Web-based Real Time Flood Forecasting Using SWAT Model

By

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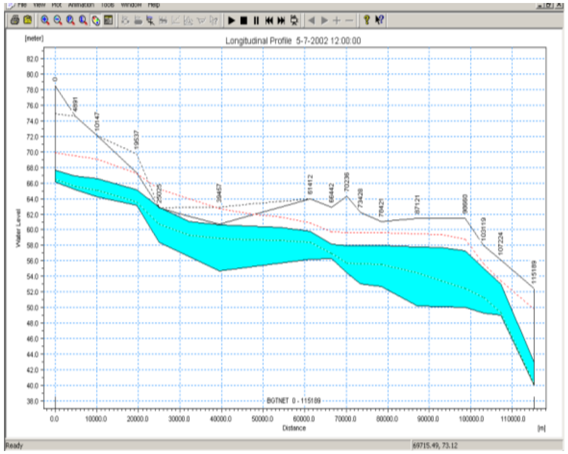
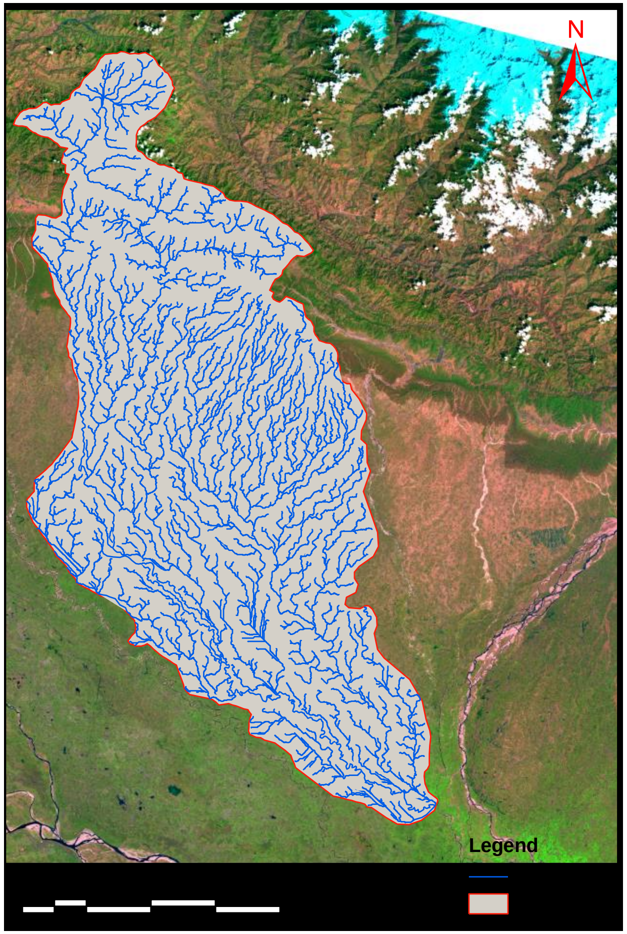
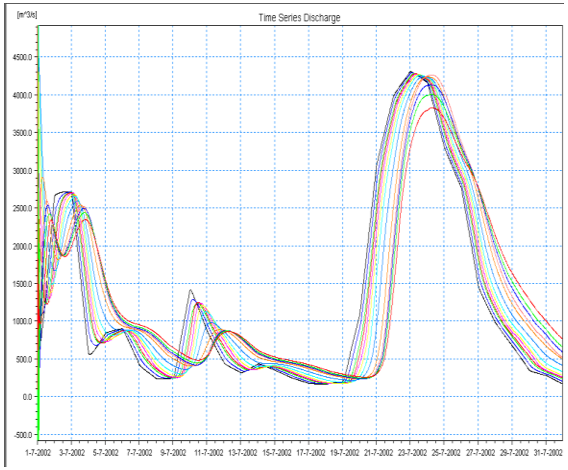
Use of New Technologies & Softwares in Flood sector





