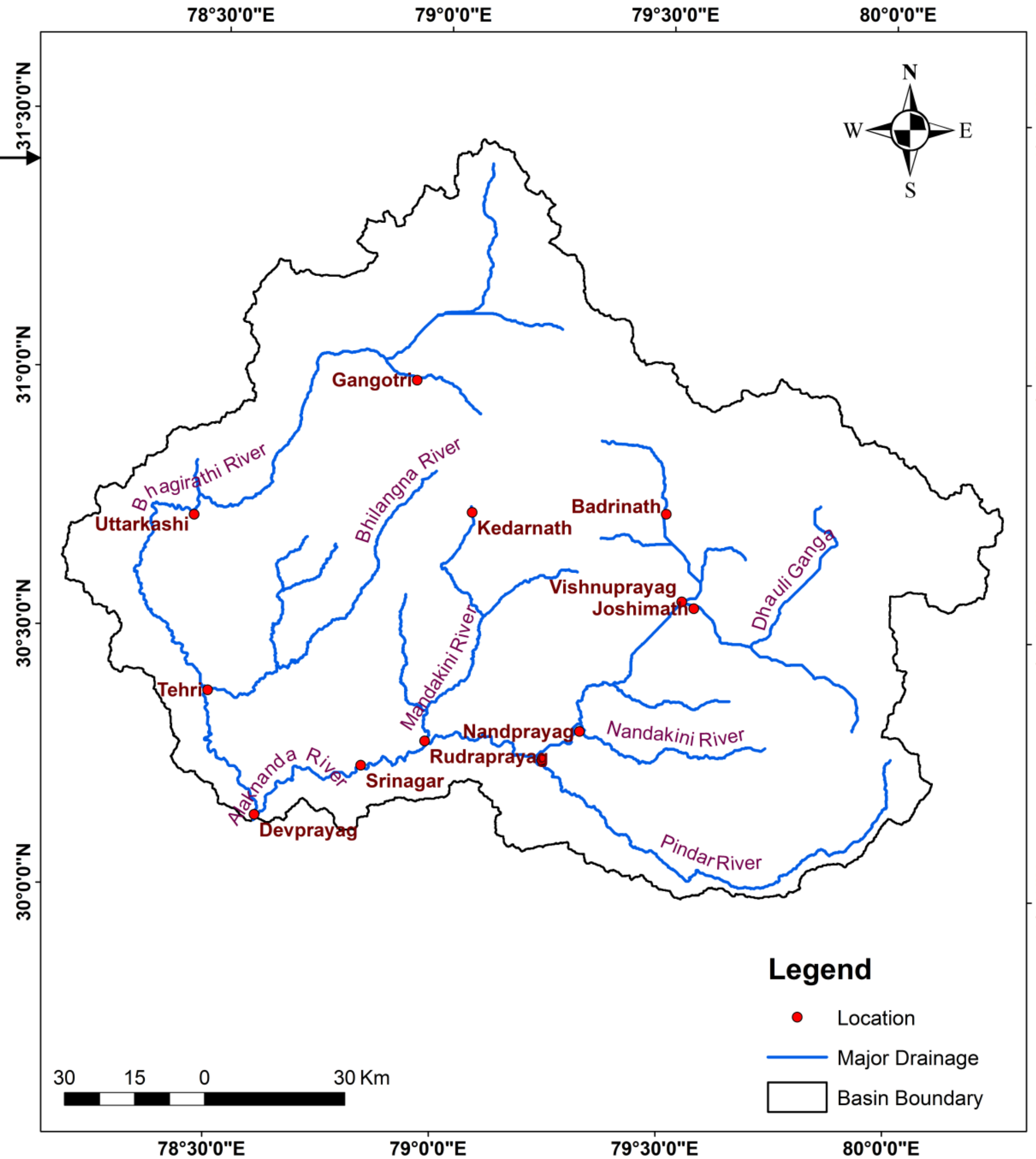
- Bhagirathi and Alaknanda Rivers join at Devprayag to form Ganga.
- Bhagirathi River originates from snout of Gangotri Glacier at Gomukh (3900 m), flows for 217 km to reach Devprayag.
- Alaknanda River rises at confluence and foot of Satopanth and Bhairath Kharak Glaciers, flows for 224 km and meets Bhagirathi at Devprayag.
- Catchment area up to Devprayag = 18728 km2,
- Elevation varies from 427 m to 7785 m.
- Average RF in basin varies between 1000 to 2500 mm, 70-80% falls during June and September.

