Web-based Expected Inundation Mapping Using SWAT and HEC-RAS Model

By

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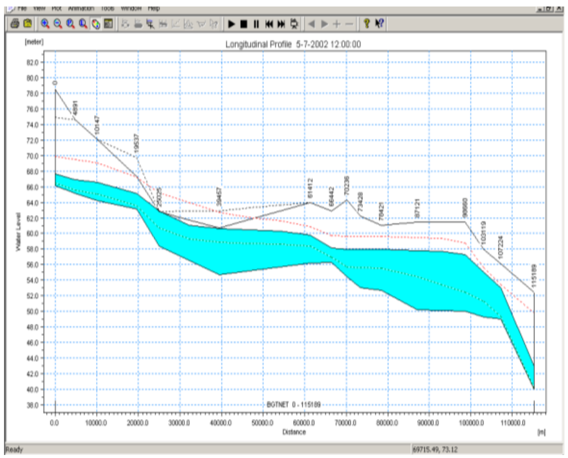
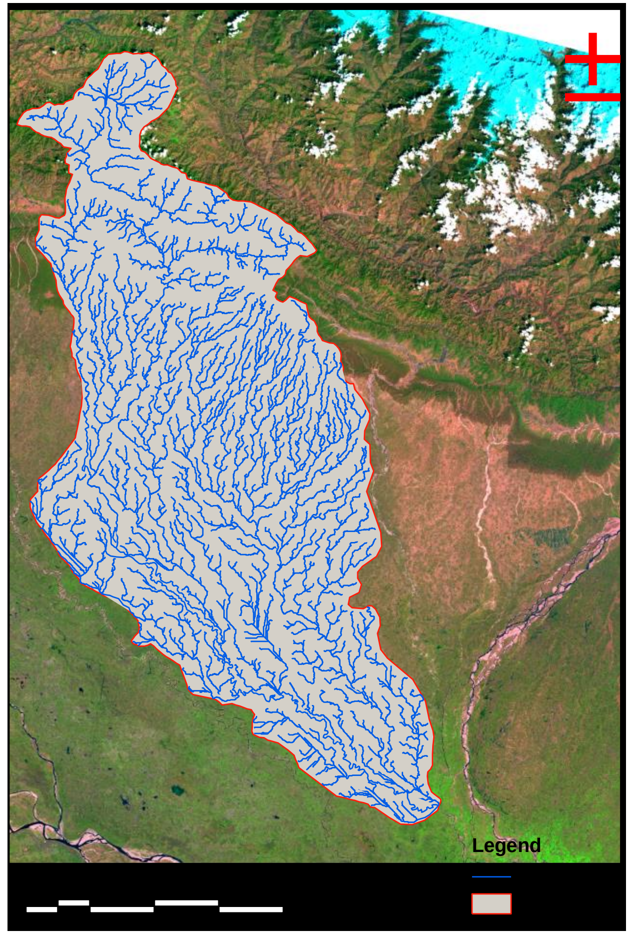
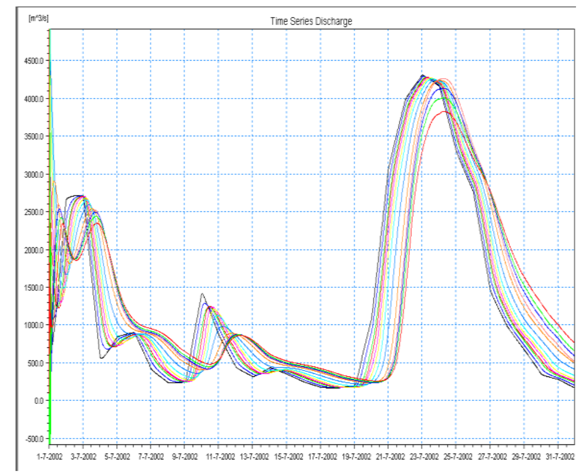
Use of New Technologies & Softwares in Flood sector







INTRODUCTION

- Flood is associated with a serious loss of life, property and damage to utilities.
- Climate change is going to further aggravate the scenario
- Strong call for action to combat the problem of flood inundation, a natural calamity induced by some super power is needed

THREE EVENTS WHICH MOTIVATE ME TO TAKE UP THE CHALLENGING RESEARCH WORK

EVENT- I

In September 2014, Heavy Rainfall centered on the North Indian state of Jammu and Kashmir caused devastating floods and landslides in the country's worst natural disaster since the 1944 Kashmir Flood Disaster. More than 700 people were "presumed dead. Destruction of bridges and roads left about more than 100,000 pilgrims and tourists trapped in the valleys

Event-2

- In June 2013, a multi-day cloudburst centered on the North Indian state of Uttarakhand caused devastating floods and landslides in the country's worst natural disaster since the 200 4 tsunami more than 5,700 people were "presumed dead. Destruction of bridges and roads left about 100,000 pilgrims and tourists trapped in the valleys

Event-2

Event-3

The man-made embankments of river Kosi failed and Flooded north Bihar, India during 18 August 2008 434 Dead bodies were found until 27 November 2008

SPATIAL LOCATIONS OF THREE SHOCKINGEVENTS




Challenges and oppotunities for Water Resource Engineers and Scientists

- Today, with modern equipments and radars we should have been able to predict the floods and expected inundation much earlier and stopped these human disasters
- Modelling scientists must face the challenge of flood disaster and suggest appropriate methodologies for saving the civilization from such natural calamities
- There is a need of integration of science and spirituality for injecting intelligence and consciousness into the methodology of real time flood forecasting and expected inundation mapping and flood hazard zoning.

Important Questions to be answered

- Where the floodplain and flood-prone areas are?
- How often the flood plain will be covered by water?
- How long the flood-plain will be covered by water?
- At what time of year flooding can be expected?

Expectation from SWAT Scientists

SWAT Scientists (modern saints) have potential to inject consciousness into the model by integrating time series error forecasting model for real time flood forecasting and expected inundation mapping

Objectives of the study

- To develop a web based flood management information network and methodology for expected inundation mapping using modified SWAT model ,HEC-RAS model and HEC-Geo-RAS model.

- To apply this methodology for expected flood inundation mapping of Bagmati river basin using web based data,

Literature Review

Gosain (1984) carried out an inter comparison of various categories of real time flood forecast models. In order to carry out this study three models, which belong to three different categories,

(I) A model based on unit hydrograph theory which was developed for the purpose of real time forecasting,

(II) A ARMAX (autoregressive moving average with exogenous input) model and

(III) A conceptual watershed model known as NWSRFS (National Weather Service River Forecast System)

In this study two criteria were used, one based on the accuracy of the forecasts and another based on the user's requirements of the model. The three models performed equally well with respect to the graphical and numerical criteria.

But with respect to the attributes desired by general user, the UH model fared the best followed by the ARMAX model in which the model identification is a tedious job.

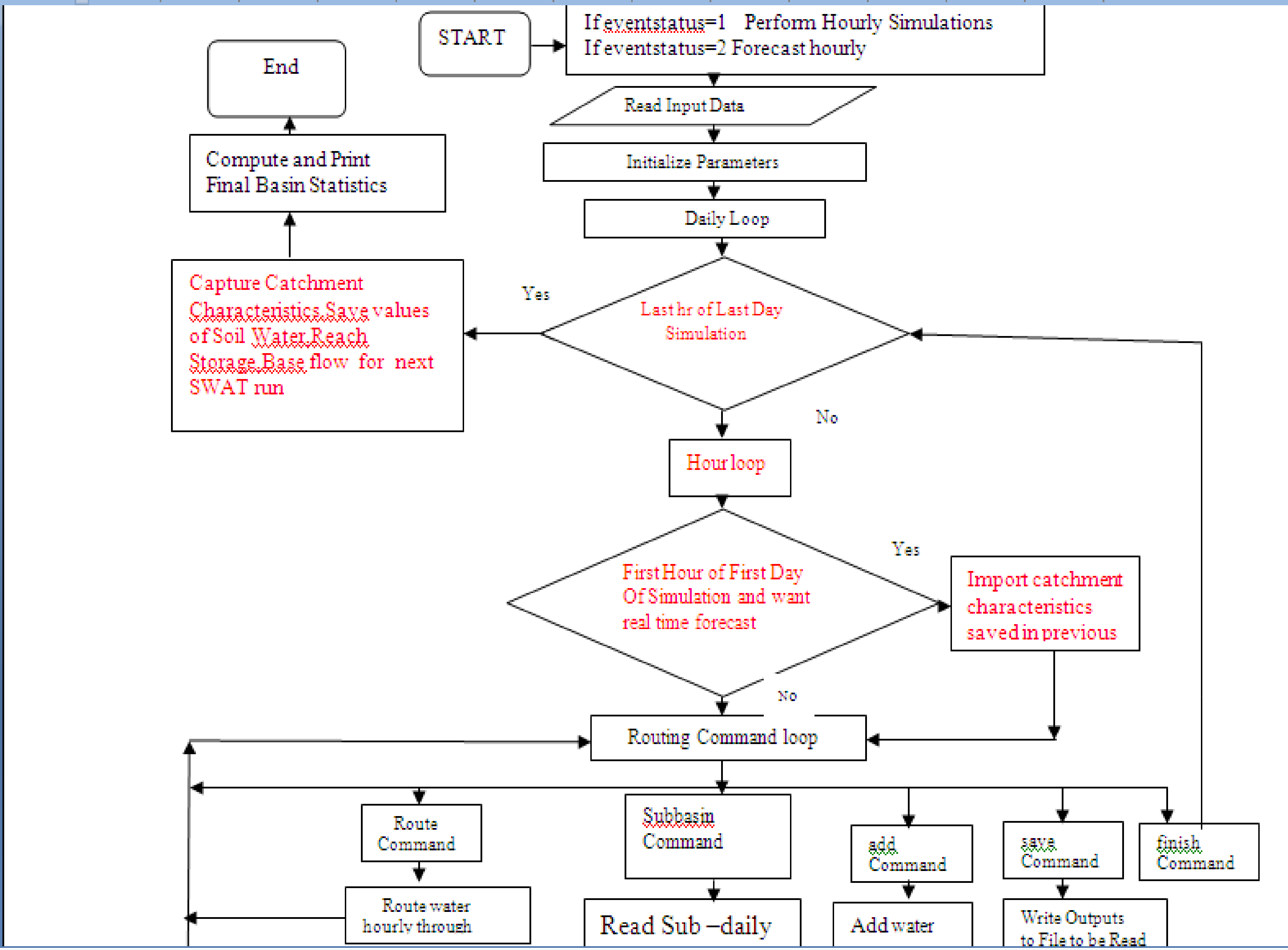
The NWSRFS model had the disadvantage of being a complex model which needs lot more expertise for its calibration and requires comparatively larger computer storage and run time than the other two models.

Literature Review

Danish Hydraulic Institute (DHI) developed a flood forecasting model the MIKE11 Flood Watch System by integrating the mathematical river model MIKE11 with spatial and non spatial databases, pre-and post processing tools, etc. in an Arc View GIS for studying and predicting flood in Bangladesh (Kjelds and Jorgensen, 1995).

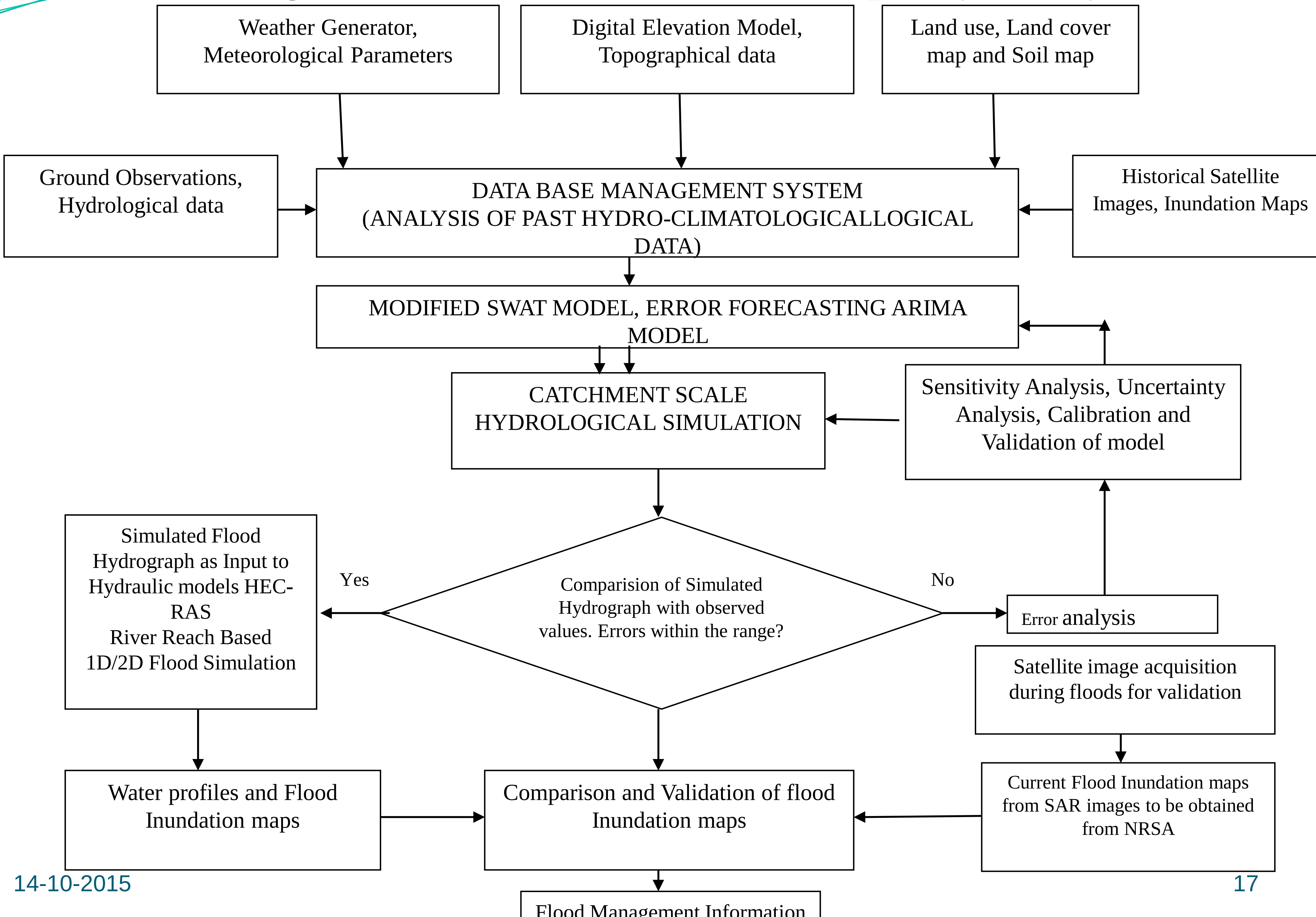
Tiwary (2012) modified SWAT Model and developed ARIMA error model for real time flood forecasting and applied this for real time flood forecasting of Bagmati River Basin. Results were found very encouraging and performance very good.

Tiwary (2012) developed Flood management information network for generating expected flood inundation mapping using SWAT and HEC-RAS model, which has been used in the present study.