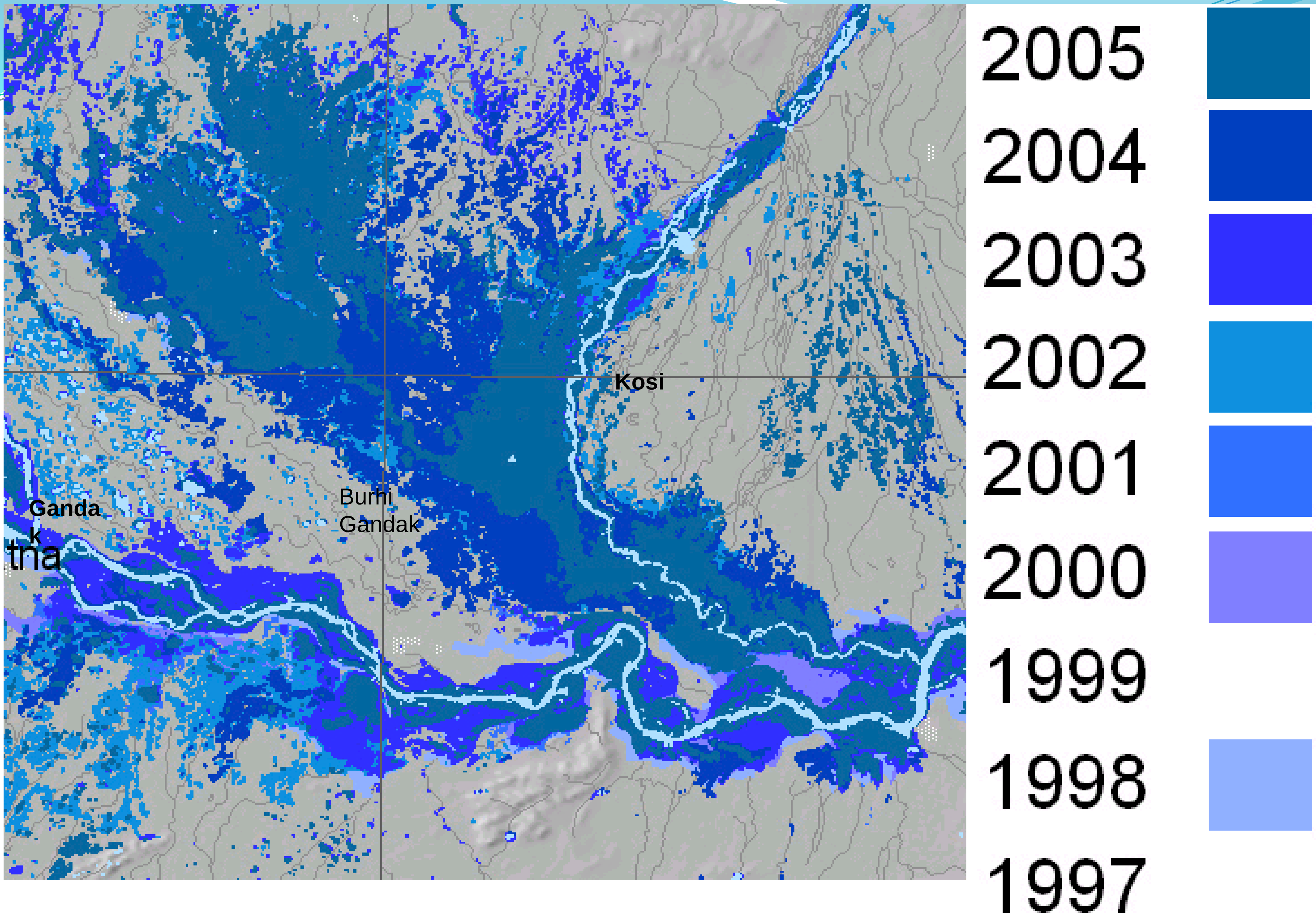


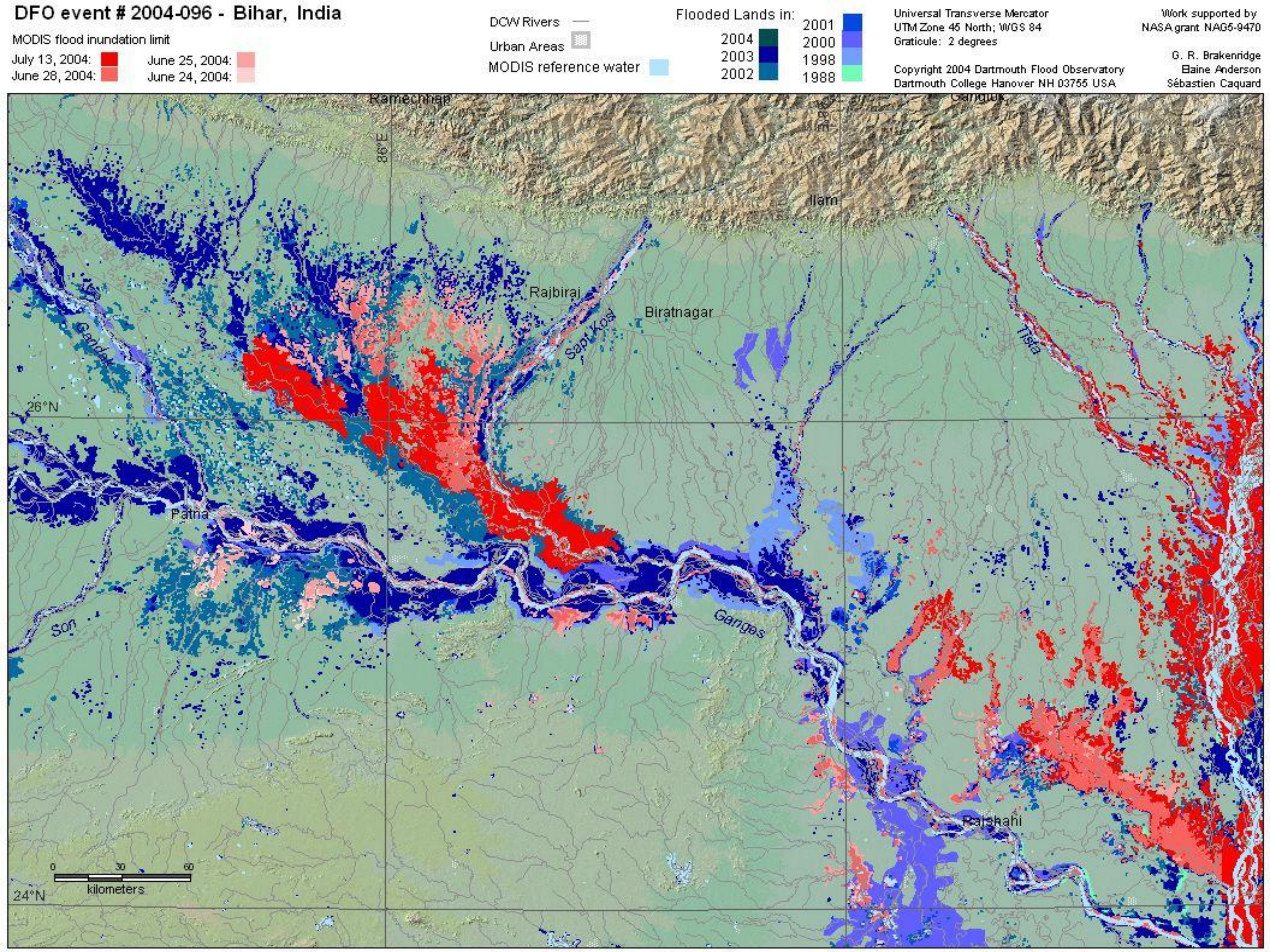
Introduction

Flood is associated with a serious loss of life, property and damage to utilities.

Event-1 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


Kosi
Burhi Gandak
Ganda k
tna
2005
2004
2003
2002
2001
2000
1999
1998
1997


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
Work supported by
NASA grant NAG5-9470
G. R. Brakenridge
Elaine Anderson
Sébastien Caquard
Ramechhap
Gangtok
86°E
88°E
Ilam
Rajbiraj
Biratnagar
Sapt Kosi
Tista
Gandak
26°N
Patna
Son
Ganges
Rajshahi
0
30
60
kilometers
24°N




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

Dehradun -Capital of Uttarakhand

Challenge 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

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?