Upper Ganga Basin (Contd.)

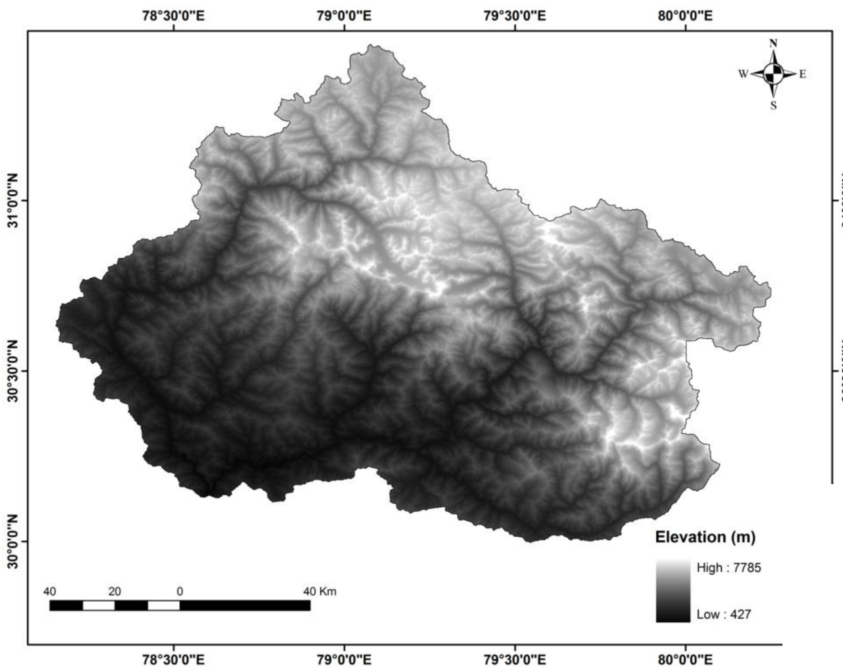
- Time series (1990-2005) of daily precipitation, min/ max temp, solar radiation and wind speed measured at 7 stations were used.
- Precipitation data from Asian Precipitation - Highly-Resolved Observational Data Integration Towards Evaluation of Water Resources (APHRODITE's Water Resources) were used.
- APHRODITE's is state-of-the-art daily ppt datasets with high-resolution grids for Asia, created primarily with data obtained from ground-based observation network (http://www.chikyu.ac.jp/precip/).
- APHRODITE grid data of 0.25°×0.25° were used.
- Daily stream flow data were collected from CWC gauging stations.