START
If eventstatus=1 Perform Hourly Simulations
If eventstatus=2 Forecast hourly
Read Input Data
Initialize Parameters
Daily Loop
Last hr of Last Day Simulation
Yes
No
Capture Catchment Characteristics.Save values of Soil Water,Reach Storage,Base flow for next SWAT run
Compute and Print Final Basin Statistics
End
Hour loop
First Hour of First Day Of Simulation and want real time forecast
Yes
Import catchment characteristics saved in previous
No
Routing Command loop
Route Command
Route water hourly through
Subbasin Command
Read Sub –daily
add Command
Add water
save Command
Write Outputs to File to be Read
finish Command

Flood management information network developed by Tiwary (2012)



SWAT DIMENSION FOR FLOOD PLAIN

Figure 3.8 Illustration of flood plain dimensions

The bottom width of the floodplain, $W_{btm.fld}$, is $W_{btm.fld} = 5. W_{bankfull}$ SWAT assumes the floor plain side slopes have a 4:1 run to rise ratio ($Z_{fld} = 4$). The slope of the flood plain sides is then 0.25. When flow is present in the flood plain, the calculation of the flow depth, cross-sectional flow area and wetting perimeter is a sum of the channel and floodplain components:

$depth = depth_{bankful} + depth_{fld}$

$$A_{ch} = (W_{btm} + Z_{ch}.\ depth_{bankfull}).depth_{bankfull} + (W_{btm.fld} + z_{fld}.depth_{fld}).depth_{fld} \ldots\ldots (3.1.4.11)$$

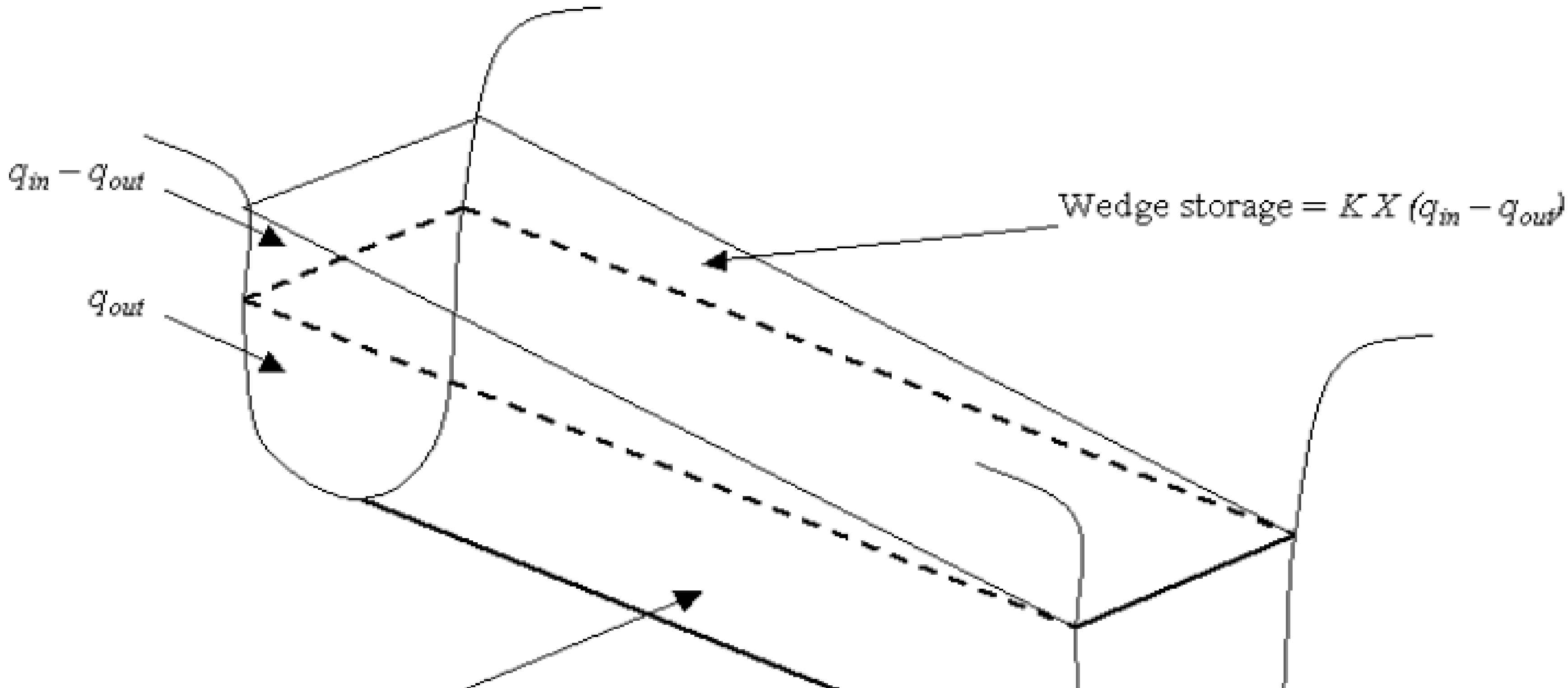
$$P_{ch} = W_{btm} + 2.depth_{bankfull}.\sqrt{1+z_{ch}^2} + 4.W_{bankfull} + 2.depth_{fld}.\sqrt{1+z_{fld}^2}$$

SWAT RECOMMENDATION FOR SAFE WATERWAY

- Users are required to define the width and depth of the channel when filled to the top of the bank as well as the channel length, slope along the channel length and Manning's "n" value. SWAT assumes the channel sides have a 2:1 run to rise ratio (z_{ch} = 2.1). The slope of the channel sides is then 0.5. The bottom width is calculated from the bankfull, width and depth with the equation:

Muskingum Routing Method

The Muskingum routing method models the storage volume in a channe length as a combination of wedge and prism storages



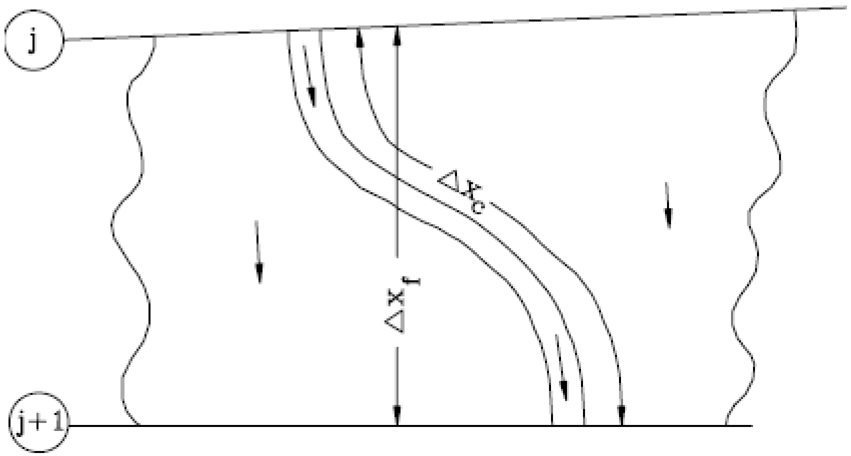
$$V_{stored} = K \cdot \left(X \cdot q_{in} + (1 - X) \cdot q_{out} \right)$$

The weighting factor, X, has a lower limit of 0.0 and an upper limit of 0.5. This factor is a function of the wedge storage. For reservoir-type storage, there is no wedge and $X = 0.0$. For a full-wedge, $X = 0.5$. For rivers, X will fall between 0.0 and 0.3 with a mean value near 0.2.

$$q_{out,2} = C_1 \cdot q_{in,2} + C_2 \cdot q_{in,1} + C_3 \cdot q_{out,1}$$

where $q_{in,1}$ is the inflow rate at the beginning of the time step (m^3/s), $q_{in,2}$ is the inflow rate at the end of the time step (m^3/s), $q_{out,1}$ is the outflow rate at the beginning of the time step (m^3/s), $q_{out,2}$ is the outflow rate at the end of the time

Governing Equations for flood inundation mapping



Two dimensional characteristics of interaction between channel and flood plain flows

Channel and floodplain flows

When the river rises water moves laterally away from the channel, inundating the flood plain and filling the available storage area. As the depth increases, the floodplain begins to convey water downstream generally along a shorter path than that of the main channel. When the river stage is falling, water moves toward the channel from the overbank supplementing the flow in the main channel

Governing equations for unsteady flow and flood inundation mapping

Continuity Equation

The continuity equation describes conservation of mass for the one-dimensional system. From previous text, with the addition of a storage term, S, the continuity equation can be written as:

$$\frac{\partial A}{\partial t} + \frac{\partial S}{\partial t} + \frac{\partial Q}{\partial t} - q_1 = 0$$

Where: x = distance along the channel,

t = time,

Q = flow,

Governing equations for unsteady flow and flood inundation mapping

Momentum Equation

The momentum equation states that the rate of change in momentum is equal to the external forces acting on the system. From Appendix A, for a single channel:

$$\frac{\partial Q}{\partial t} + \frac{\partial (VQ)}{\partial x} + gA\left(\frac{\partial z}{\partial x} + S_f\right) = 0\ 0 \qquad (3.2.2.12)$$

Where; g = acceleration of gravity

S_f = friction slope,

V = velocity.

The above equation can be written for the channel and for the floodplain:

$$\frac{\partial Q_c}{\partial t} + \frac{\partial (V_c Q_c)}{\partial x_c} + gA_c\left(\frac{\partial z}{\partial x_c} + S_{fc}\right) = M_f\ 0 \qquad (3.2.2.13)$$

$$\frac{\partial Q_f}{\partial t} + \frac{\partial (V_f Q_f)}{\partial x_f} + gA_f\left(\frac{\partial z}{\partial x_f} + S_{ff}\right) = M_c\ 0 \qquad (3.2.2.14)$$

Where M_c and M_f are the momentum fluxes per unit distance exchanged between the

The above equation can be written for the channel and the floodplain:

$$\frac{\partial Q_c}{\partial x_c} + \frac{\partial A_c}{\partial t} = q_f \qquad (3.2.2.7)$$

and

$$\frac{\partial Q_f}{\partial x_f} + \frac{\partial A_f}{\partial t} + \frac{\partial S}{\partial t} = q_c + q_1 \qquad (3.2.2.8)$$

where the subscripts c and f refer to the channel and floodplain, respectively, q_1 is the lateral inflow per unit length of floodplain, and q_c and q_f are the exchanges of water between the channel and the floodplain.

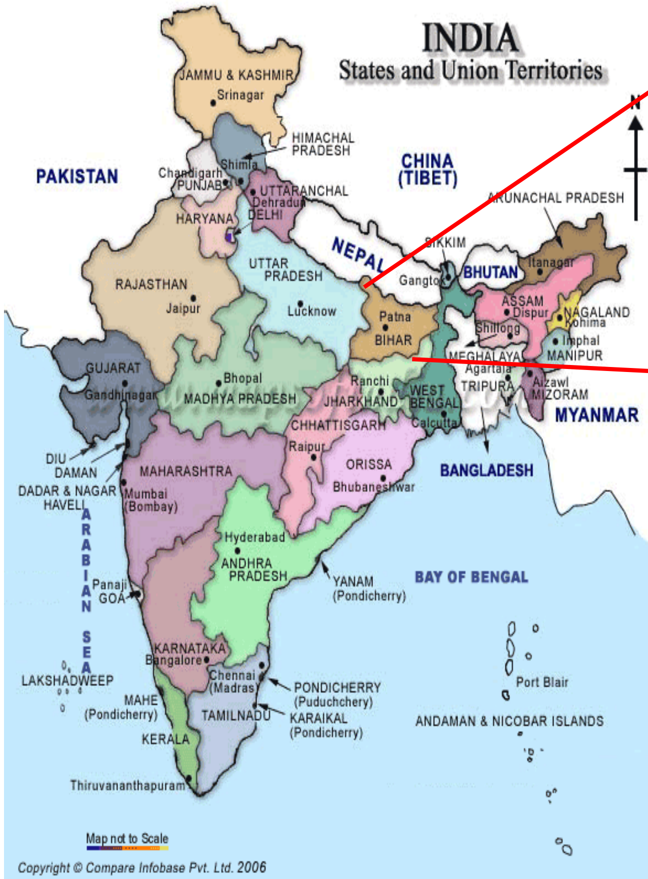
Equations given above are now approximated using implicit finite differences

$$\frac{\partial Q_c}{\partial x_c} + \frac{\partial A_c}{\partial t} = \bar{q}_f \qquad (3.2.2.9)$$

$$\frac{\partial Q_c}{\partial x_c} + \frac{\partial A_c}{\partial t} + \frac{\partial S}{\partial t} = \bar{q}_c + \bar{q}_1 0 \qquad (3.2.2.10)$$

The exchange of mass is equal but not opposite in sign such that $\Delta x_c q_c$ = $-q_f \Delta x_f$. Adding

Study Area



INDIA
States and Union Territories
N
JAMMU & KASHMIR
Srinagar
HIMACHAL PRADESH
Shimla
Chandigarh
PUNJAB
UTTARANCHAL
Dehradun
DELHI
HARYANA
PAKISTAN
CHINA (TIBET)
ARUNACHAL PRADESH
NEPAL
SIKKIM
Gangtok
BHUTAN
Itanagar
RAJASTHAN
Jaipur
UTTAR PRADESH
Lucknow
Patna
BIHAR
ASSAM
Dispur
NAGALAND
Kohima
Shillong
MEGHALAYA
Imphal
MANIPUR
Agartala
TRIPURA
Aizawl
MIZORAM
MYANMAR
GUJARAT
Gandhinagar
Bhopal
MADHYA PRADESH
Ranchi
JHARKHAND
WEST BENGAL
Calcutta
CHHATTISGARH
Raipur
ORISSA
Bhubaneshwar
BANGLADESH
DIU
DAMAN
DADAR & NAGAR HAVELI
MAHARASHTRA
Mumbai (Bombay)
ARABIAN SEA
Hyderabad
ANDHRA PRADESH
YANAM (Pondicherry)
BAY OF BENGAL
Panaji
GOA
KARNATAKA
Bangalore
Chennai (Madras)
PONDICHERRY (Puduchchery)
KARAIKAL (Pondicherry)
LAKSHADWEEP
MAHE (Pondicherry)
TAMILNADU
KERALA
Thiruvananthapuram
Port Blair
ANDAMAN & NICOBAR ISLANDS
Map not to Scale
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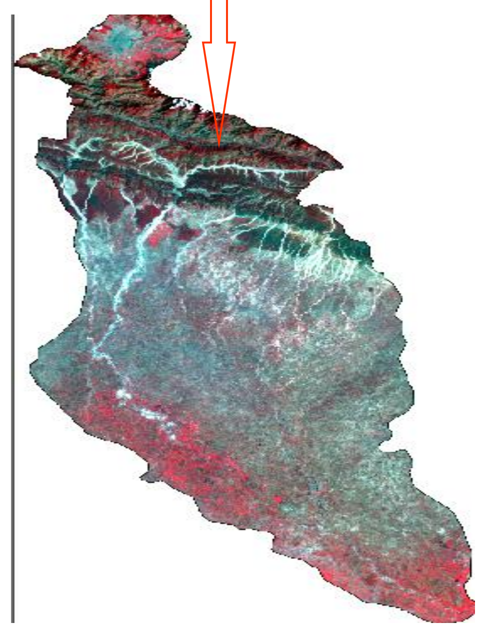
BIHAR
2001
Pashchim Champaran
Purba Champaran
Sitamarhi
Sheohar
Gopalganj
Madhubani
Siwan
Muzaffarpur
Supaul
Araria
Kishanganj
Darbhanga
Saran
Madhepura
Vaishali
Samastipur
Saharsa
Purnia
Buxar
Bhojpur
Patna
Khagaria
Begusarai
Katihar
Rohtas
Jehanabad
Nalanda
Lakhisarai
Bhagalpur
Kaimur (Bhabua)
Sheikhpura
Munger
Nawada
Aurangabad
Gaya
Jamui
Banka



DFO event # 2004-096 - Bihar, India

MODIS flood inundation limit
July 13, 2004:
June 28, 2004:
June 25, 2004:
June 24, 2004:

DCW Rivers
Urban Areas
MODIS reference water

Flooded Lands in:
2004
2003
2002
2001
2000
1998
1988

Universal Transverse Mercator
UTM Zone 45 North; WGS 84
Graticule: 2 degrees

Copyright 2004 Dartmouth Flood Observatory
Dartmouth College Hanover NH 03755 USA

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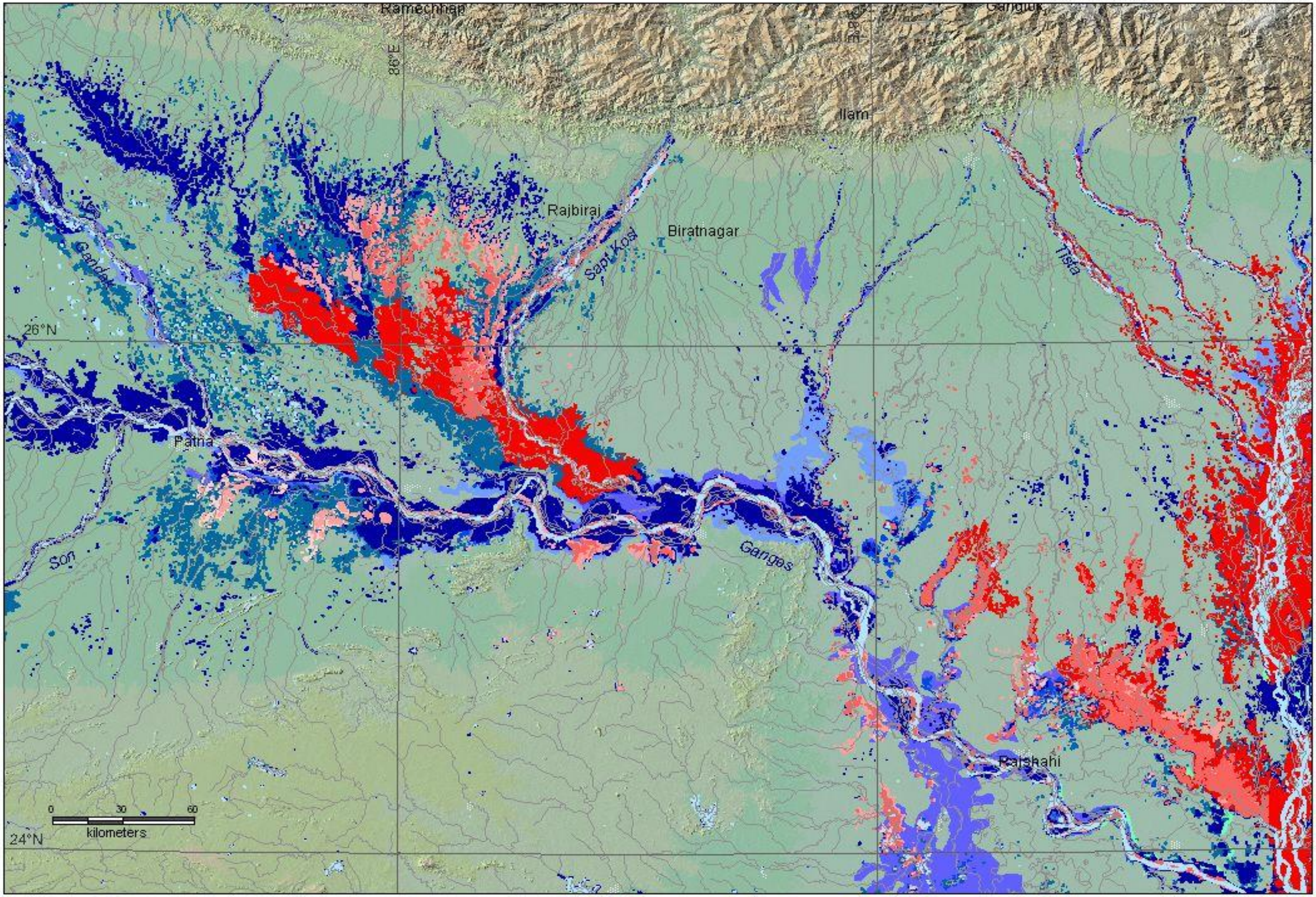
NASA grant NAG5-9470