Objective of the study

- To modify SWAT model for real time flood forecasting and apply modified SWAT model for real time flood forecasting of river basins using web based data,
- To enhance the forecast lead time by incorporating the rainfall forecast issued by IMD and assess its accuracy.

- To map expected inundation, and flood zonation by integrating SWAT outputs into HEC GeoRAS and HEC-RAS models

Real Time Flood Forecasting and Flood Plane Zoning System

COPONENTS

- The Real Time Flood Forecasting and Flood Plain Zoning System usually consists of one or more of the following components:

  1. Rainfall Runoff Model.
  2. Runoff Routing Model.
  3. Error Analysis and Updating Technique
  4. Hydrodynamic model for channel routing (HEC-RAS)
  5. Generating TIN and delineating flood plain

METHODOLOGY USED IN PRESENT STUDY

1. Watershed delineation using SRTM DEM
2. Formation of HRUS
3. Writing input tables
4. Runoff generation using Green Ampt Method
5. Developing subroutines and modifying SWAT for real time flood forecasting application

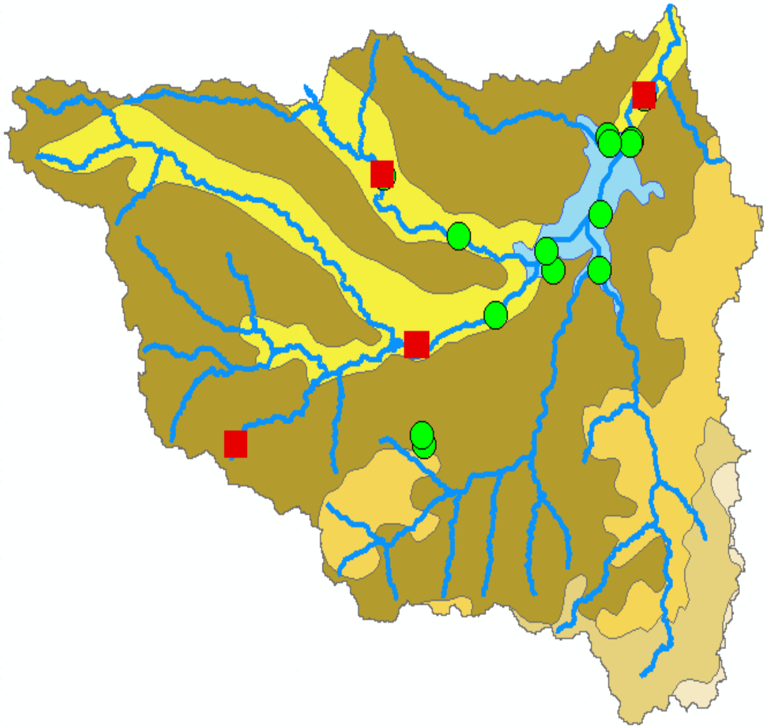
Models for Forecasting

- Statistical/ Black box
  - Correlation
  - UH Based
  - Stochastic (ARMAX)
- Conceptual (Water Balance)
  - SWAT
  - HEC-HMS