Index map of Upper Ganga Basin

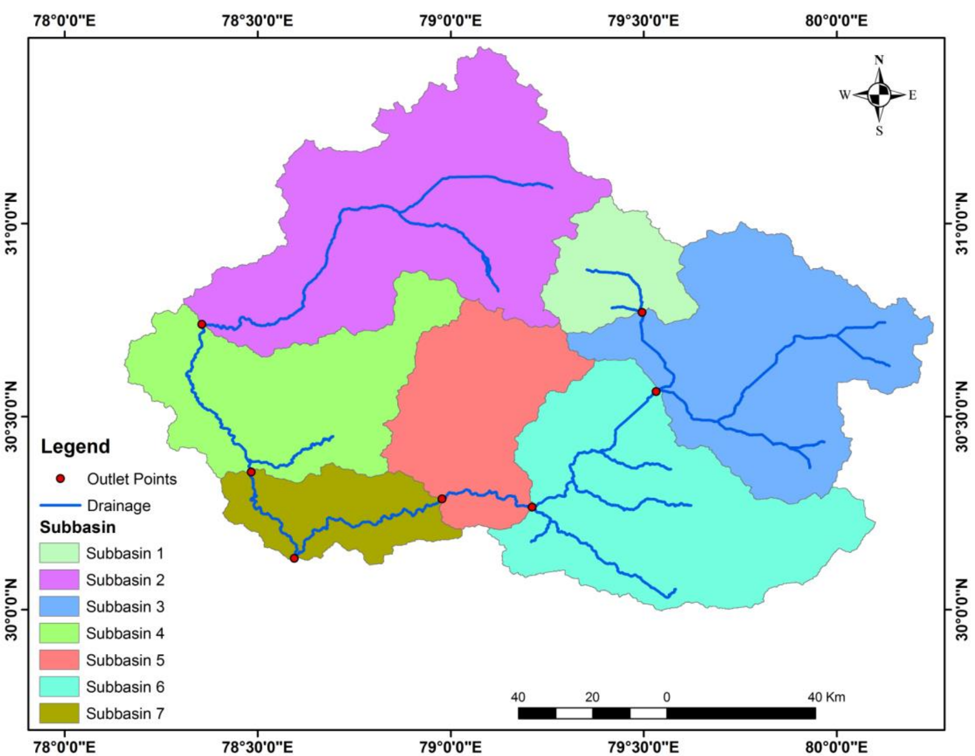




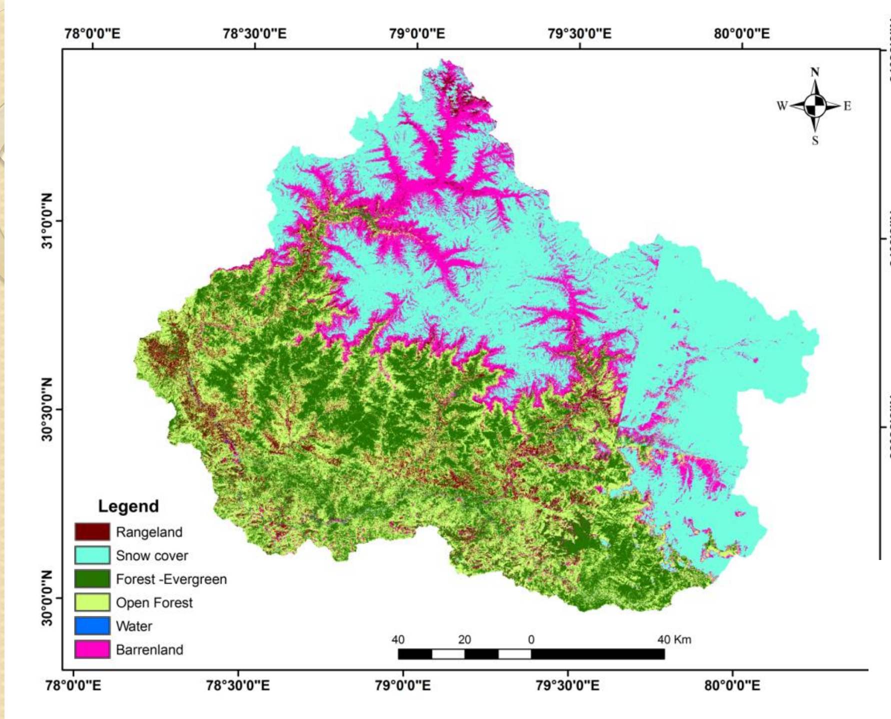
DEM of Upper Ganga Basin



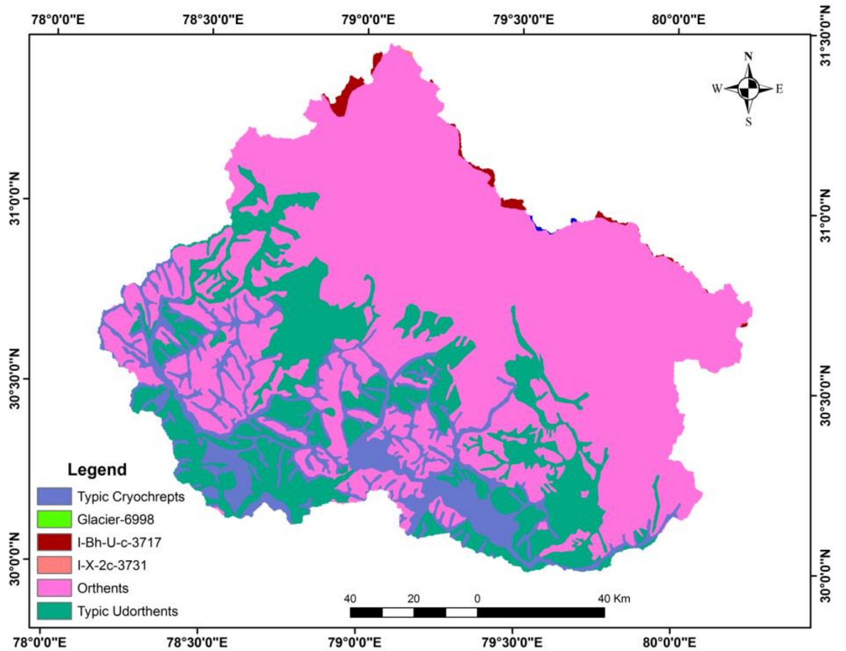
Subbasins of Upper Ganga Basin



LULC map of Ganga Basin



Soil map of Ganga Basin



Model Set Up

- River network for Beas and Upper Ganga Basin were delineated from ASTER DEM by using the ArcSWAT 2009 GIS interface.
- To obtain a reasonable numbers of HRUs, a combination of landuse and soil (thresholds of 10% in LULC and soil type) were used.
- Beas basin was divided into 6 sub-basins and 97 HRUs; UGB into 7 sub-basins and 126 HRUs.
- Observed daily stream flow data from 1990 to 1998 were used for calibration; data from the year 1999 to 2005 for validation.
- Data for first two years (1990-91) were reserved as “warm-up” period. Model calibration statistics computed for 1992-98.

Model Set Up (Contd.)

- SWAT has a large number of parameters to describe different hydrological conditions and features across the basin.
- To evaluate model performance, computed hydrographs were compared with observed.
- Statistical performance measures of hydrological models are computed to determine how the values simulated by the model match with those observed.
- Statistical criteria used to evaluate model performance were the goodness-of-fit (R^2), the Nash-Sutcliffe efficiency index (NSE) and coefficient of regression line multiplied by the coefficient of determination (bR^2).
- Model performance is considered to be better as R^2 and NSE approach unity.
- Streamflow data for Ganga basin is classified. Hence, scaled flow values have been shown.

RESULTS AND DISCUSSIONS