G. R. Brakenridge
Elaine Anderson
Sébastien Caquard



Model Set up for study area

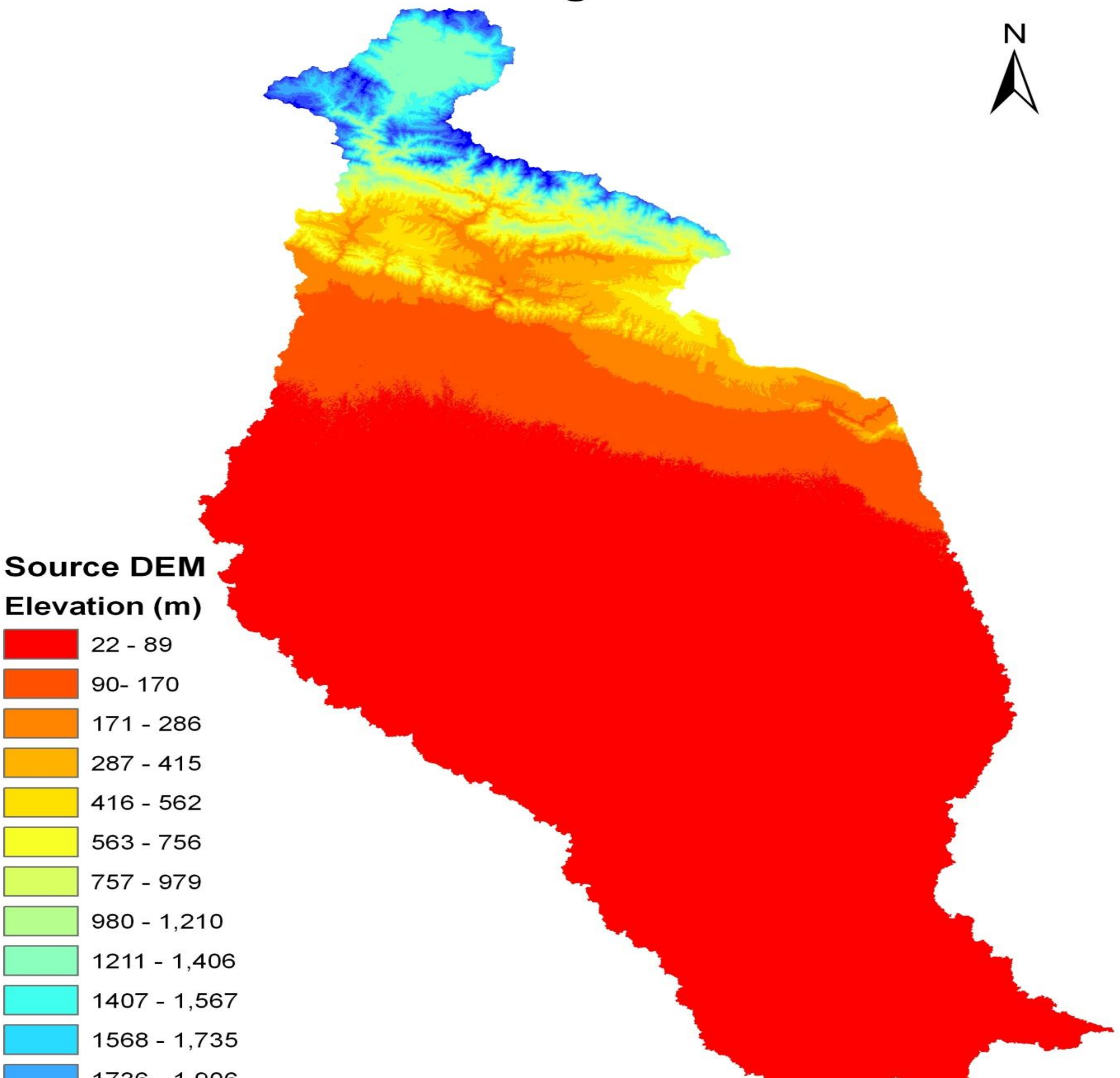
Data sets used

- The SWAT model requires data on terrain, land use, soil, and weather for assessment of inflows and outflows of reaches. Following datasets have been used for setting up of the SWAT model:
- (1) DEM – SRTM (90 m resolution)
- (2) Landuse – Global USGS (2 M)
- (3) Soil – FAO Global soil (5 M)
- (4) Rain gauges /Temperature gauges – IMD
- (5)Stream Gauges – CWC
- Rainfall data- Aphroditedridded rainfall data, real time rainfall data downloaded from websites

Hydro meteorological data available on websites

Rainfall and water levels of Hayaghat gauge station were downloaded from websites

- www.imdaws
- www.hydrology.gov.np
- www.fmis.bih.nic


N
Source DEM
Elevation (m)
22 - 89
90- 170
171 - 286
287 - 415
416 - 562
563 - 756
757 - 979
980 - 1,210
1211 - 1,406
1407 - 1,567
1568 - 1,735

Land use classes for the Bagmati basin

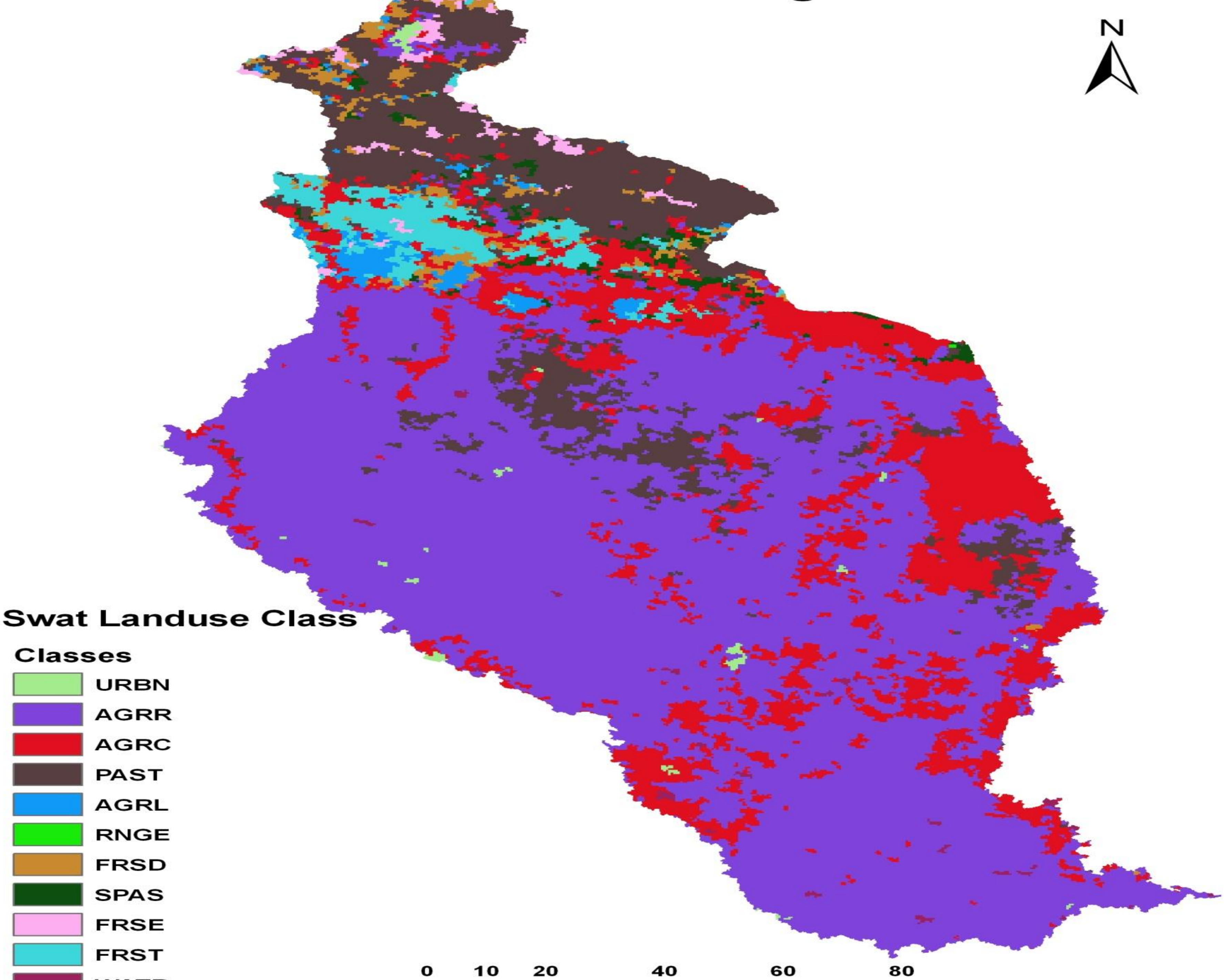
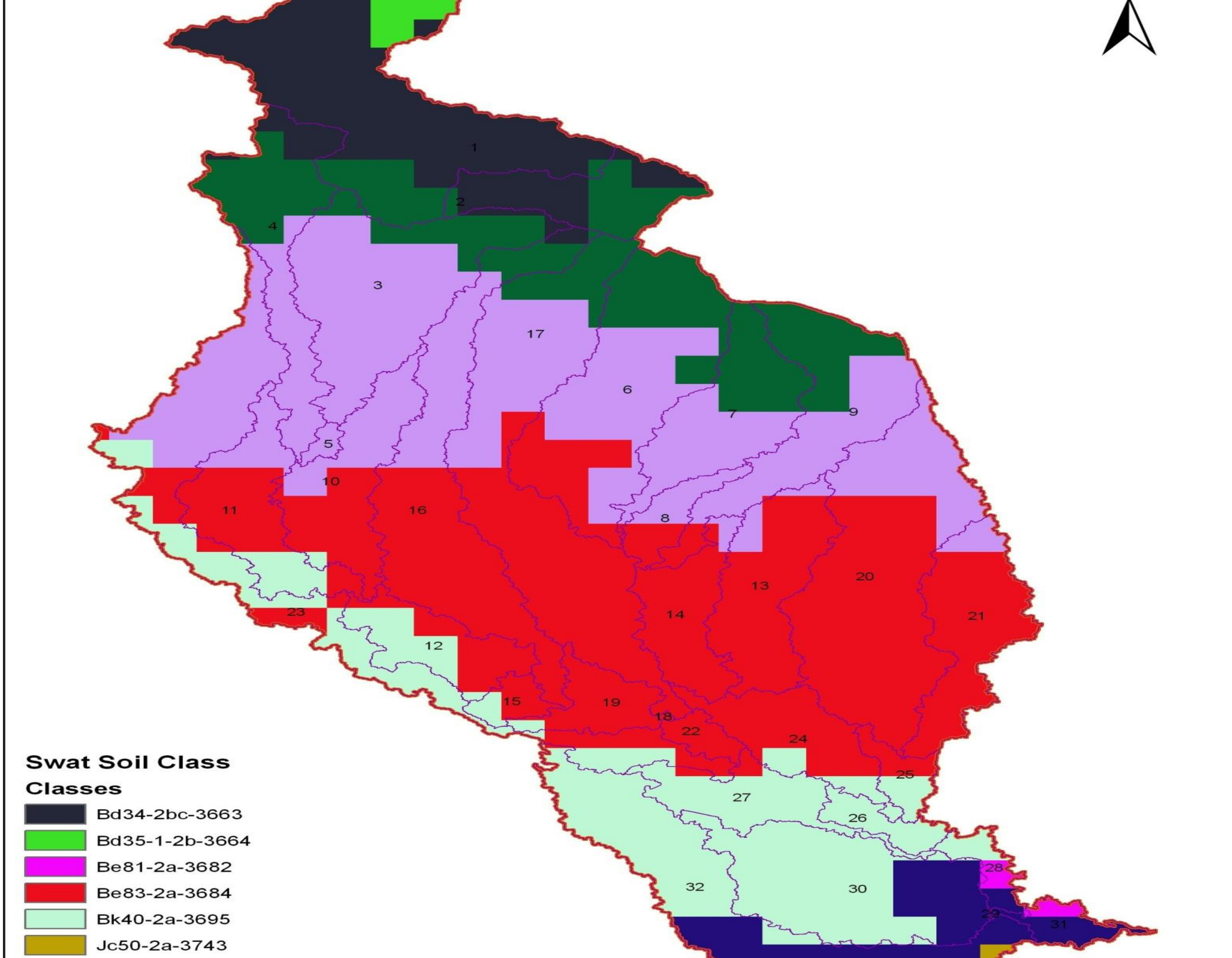


Table 6.4 Details of landuse

NAME	GLB_LU	LANDUSE
URBN	URMD	Urban
AGRR	CRDY	Agricultural Land-Row Crop
AGRC	CRIR	Pasture
PAST	CRGR	Pasture
AGRL	CRWO	Agricultural Land-Generic
RNGE	GRAS	Range-Grasses
FRSD	SHRB	Forest-Deciduous
SPAS	SAVA	Summer Pasture
FRSE	FOEB	Forest-Evergreen
FRST	FOMI	Forest-Mixed
WATR	ICES	Ice/Water



Swat Soil Class
Classes
Bd34-2bc-3663
Bd35-1-2b-3664
Be81-2a-3682
Be83-2a-3684
Bk40-2a-3695
Jc50-2a-3743
1
2
3
4
5
6
7
8
9
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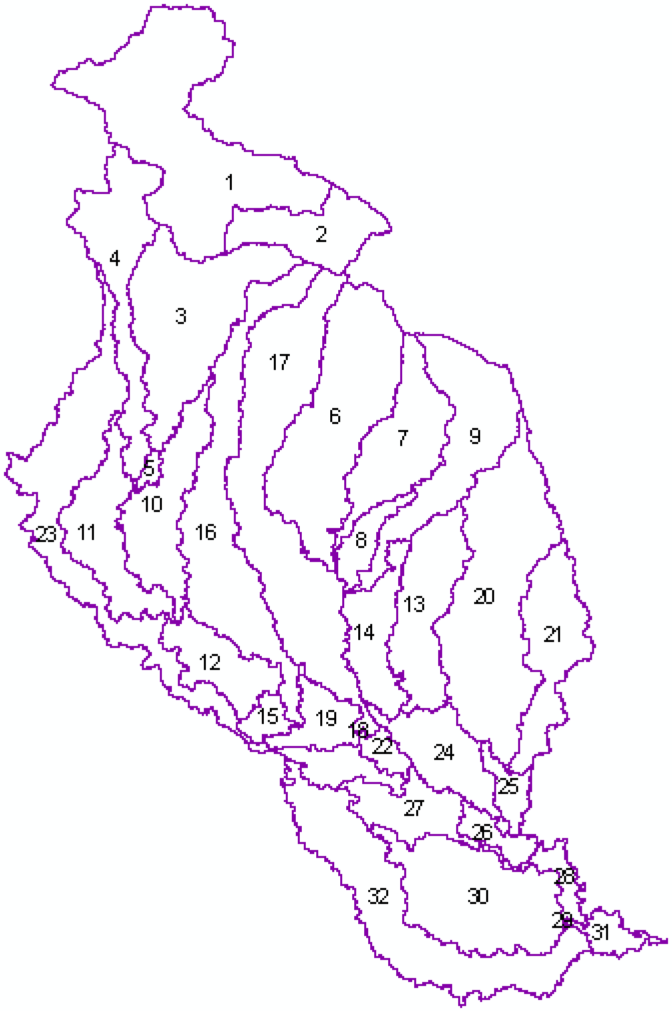
32