Methods for Flood Forecasting

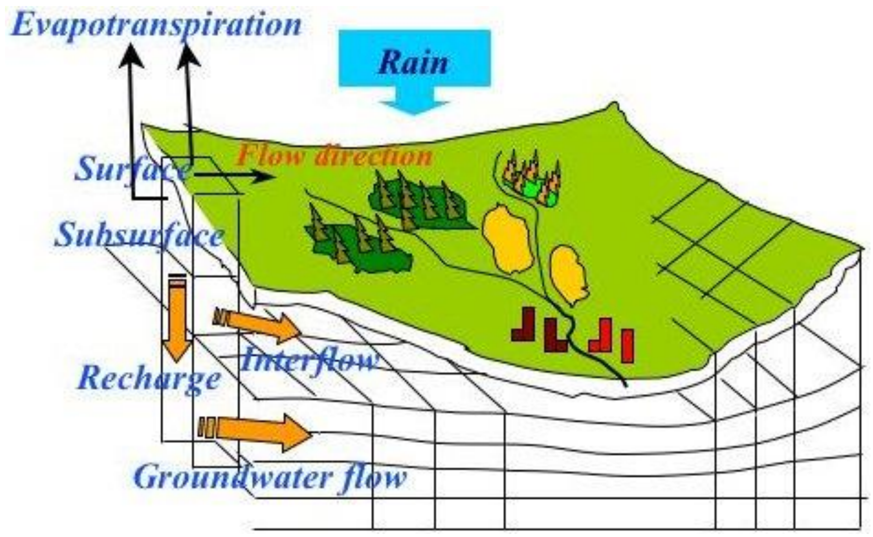
Simple correlations

- Use very little data
- Only gauge data is sufficient
- Work very well for reaches that ha small contribution from rain



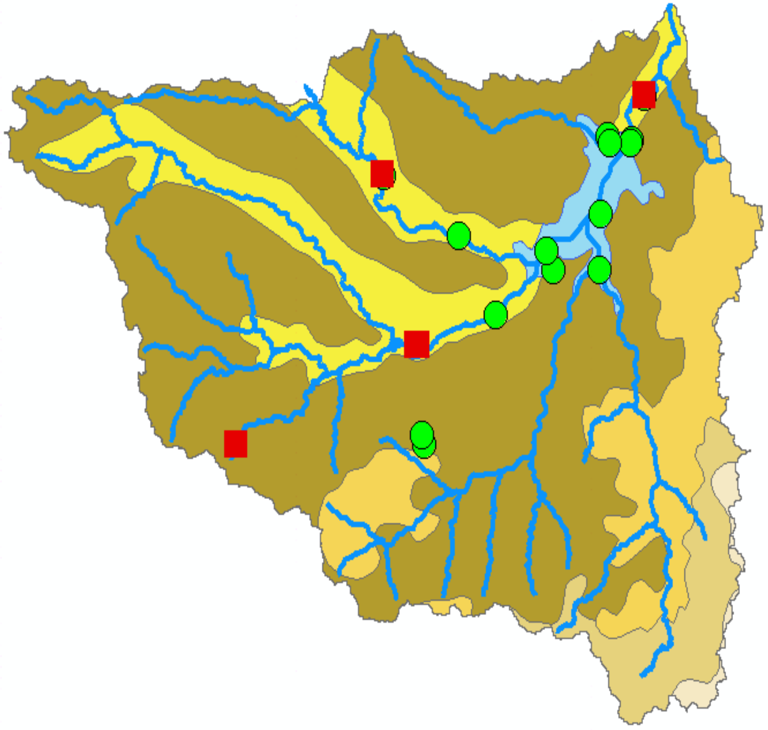
Physically Based Models

To use the equations of mass, energy and momentum to describe the movement of water over the land surface and through the unsaturated and saturated zones.