- **SUFI-2 optimization software was used to calibrate, validate, and perform uncertainty analysis based on measured river discharge.**
- **Parameter sensitivities were determined by using multiple regression system that regresses Latin Hypercube generated parameters against objective function values.**
- **Nineteen calibrated parameters including 9 snowmelt related parameters were used for global sensitivity analysis.**
- **Three parameters, viz. Snow temperature lag TIMP, snowmelt base temperature SMTMP and minimum temperature index melt factor SMFMN were found to be important.**

RESULTS AND DISCUSSIONS (Contd.)

- **Parameter ranges are expectedly different for two catchments.**
- **Curve numbers for both catchments is nearly same.**
- **Beas catchment: snow related parameters such as Tlapse and Plapse, snowfall temperature and snowmelt base temp do not vary much.**
- **SNO50COV (fraction of snow volume represented by SNOCOVMX) that corresponds to 50% snow cover is high; snow cover area and snowmelt contribution is more.**
- **Range of Sol_AWC and Sol_K parameters (related with available soil water content) are different and their values are high for Ganga catchment.**

RESULTS AND DISCUSSIONS (Contd.)

- **Ganga: ET values are higher for Ganga.**
- **Ground water related parameters (Alpha_BF and GW_Delay) are more for Ganga basin than Beas -- these parameters control water exchange between stream and ground water evaporation.**
- **Revapmn and GW_revap were not very much sensitive for these basins.**
- **As soil evaporation compensation factor (ESCO) values is reduced, SWAT extracts more water for evaporation from deeper levels. ESCO is low for Beas – this is seen in low ET values from this catchment.**