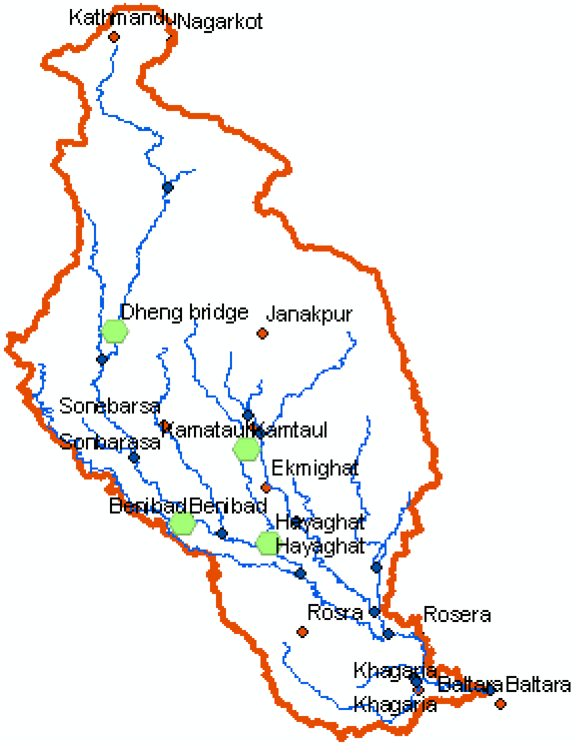
Soil Details

SEQN	SNAM	NLAYERS	HYDGRP	TEXTURE	SOL_AWC1	SOL_K1	CLAY1	SILT1	SAND1
3663	3663	2	C	LOAM	0.117	35.65	24	35	42
3664	3664	2	C	LOAM	0.157	28.52	17	36	47
3682	3682	2	D	LOAM	0.175	7.77	24	36	40
3684	3684	2	C	LOAM	0.175	13.92	22	38	41
3695	3695	2	C	LOAM	0.175	14.96	20	40	40
3743	3743	2	D	LOAM	0	6.48	18	44	38
3761	3761	2	C	LOAM	0.175	24.73	20	34	46
3808	3808	2	D	LOAM	0.175	6.17	21	35	44
3851	3851	2	D	CLAY_LOAM	0.137	7.17	27	35	37

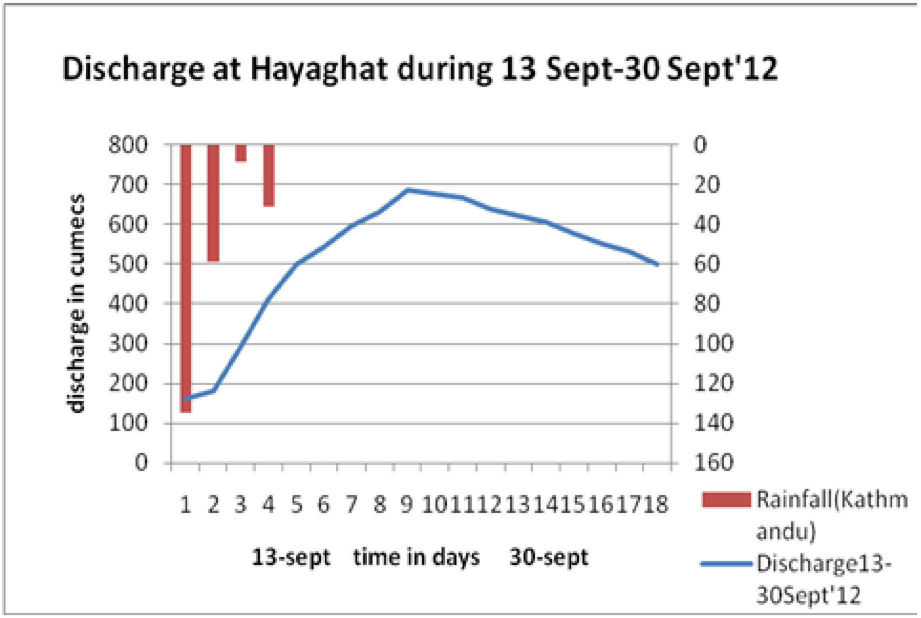
Division into subbasins

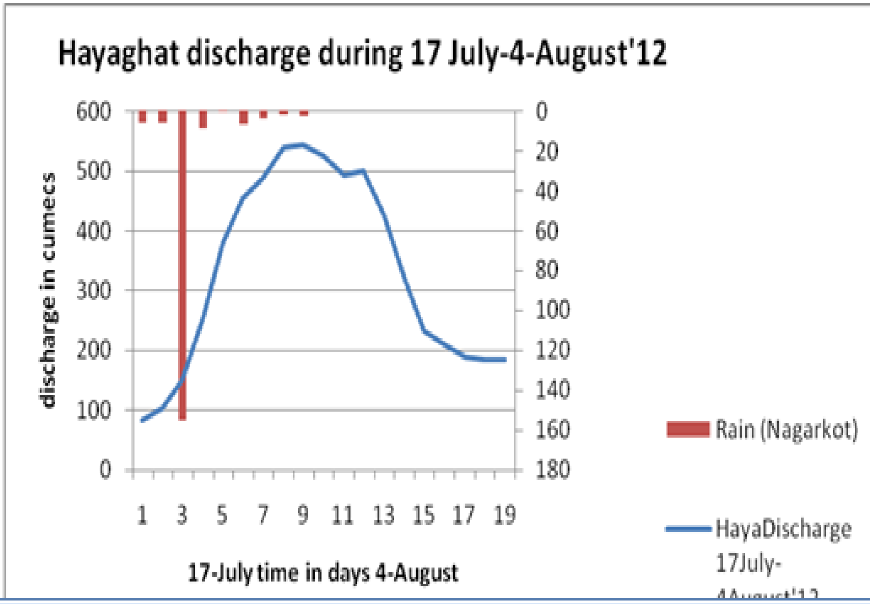


GAUGE STATIONS



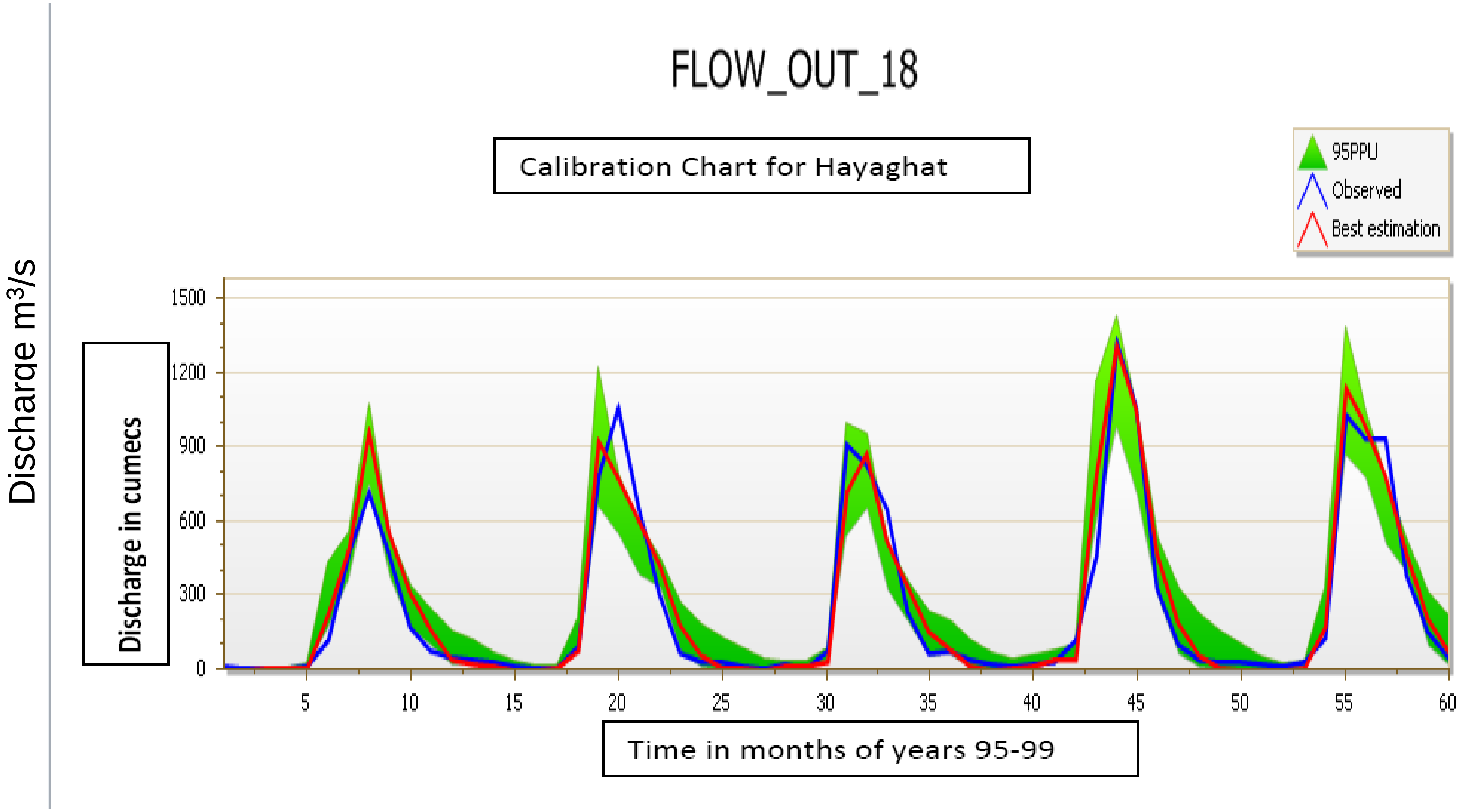
Analysis of web-based real time data





It can be concluded that rainfall of Nepal portion produces peak discharge at Hayaghat after 4-5 days. Hence correlation between rainfalls of Nepal portion and runoff of Hayaghat is very important. The lead time at Hayaghat for rainfall of Nepal portion can be considered 4-5 days.

Calibration - Output



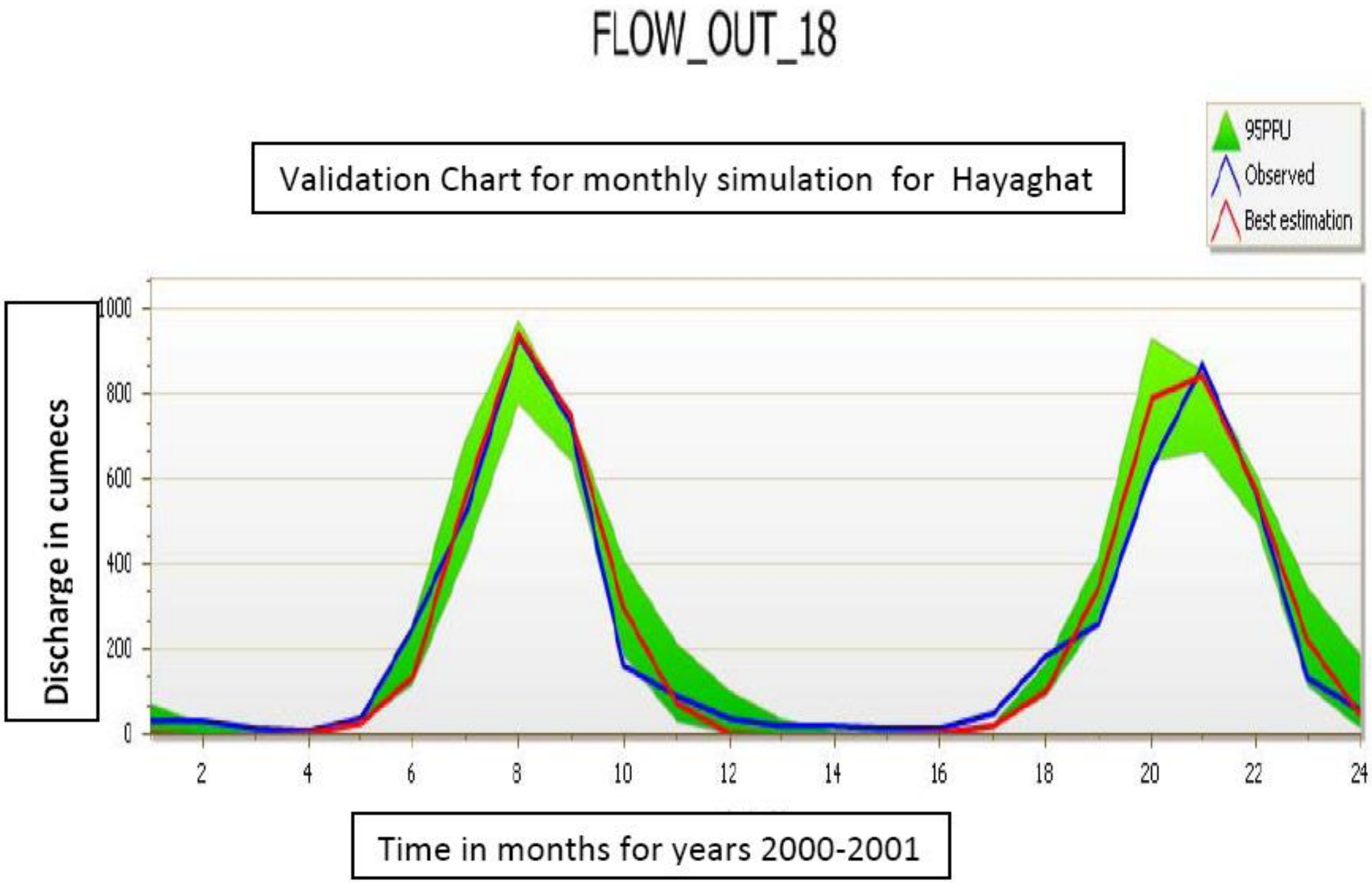
Calibration Results

- Seventeen parameters were selected for sensitivity analysis, calibration, validation and uncertainty analysis to be carried out by SWAT-CUP4 using SUFI algorithm. On the basis of global sensitivity analysis it can be concluded that most sensitive parameter is CN2.mgt followed by GW_DELAY, CH_N2.rte, ESCO.hru, HRU_SLP.hru, GWQMN.gw, GW_REVAP.gw and SURLAG.bsn. P-factor and r-factor for calibration were found to be 0.74 and is 0.44 respectively, which are very much within the range recommended for a perfect model.

Calibration Results

- Seventy four percent observed and simulated values lie in 95PPU. P-factor and r-factor for validation period are 0.63 and 0.36 respectively which are satisfactory. Nash-Sutcliffe coefficient for calibration period for Hayaghat gauge station was found to be 0.95 which indicates best performance of the model. Nash-Sutcliffe coefficients for validation of the model for daily simulation for years 2004 and 2010 were found to be 0.93 and 0.91 respectively. For hourly simulation for years 2004, 2005, 2010, 2011 Nash-Sutcliffe coefficients were found to be 0.65, 0.84, 0.74, and 0.64 respectively which are within the range of good performance.