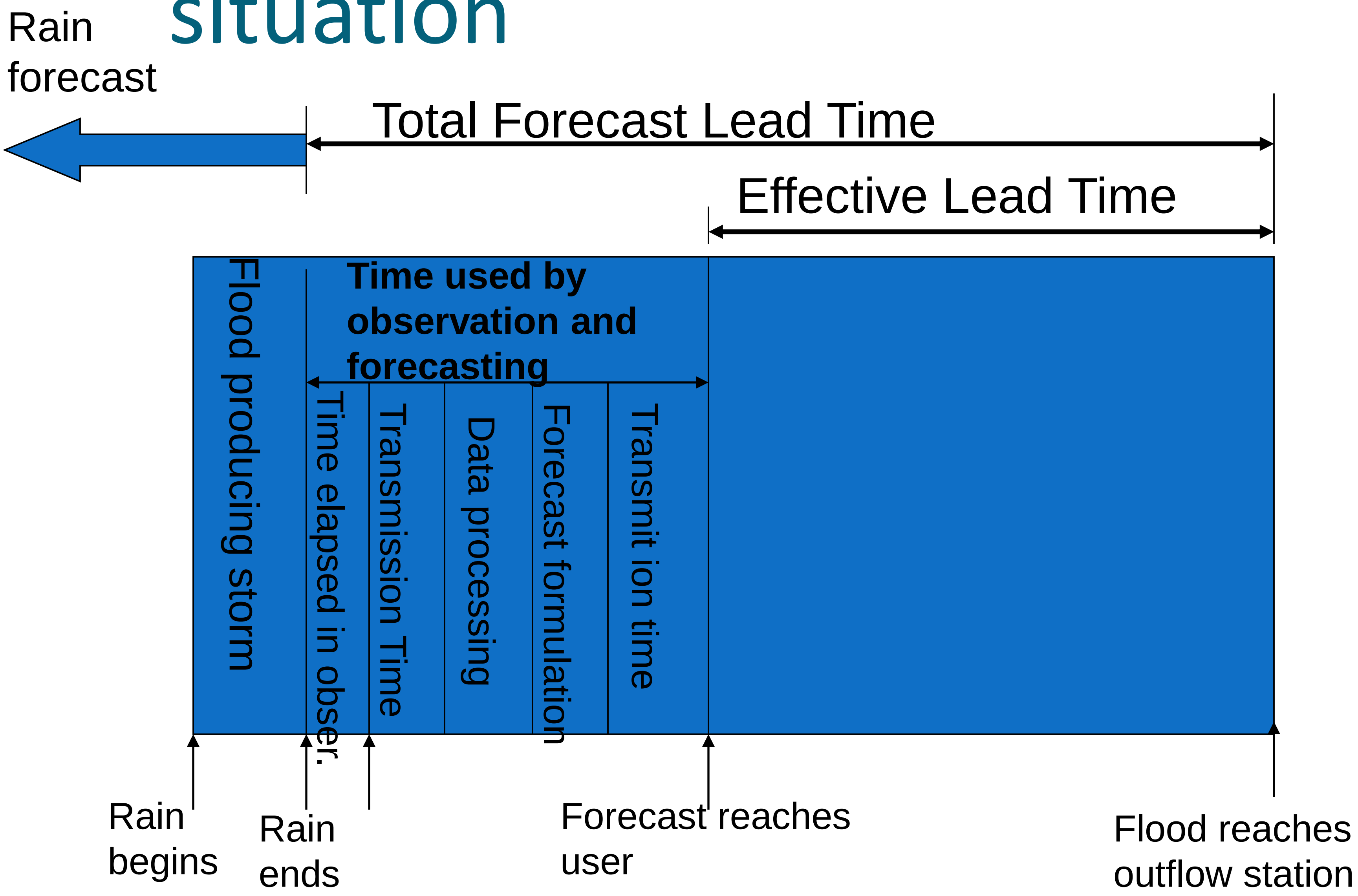


Ways to enhance the forecasts

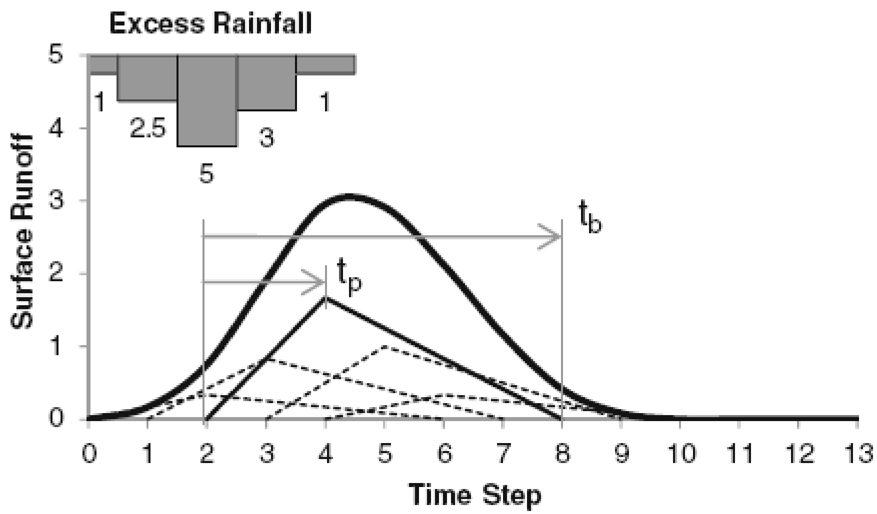
- Enhanced forecasts require data on rainfall
  - To incorporate the contribution of the catchment
  - To incorporate the impact of spatial variability
  - Forecast lead time increases on account of catchment lag
  - Addition to lead time is possible through precipitation forecasting