Modeling Results

Beas Basin

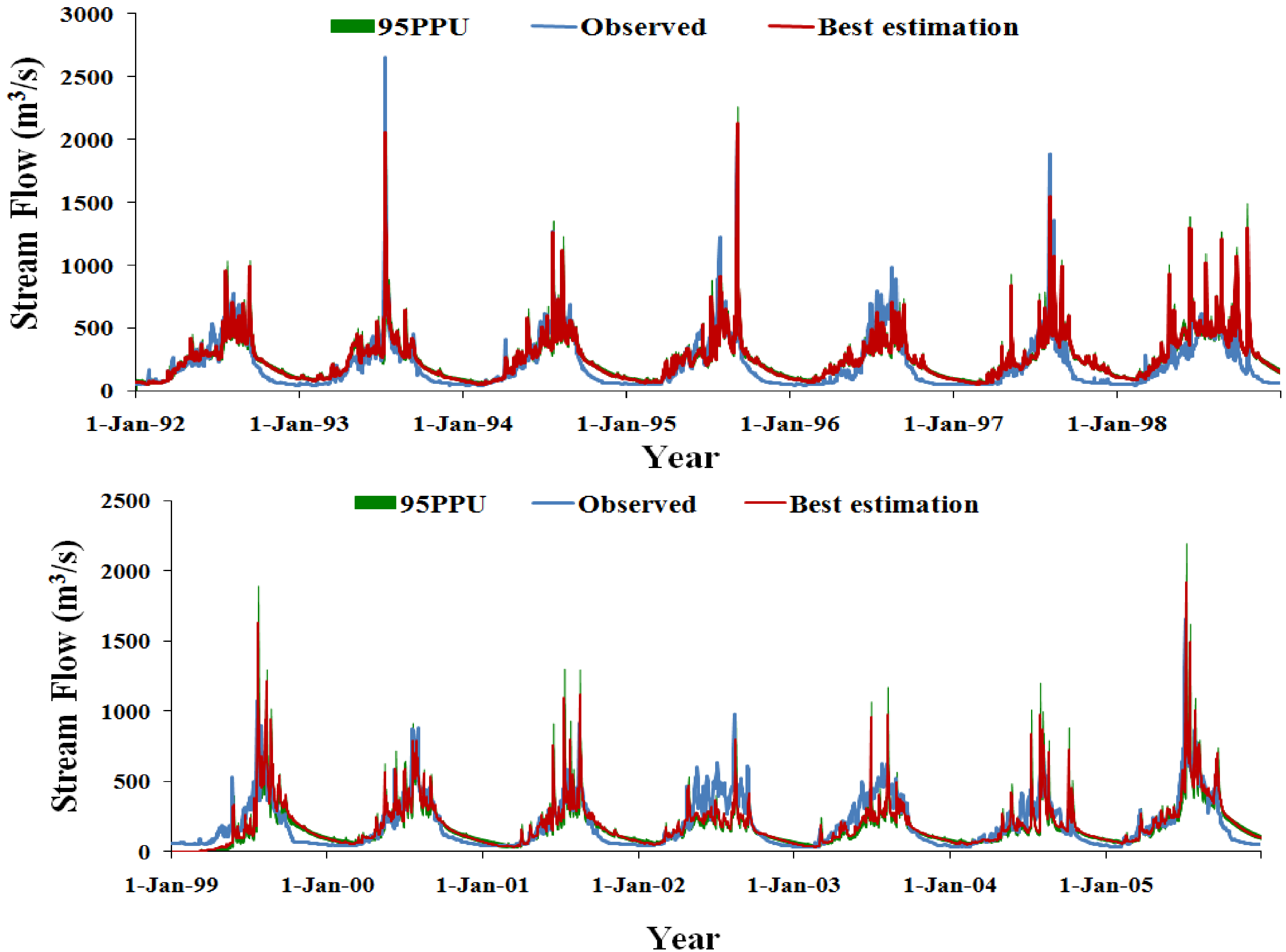
- COD and NSE were (0.75 / 0.71) and (0.70 /0.70) for cal and val.

Ganga Basin

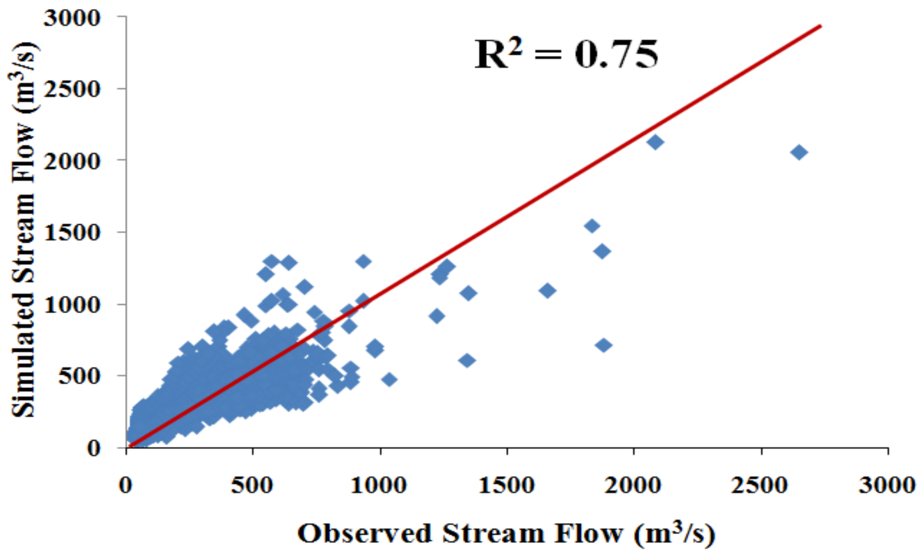
- COD (R^2) was 0.84 for Cal. 0.72 for val. NSE for cal and val was 0.84 and 0.65.