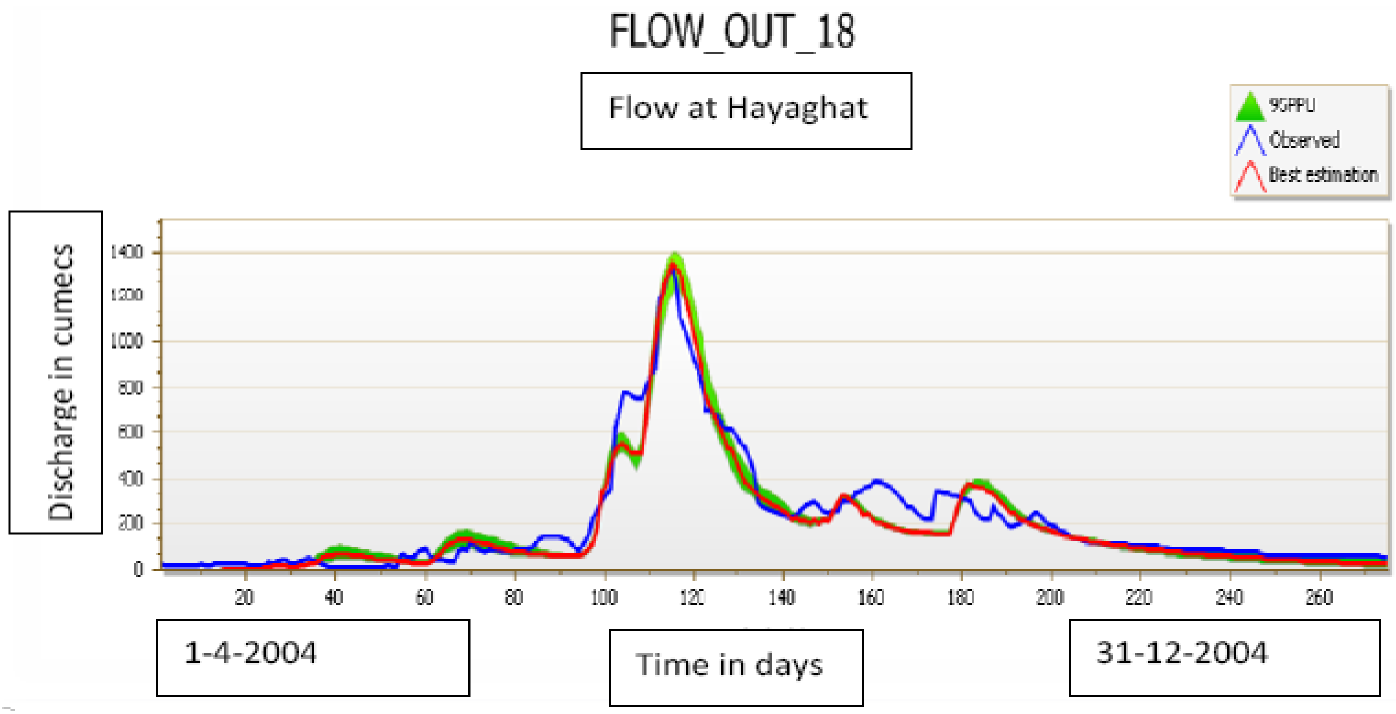
Validatio for monthly flow



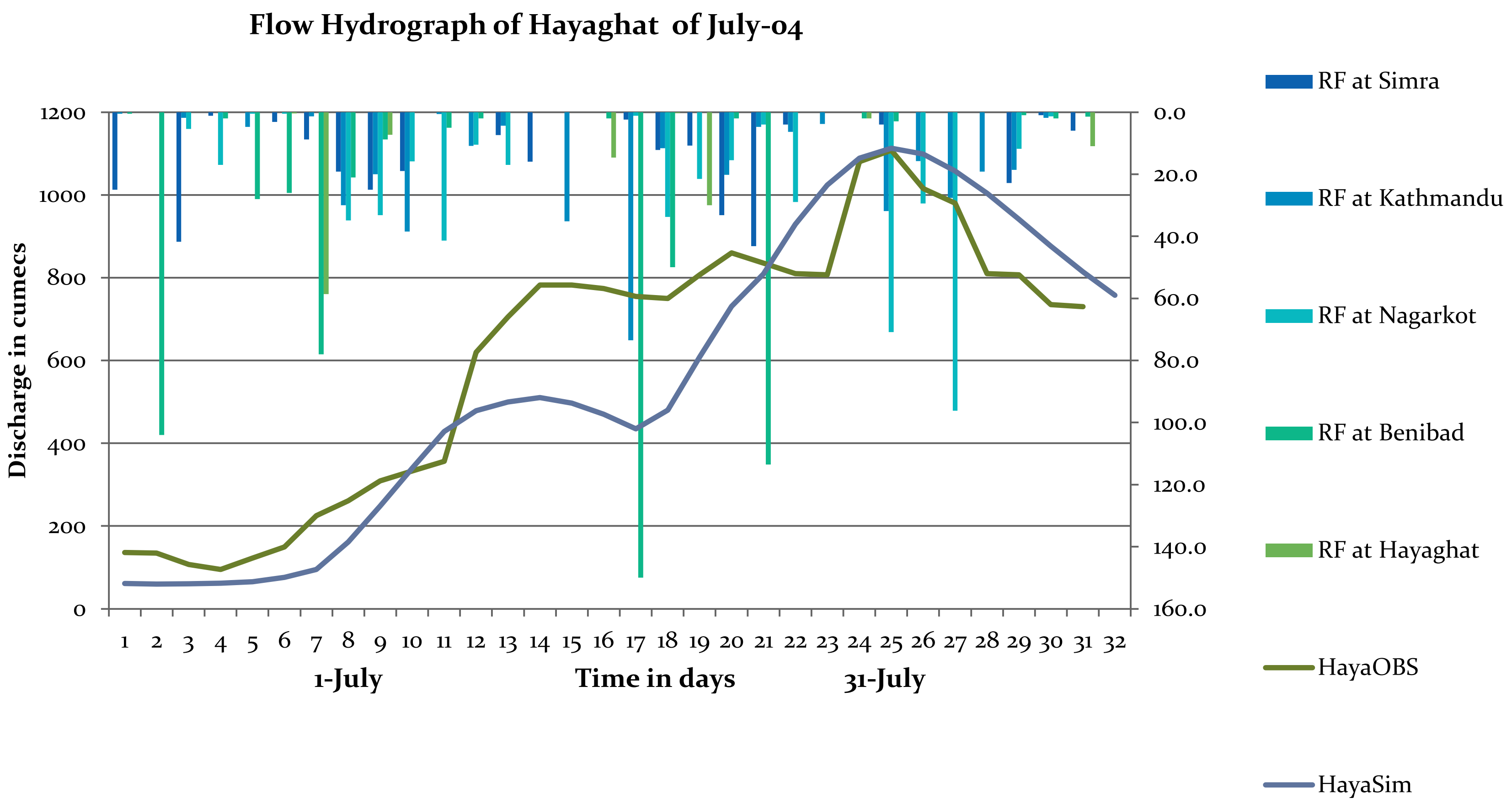
Model Performance Test

- The correlation statistics (R^2) was determined to measure the linear correlation between the actual and the predicted values and it was found to be 0.93 which indicates the best performance of the model.
- $R^2 = \; = 0.96$
-
- To estimate the efficiency of the fit, the Nash-Sutcliffe coefficient (Nash) (Nash and Sutcliffe, 1970) was used. It was found to be 0.96 which indicates the best performance of the model.
-

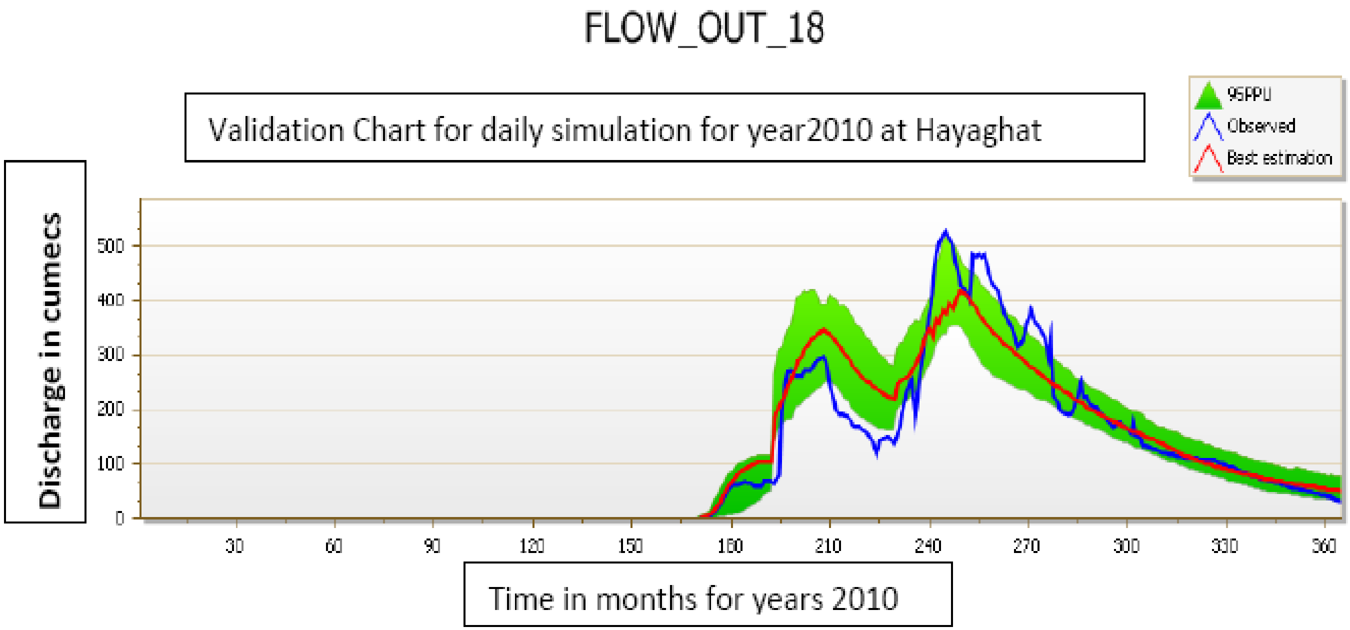
Daily Flow Valdation



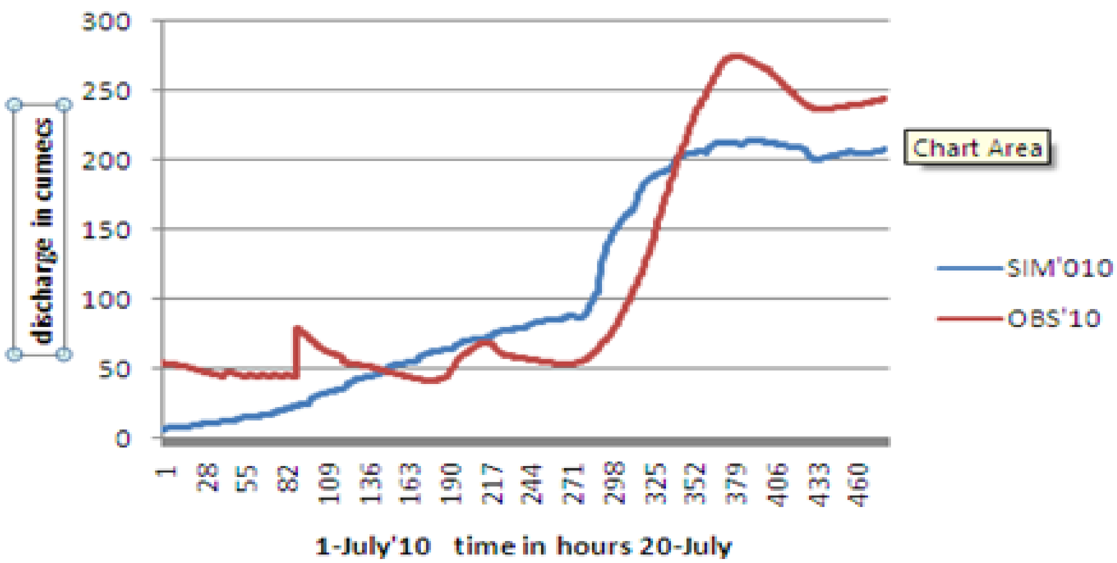
Flow Hydrograph Daily Simulation



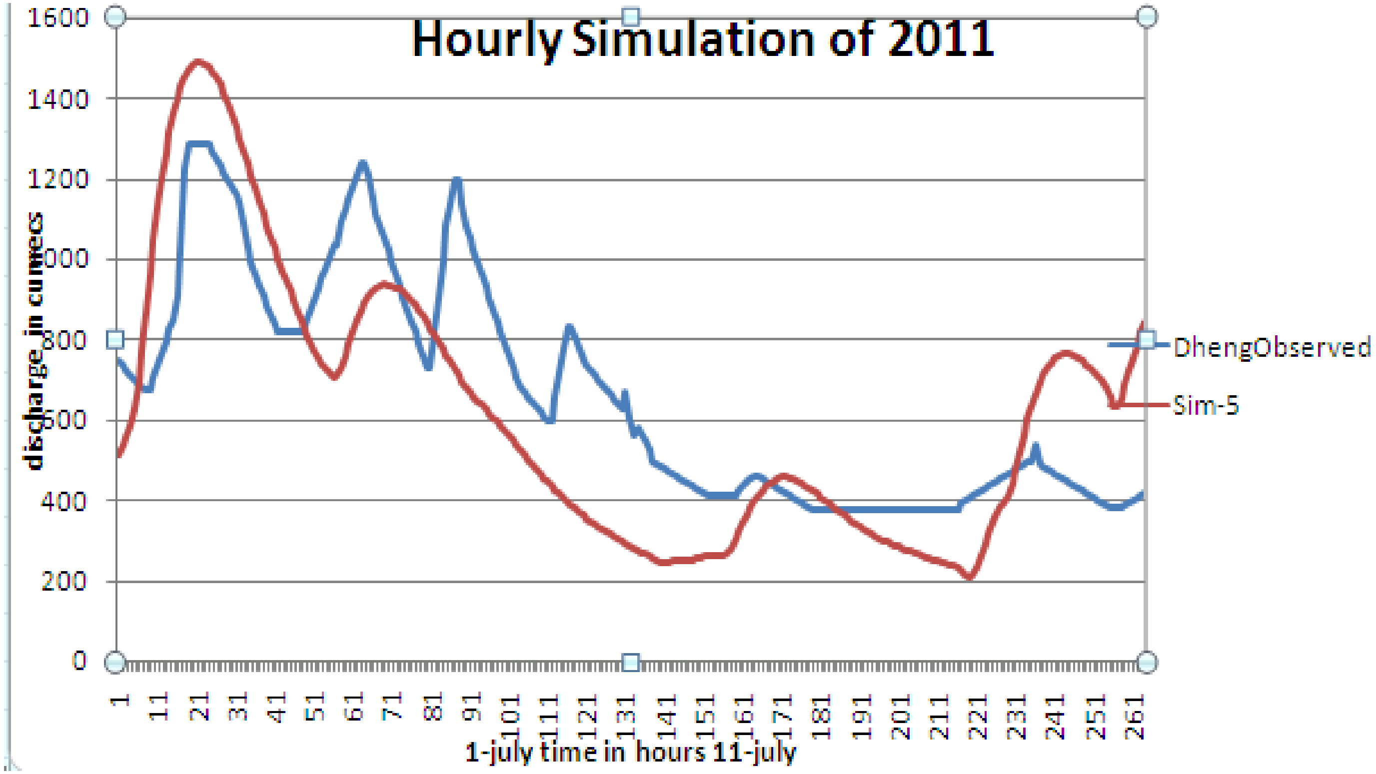
Valdation for daily flow 2010



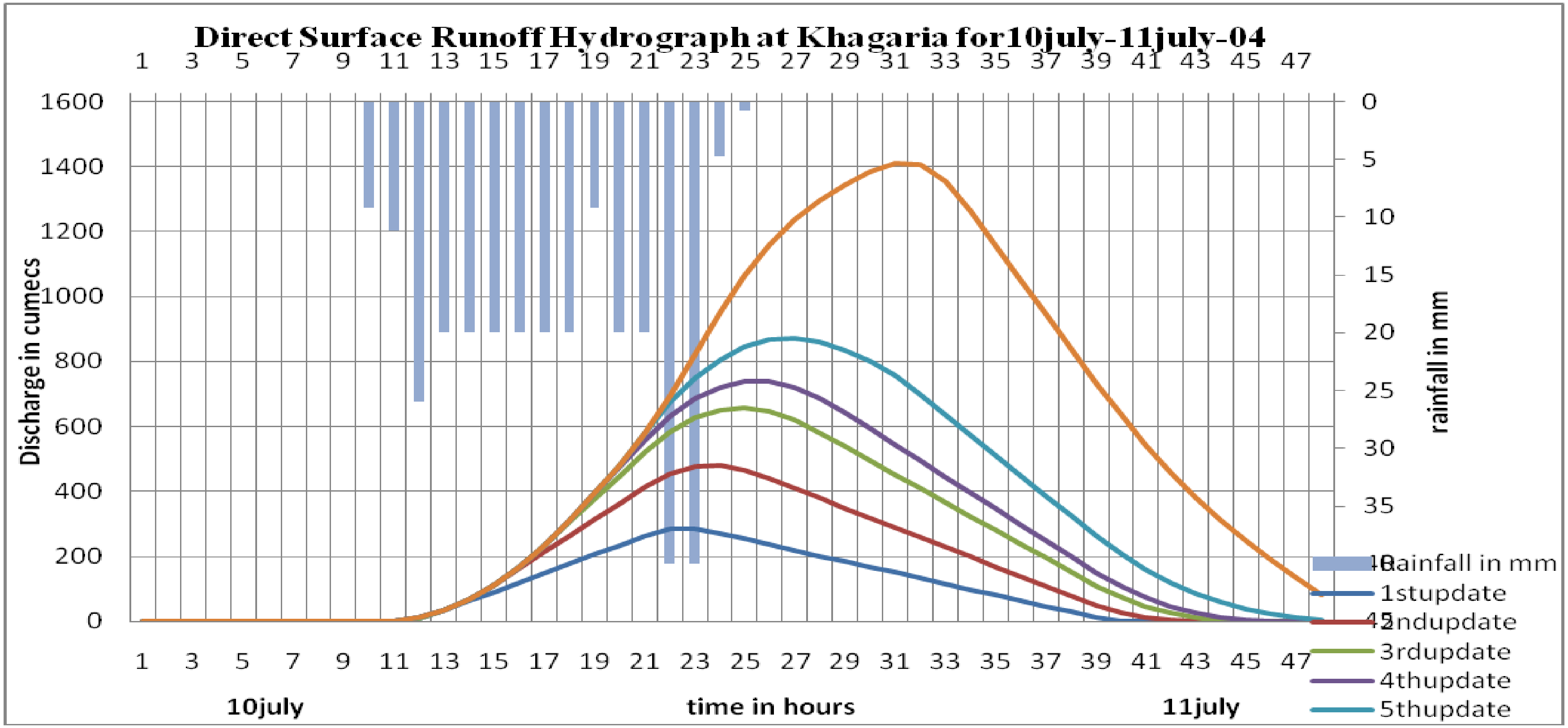
Validation of hourly Simulation of 2010 Flood Event