Typical flood forecasting situation



Surface runoff hydrograph generated by superimposing dimensionless triangular unit hydrographs



Gamma Distribution UH Method

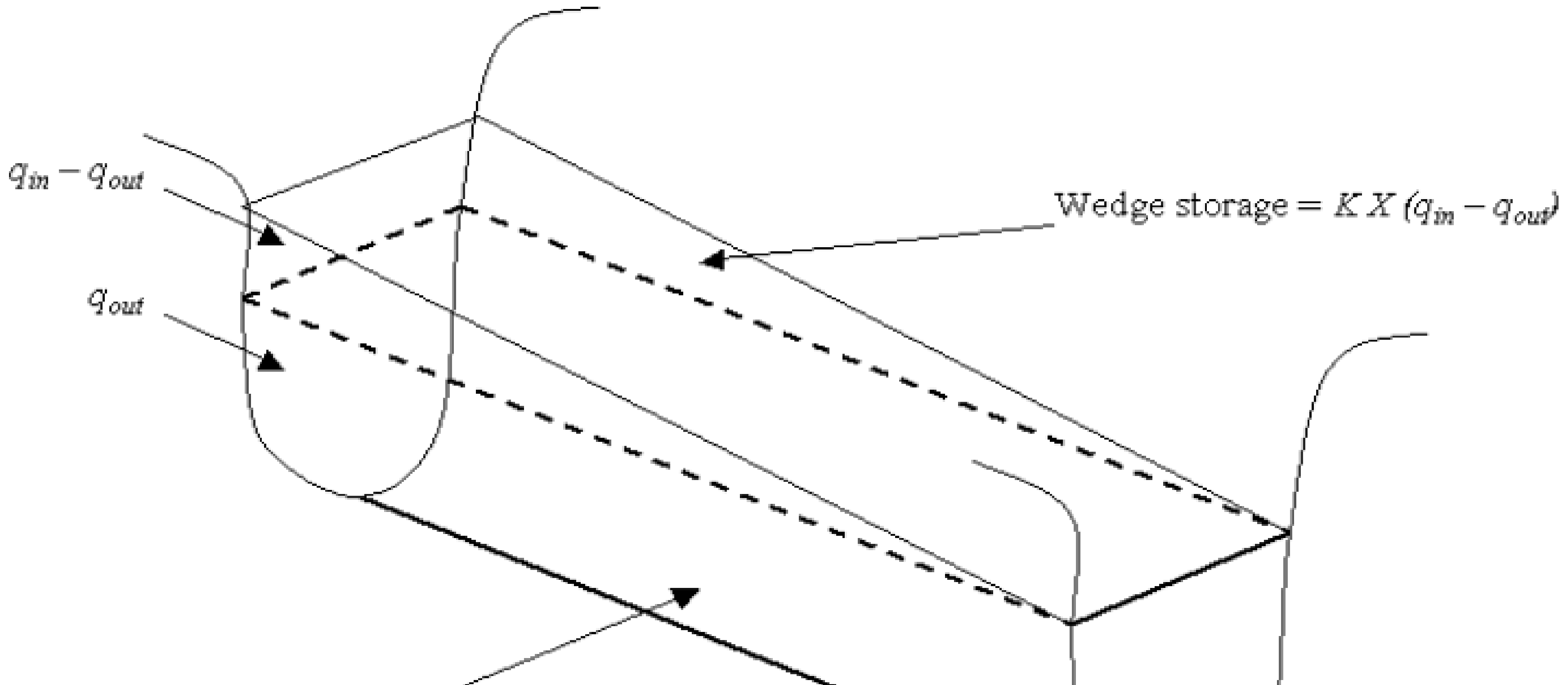
The gamma distribution UH method adapted from Aron and White (1982) defines unit flow as follows:

$$q_{uh} = \left(\frac{t}{t_p}\right)^{\alpha} \cdot \exp\left(\left(1 - \left(\frac{t}{t_p}\right)\right)^{\alpha}\right)$$

where α is a dimensionless shape factor which is larger than zero.