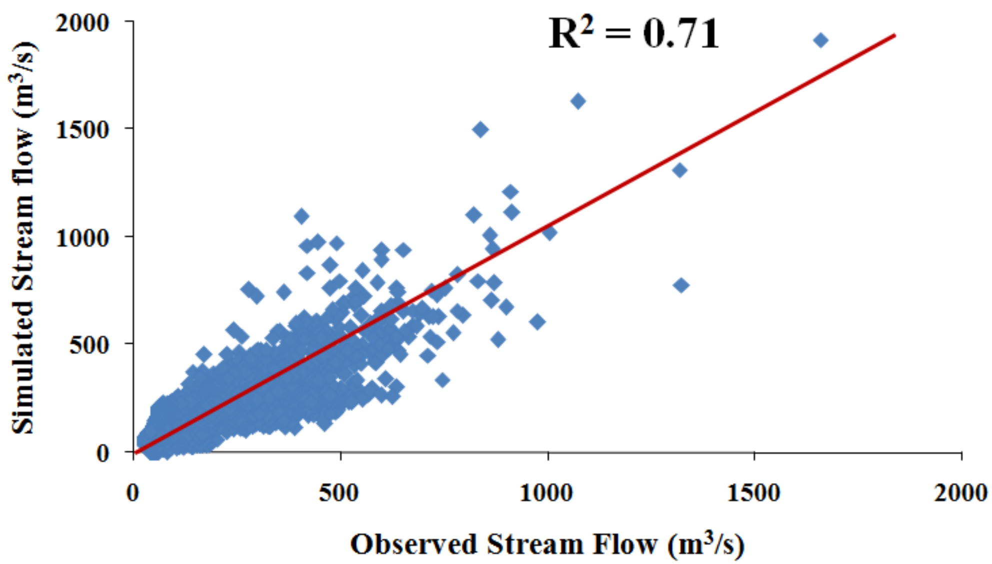
- Modeling results of Upper Ganga basin better than Beas basin.
- SWAT model is suitable for hilly watersheds.

Time series of daily observed and simulated stream flow of Beas River basin during calibration (top) and validation (bottom) period