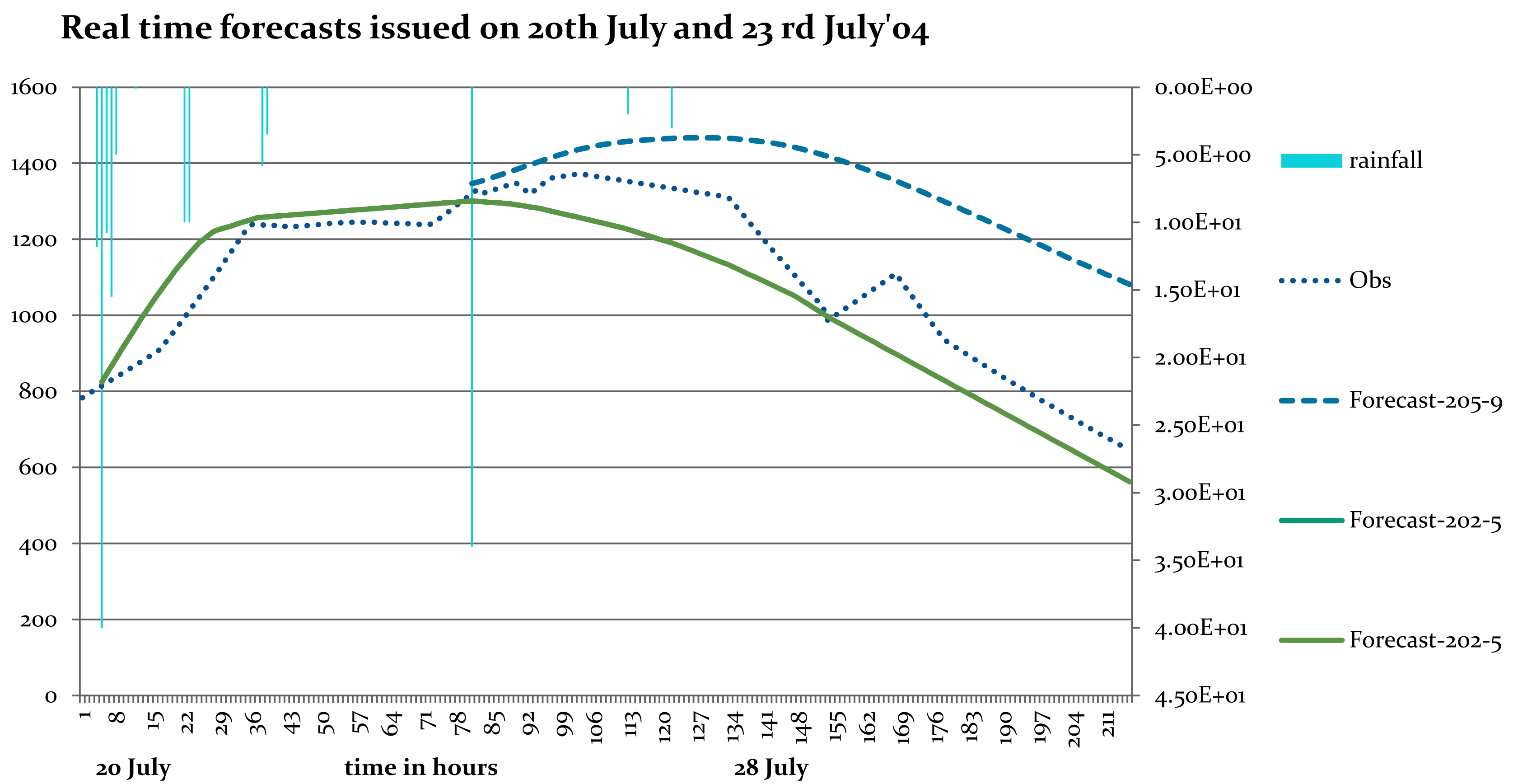
Validation of hourly Simulation of 2011 Flood Event



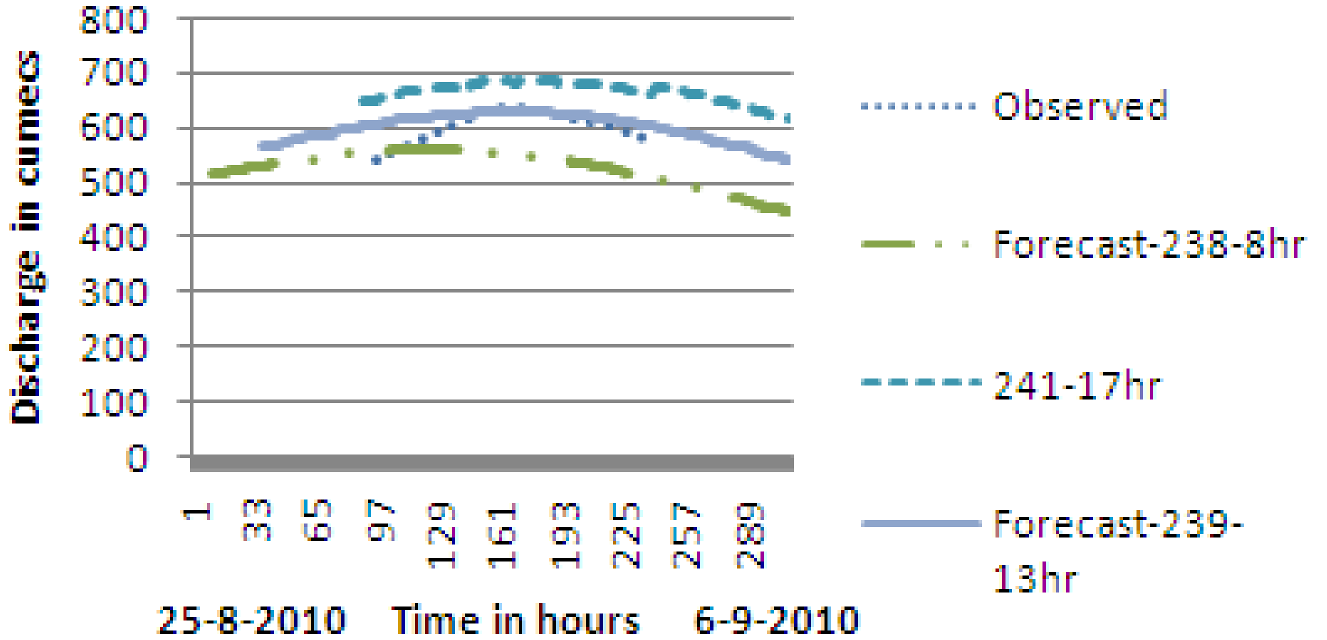
Real time flood forecasting graph generated by SWAT model



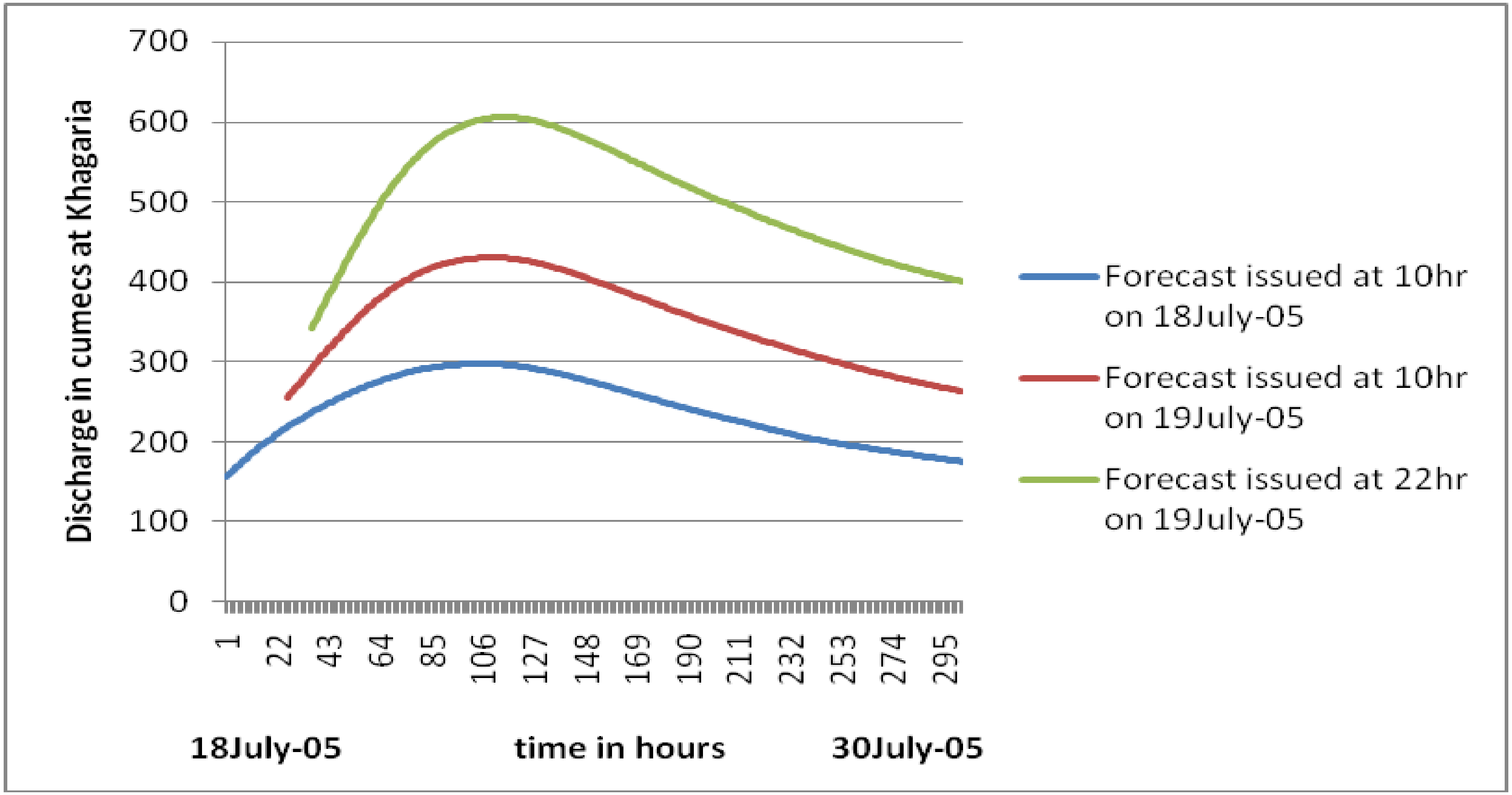
Real time forecasting graphs for 2004 Flood Event



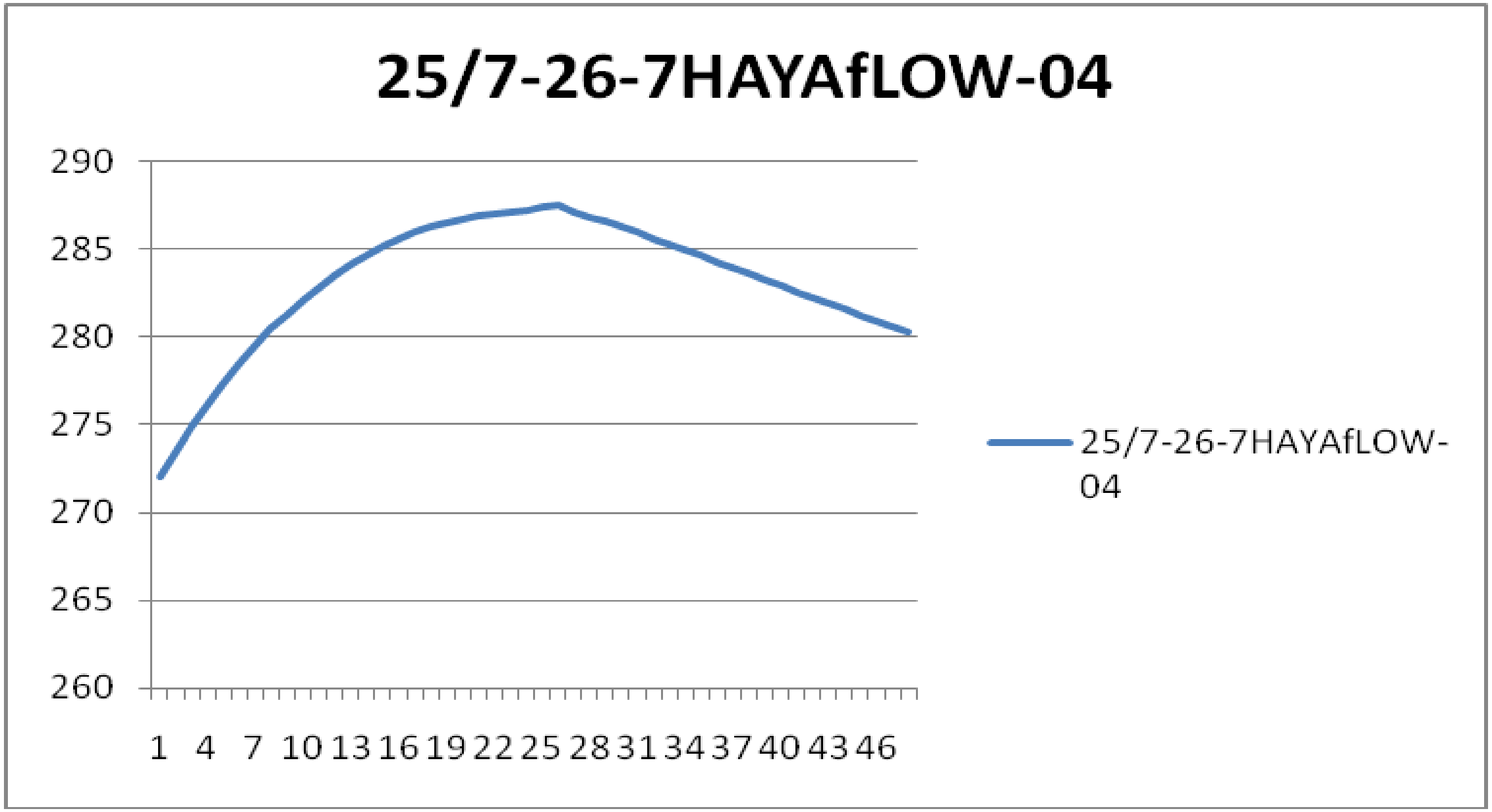
Real time forecast for 2010 Flood event



Real time flood forecasting Graphs generated by Modified SWAT model

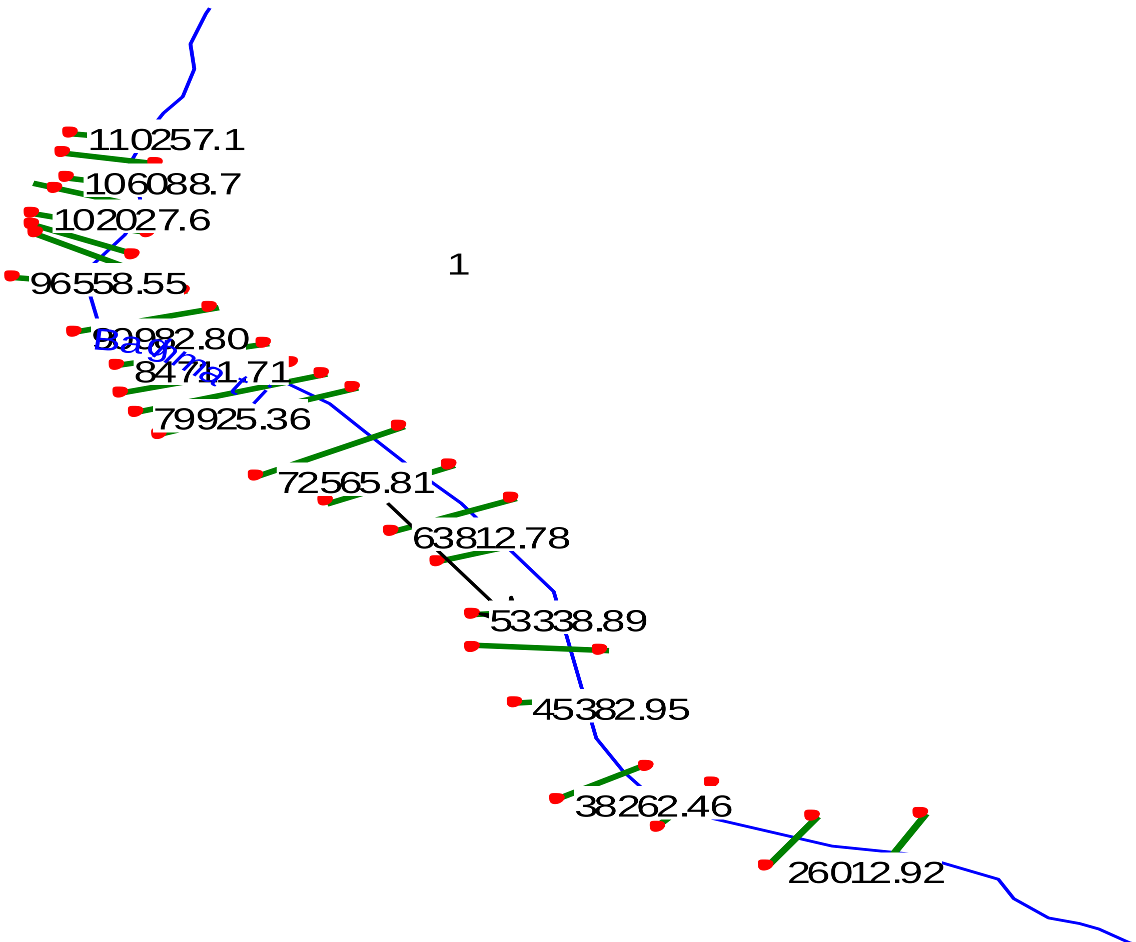


Real time flood forecasting of Haya for 2004 Flood event



TRANSLATING FORECAST INTO INUNDATION MAP

CROSS-SECTION POSITIONS



DATA NEEDED FOR RUNNING HEC-RAS FOR EXPECTED INUNDATION MAPPING

1.Plan of river showing a stretch of 273 km downstream of Dheng Bridge

2.Cross sections of Bagmati river (measured or derived from SRTM DEM)