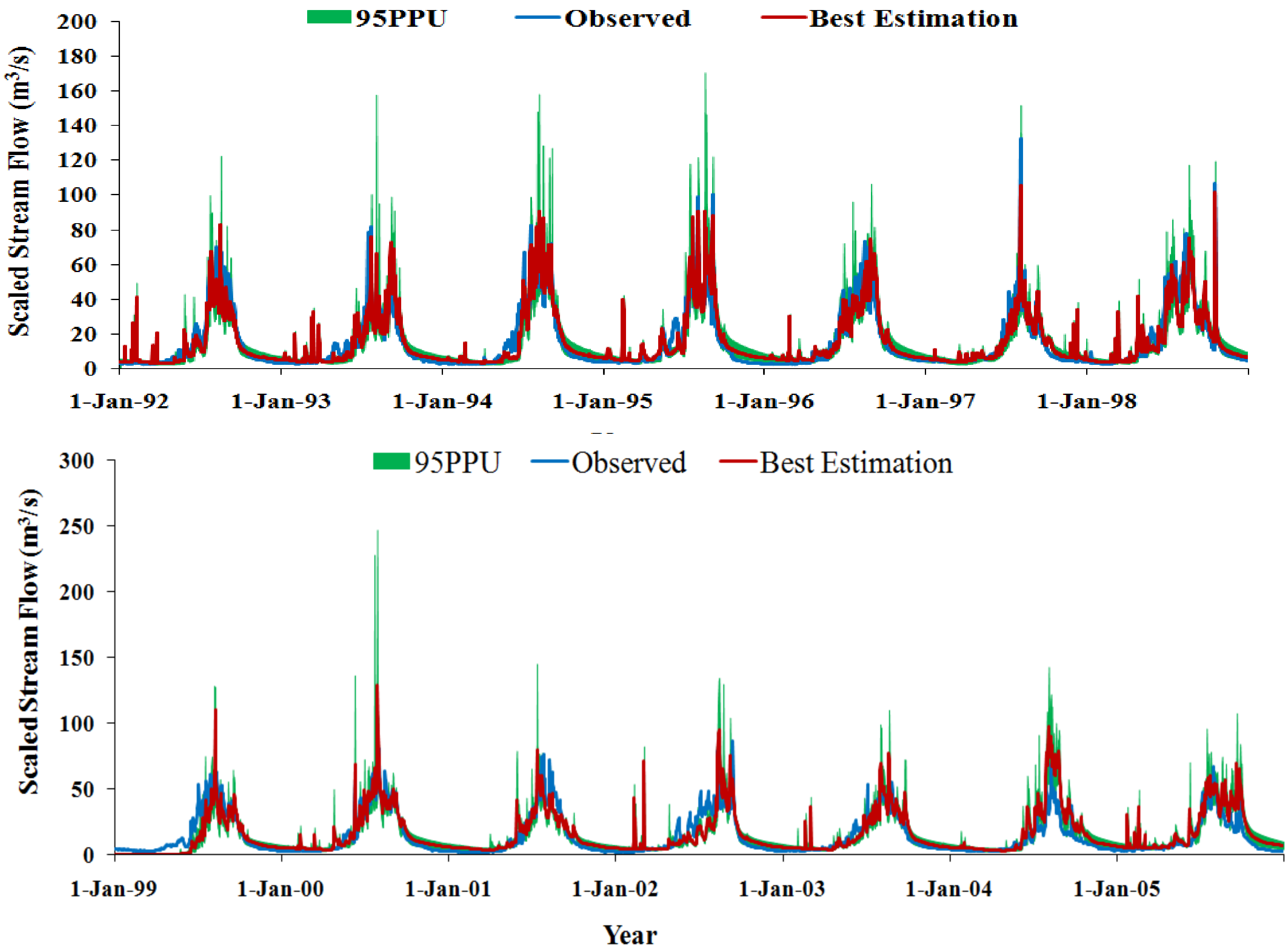


Scatter plot of Beas basin during calibration (top) period (1992-2000) and Validation (bottom) period (2001-2005)