3. Forecasted hydrographs Simulated by modified SWAT model as boundary conditions at various cross sections.

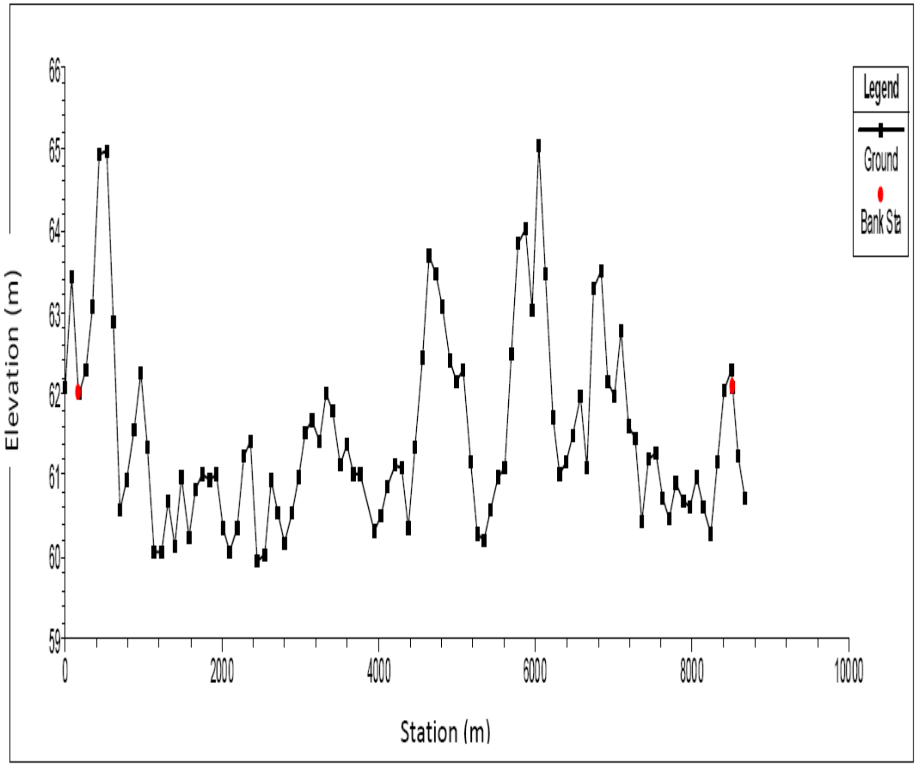
Cross Sections Data used

Data created by HEC-Geo-RAS in GIS format were imported to HEC-RAS project, using geometric data editor. Cross sections were entered properly. Regarding cross sections HEC-RAS has two options (1) extracting cross sections from DEM of SWAT model or (2) entering the real cross sections obtained from field manually.

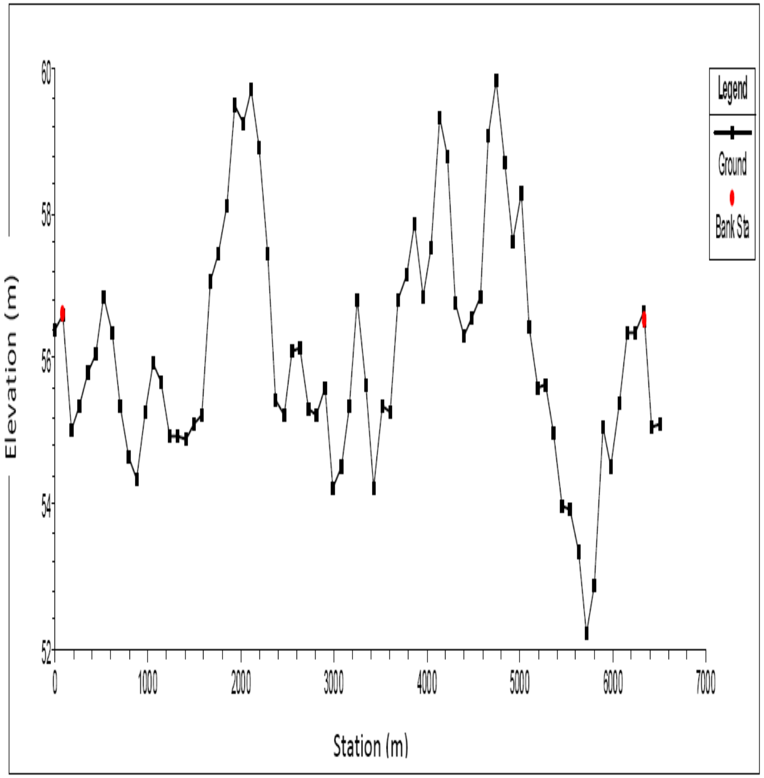
Here in the present study actual cross sections extracted from DEM have been used measured cross sections obtained from the field were entered manually for some locations.

Cross sections derived from SRTM differed from measured ones by 2-5 %

Some Cross Sections derived from SRTM can be Seen below



30 km downstream from Dheng Bridge

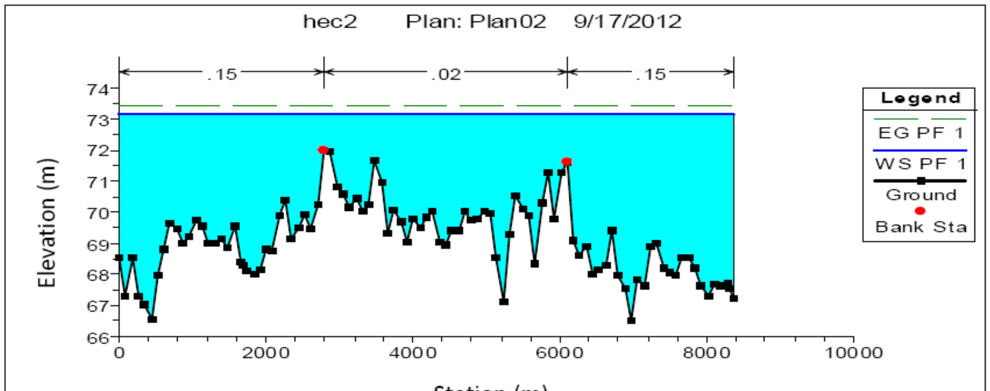


63 km downstream from Dheng Bridge

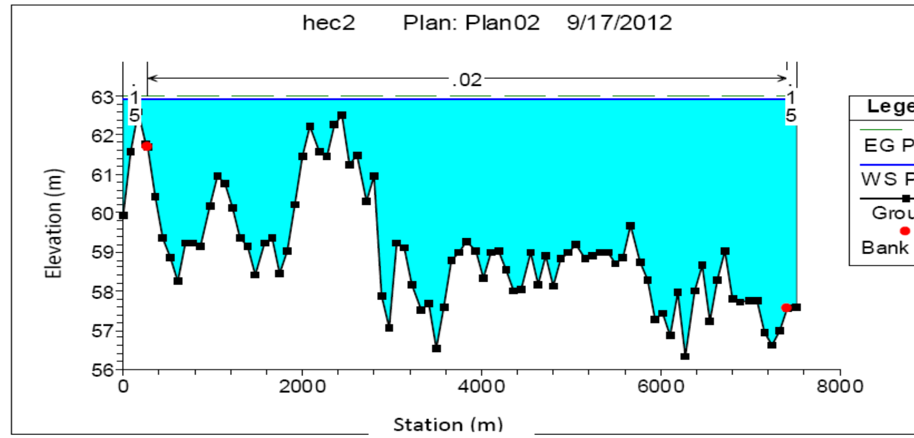
:

Water levels obtained from Hydrodynamic simulation for 13 July 2002 Flood event

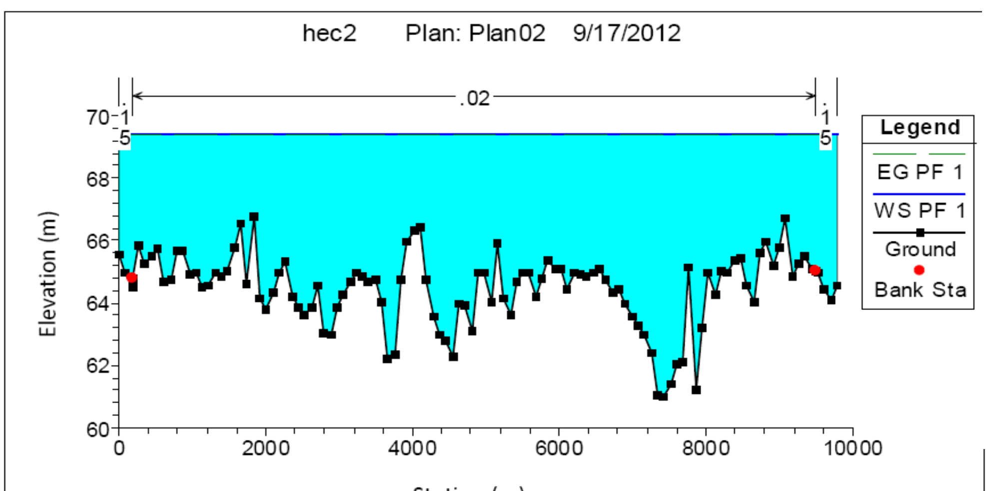
Distance (m) from Dheng	Water Level (m) (Our Simulation)	Water Level (m) (measured)	Difference (m)
0.0 (Dheng)	70.56	74.003	3.443
5000	68.99	69.796	0.806
10000	69.54	69.004	-0.536
20000	67.53	67.811	0.281
250000	64.98	65.393	0.413
39456.61	63.66	62.811	-0.849
61411.92 (Runisaidpur)	61.85	59.009	-2.841

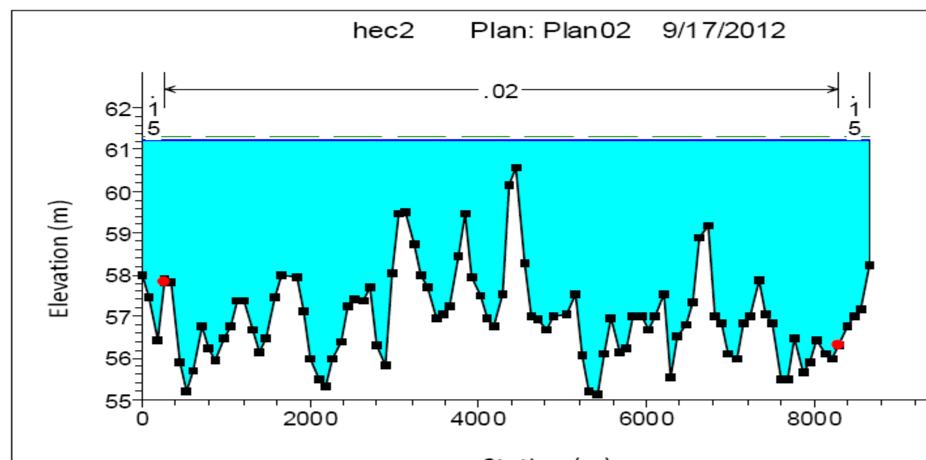


Water level in cross sections of Bagmati river 5 km downstream of Dheng Bridge



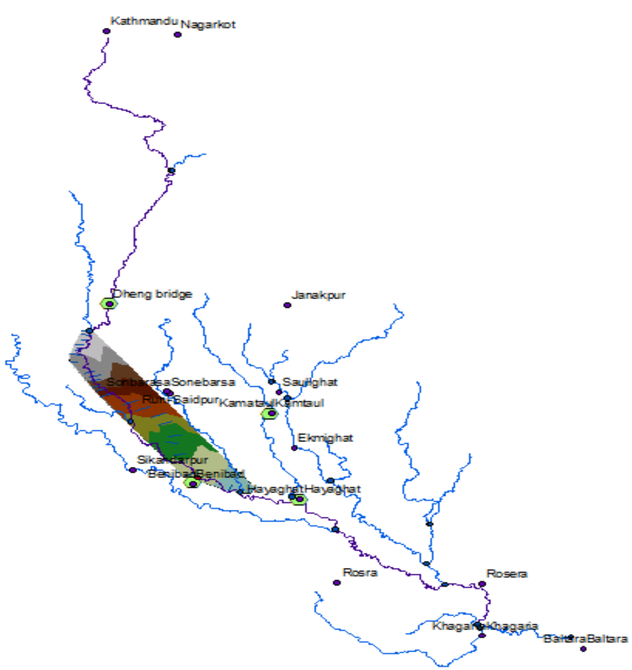
Cross section of Bagmati river at Runnisaidpur (64 k