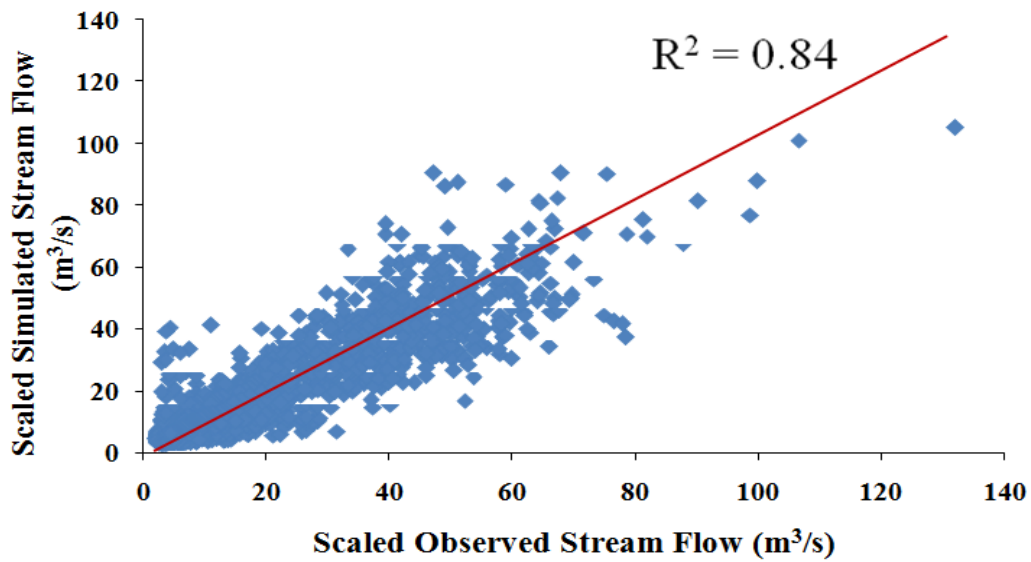


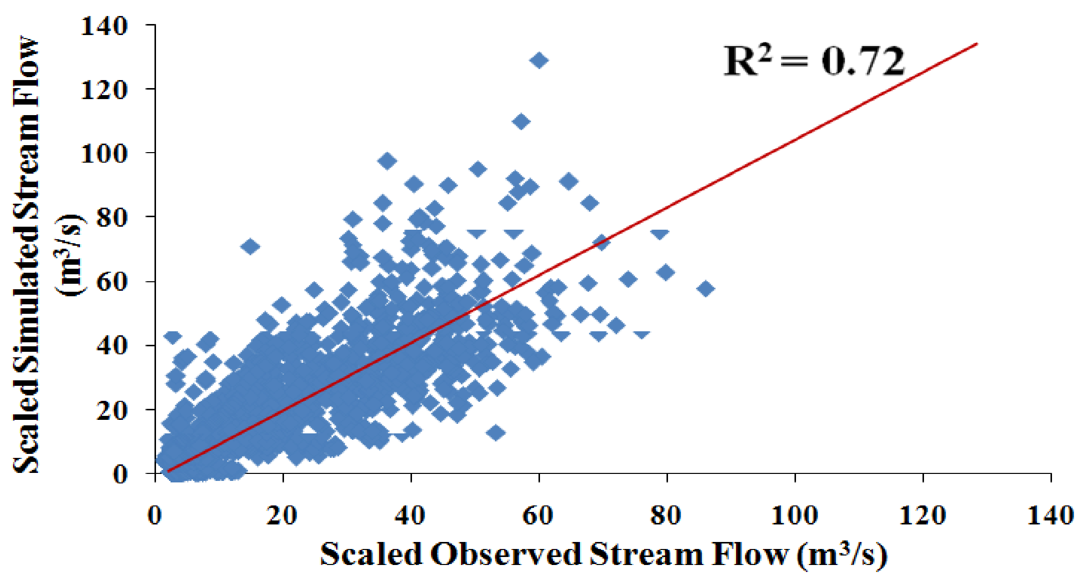


Time series of daily observed and simulated stream flow of Ganga River basin during calibration (top) and validation (bottom) period



Scatter plot of Ganga Basin during calibration (top) period (1992-2000) and Validation (bottom) period (2001-2005)





Water balance components (mm)

S.N.	Water balance Parameters	Beas basin		Ganga Basin	
		Calibration (years 1992-1998)	Validation (years 1999-2005)	Calibration (years 1992-1998)	Validation (years 1999-2005)
1	Precipitation	1227.40	967.20	1398.10	1353.00
2	ET	171.60	168.20	279.6	266.4
3	Surface Runoff	16.40	17.99	28.18	51.38
4	Lateral Flow	336.63	261.71	564.78	634.52
5	Ground water flow	401.55	284.76	277.97	158.12
6	Water yield	754.56	564.43	870.59	843.35
7	Snowfall	628.20	414.36	420.78	368.60
8	snowmelt	303.14	152.21	158.34	108.26

CONCLUSIONS

- Response of hilly parts of two Himalayan river basins simulated: Ganga and Beas.
- Acceptable simulation uncertainty range for both the catchments.
- Hydrograph shapes were reproduced satisfactorily though all peaks and recession limbs could not be reproduced very well.
- SWAT model works well to model discharge hydrograph and various water balance components.
- Snow/glacier melt contribution is between 27-40% for Beas basin and 13-18% for Ganga basin.

CONCLUSIONS (Contd.)

- **Beas basin has more snow/glacier covered area, has comparatively colder climate and smaller fraction of water is lost as ET → Beas basin is comparatively less vulnerable to climate warming.**
- **Modeling framework can be employed for decision support tool to operate WRD projects:**
  - **Predict inflows over a medium- to long-time horizon**
  - **Project future inflows in changed scenarios of climate and LULC**
- **More realistic catchment representation is needed.**
- **Strengthen spatial data, soil data, ...**
- **Strengthen hydromet database including snowfall and other climatic variables at various elevations.**

Applying a Hydrologic Model

- **Klemes (1986): For a good mathematical model, it is not enough that it works well. It must work well for the right reasons.**

- **Know the catchment – a visit to study area and field investigations are always helpful and necessary.**
- **First try to get the monthly/ seasonal values of various water balance components right.**
- **Next, focus on main features of interest – hydrograph peaks, recession limb, GW levels.**
- **Use statistical indices but visual comparison of results is valuable.**
  - **– typically hydrograph, GW levels.**
  - **– Scatter plots – distribution of points.**

Way Forward

- Overcome lack of data; model users must also be data creators.
- Create modeling centers with expertize.
- Consolidate, adapt and adopt models.
- Emphasis should be on: (1) Field surveys, (2) collaboration between institutions and individuals, (3) solving real-life problems.
- Increase use of models for WRPM including real time forecasting/operation.

THANK YOU