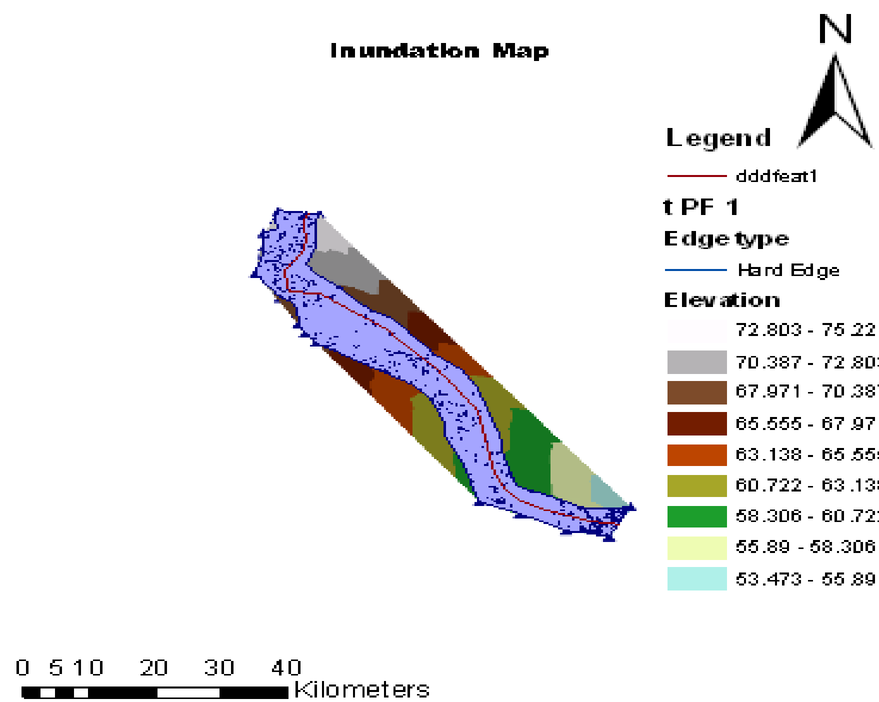




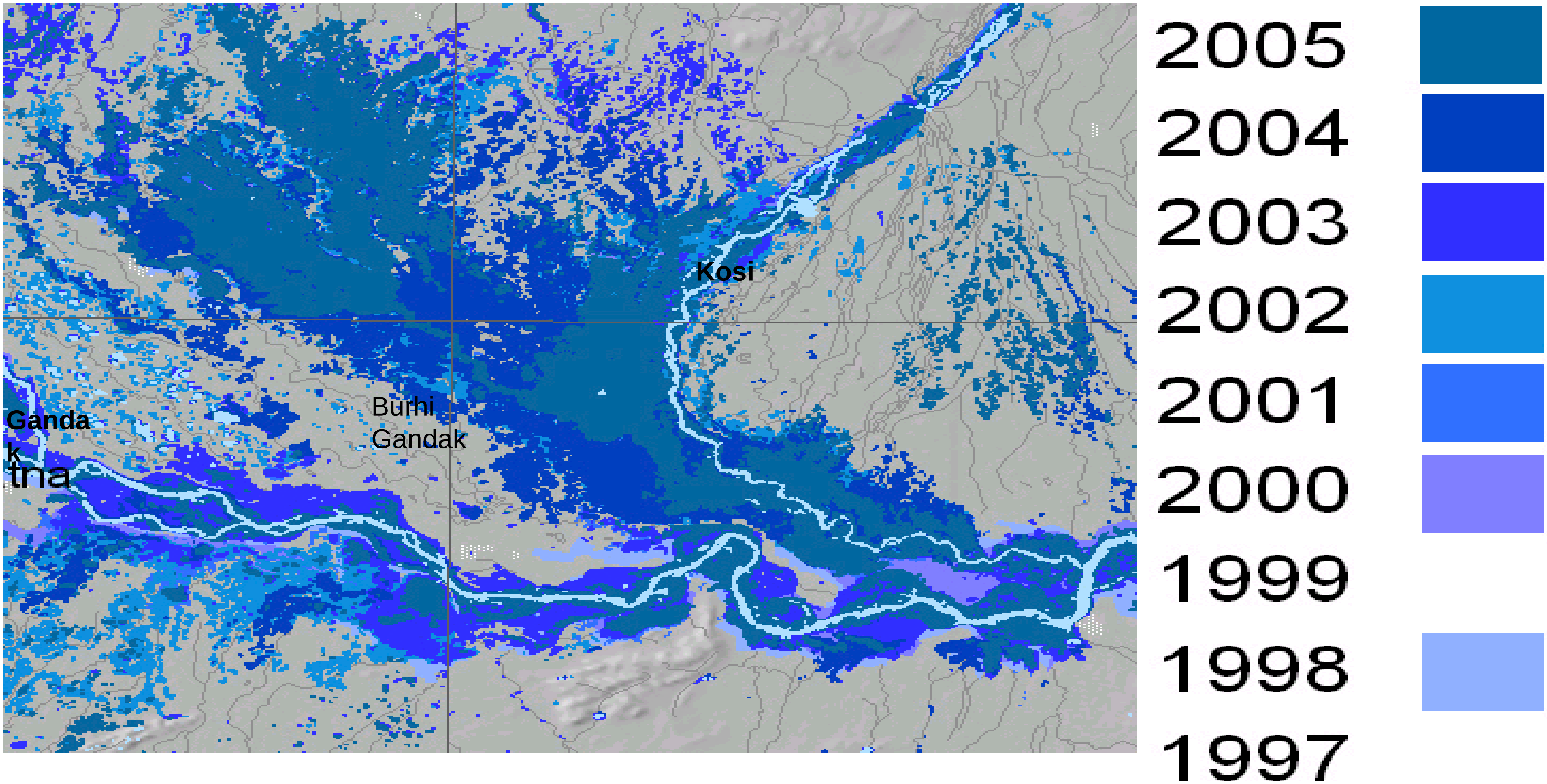
Cross section of Bagmati river 70 km fron

Expected Flood Inundation map of Bagmati river between Dheng Bridge and Hayaghat for July 2004 flood event simulated by SWAT and HEC-RAS



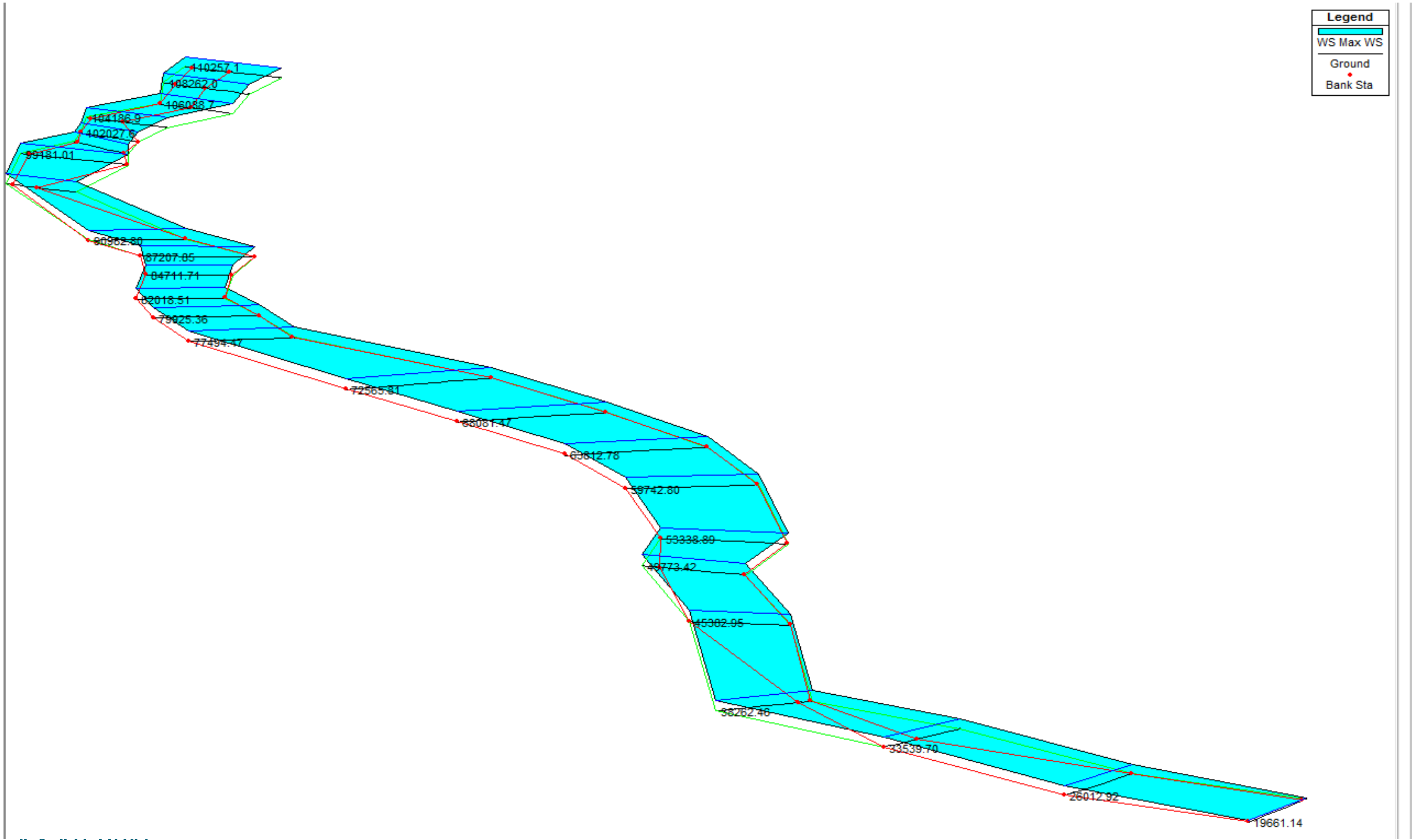


VALIDATION

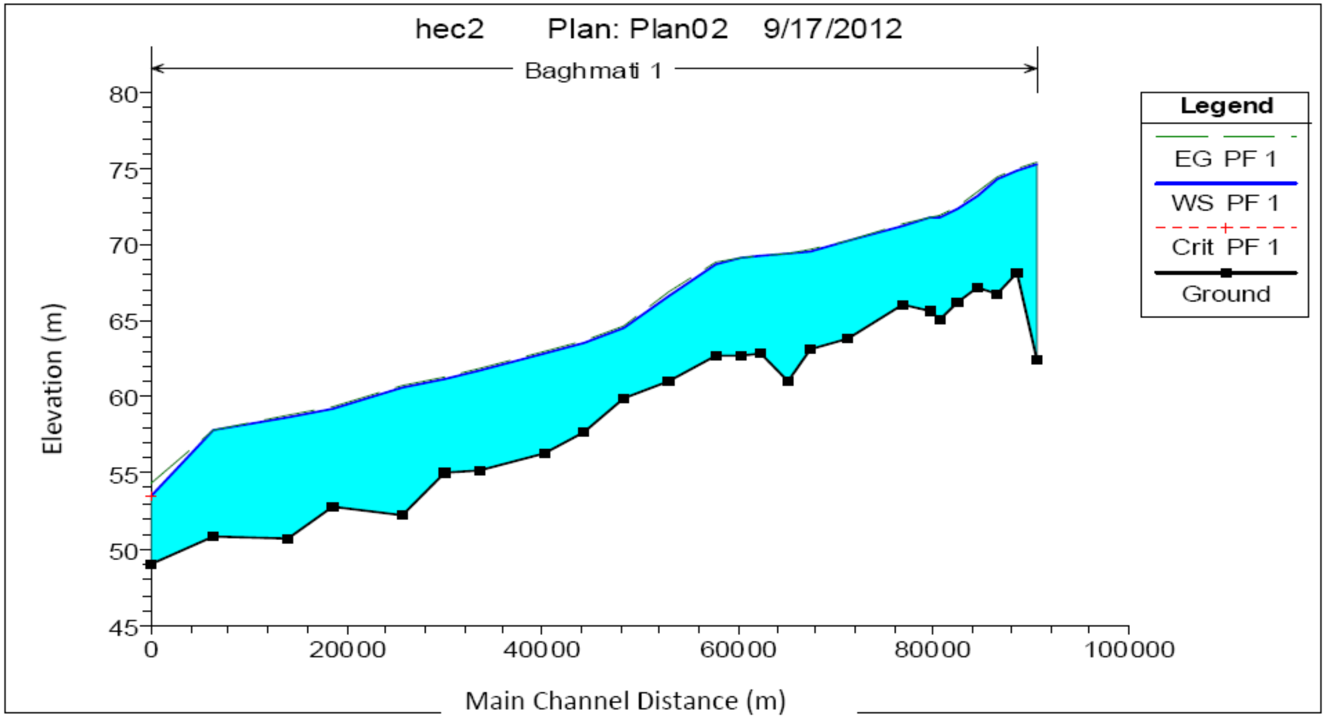


Simulated flood inundation maps were found in agreement with observed maps derived from satellite imageries obtained from NRSA, India

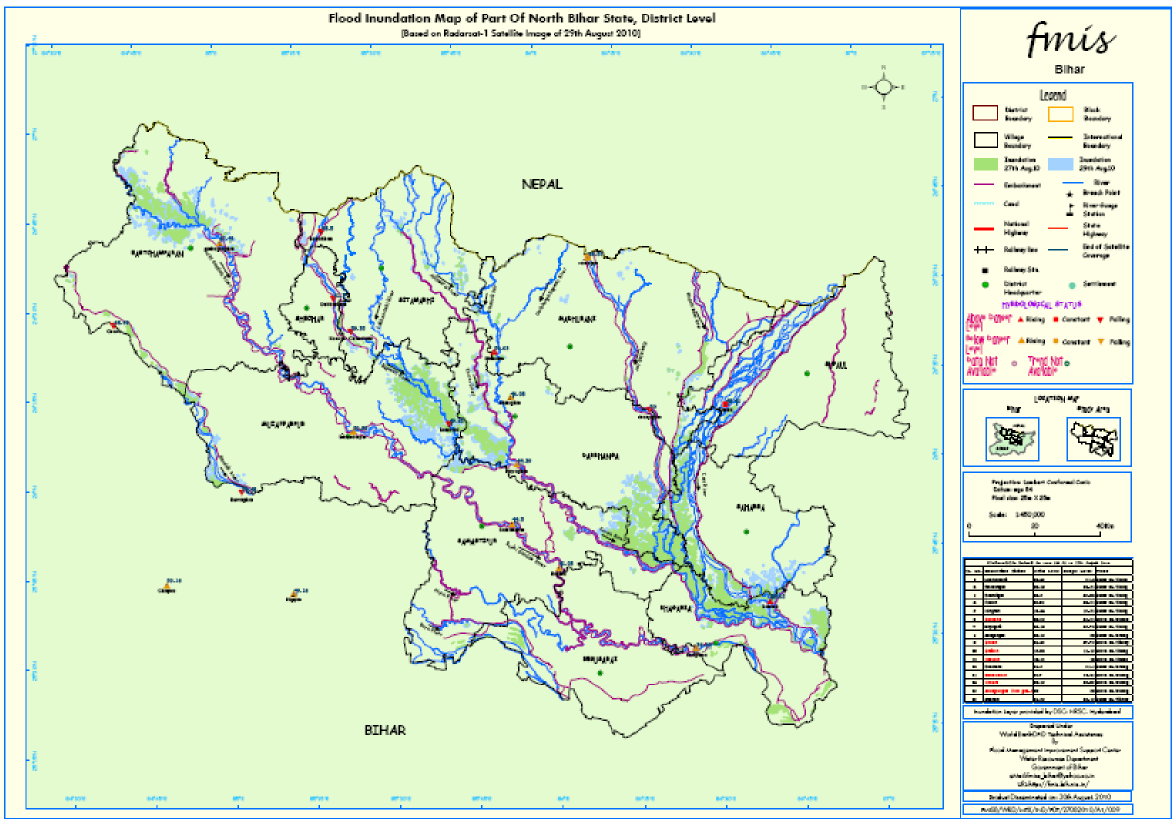
Perspective profile of Bagmati river for banked portion



Elevation profile of Bagmati river for 2004 flood event



Typical Information Product
(Flood Inundation Map of 2010 Flood Event)



CONCLUSIONS

1.Simulated Water levels are matching with that of measured water levels

2.Areas of inundation maps produced by modified SWAT model, HEC-Geo-RAS, and HEC-RAS are in agreement with corresponding observed values.

3.Hence it is concluded that modified SWAT model and HECRAS together can produce expected inundation on real time basis successfully.

4. Real Time Flood Forecasting by Modified SWAT Model has following advantages (i)Increase in lead time(catchment response delay + travel time in channel), (ii)application possible in ungauged catchments, (iii)Physically based,(iv)easy in adaptability(v)capable of modelling snow melt, percolation, lateral flow and base flow, (iv) Parsimonious, (vii) GIS based (viii) Inundation mapping and flood zonation easily possible with help of HEC-RAS, (ix) easy updating of catchment characteristics, (x) capable of incorporating rain fall forecast of IMD and increasing lead time (xi) increase in accuracy (xii) capable of generating synthetic sub-hourly hydrographs

GLOBAL CONCERN

- Hon'ble Narendra Modi, Hon'ble PM of India has announced special package for solving flood and climate change issues and has challenged scientists and engineers to solve the problem of flood inundation with help of modern technology.
- United nation has also asked all nations to submit their action plan on climate change problems.
- Water Resource Department, Govt. of Bihar, India has authorized us to collaborate with International Institutions of repute such as Purdue University, Texas University for challenging research works.
- World Bank have recently given one million dollar to WRD, Bihar, India for consultancy project for developing real time flood forecasting inundation mapping of Bagmati River Basin and Kosi River Basin of Bihar, India.

GLOBAL CONCERN

US Pope Francis during an official welcoming ceremony called for a strong action to combat climate change, calling it a problem which can no longer be left to a future generation. Obama, US President, in turn, hailed the Pontiff as a moral force who is shaking us out of our complacency with reminders to care for the poor and the planet.

IMPORTANT REALIZATION DURING RESEARCH

- SYNTHESIS OF SCIENCE AND SPIRITUALITY IS MUST FOR EXAMINING THE NATURE OF REALITY
- STARTING WITH FACTS, GETTING GOOD RESULTS, AND DEVELOPING FAITH IN THE INNOVATION AND METHODOLOGY ARE IMPORTANT STEPS
- FAITH AND CONFIDENCE COMES FROM EXPERIENCE, INTUTION AND SELF REALIZATION
- I REMEMBER THE STATEMENT OF OUR HON'BLE MASTER SRINIVASAN SIR AFTER I DISCOVERED FLOOD FORECASTING CAPABILITY OF SWAT DUE TO GRACE OF MY SPIRITUAL MASTERS

"FINALLY YOU SAW THE LIGHT IN THE TUNNEL BY THE GRACE OF SUPER CONSCIOUSNESS"

FINALLY I WANT TO REMIND YOU THAT IN SEPTEMBER-OCTOBER1893 CHICAGO , USA SWAMI VIVEKANAND DELIVERED LECTURES IN WORLD RELGIOUS CONGRESS AND PROPOUNDED THAT ULTIMATE TRUTH CAN BE REALIZED BY INTEGRATION OF MIND,INTELLIGENCE, CONSCIOUSNESS AND SUPER CONSCIOUSNESS

HOW CAN IMPERFECT SENSES REALIZE *PERFECT KNOWLEDGE?*

SHOULD'NT WE PRAY FOR HELP FROM SUPER CONSCIOUSNESS?

Thank You