Muskingum Routing Method

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

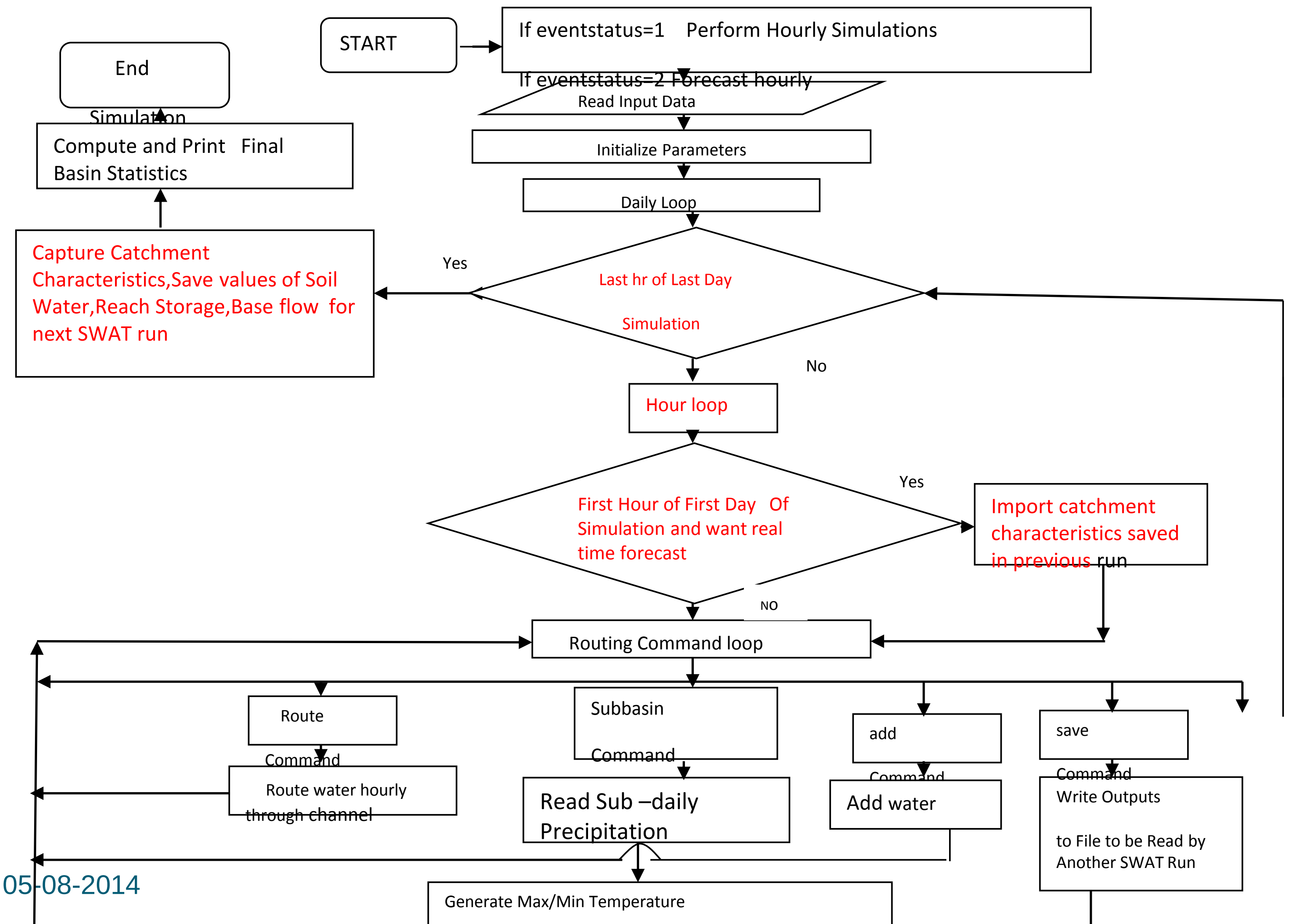


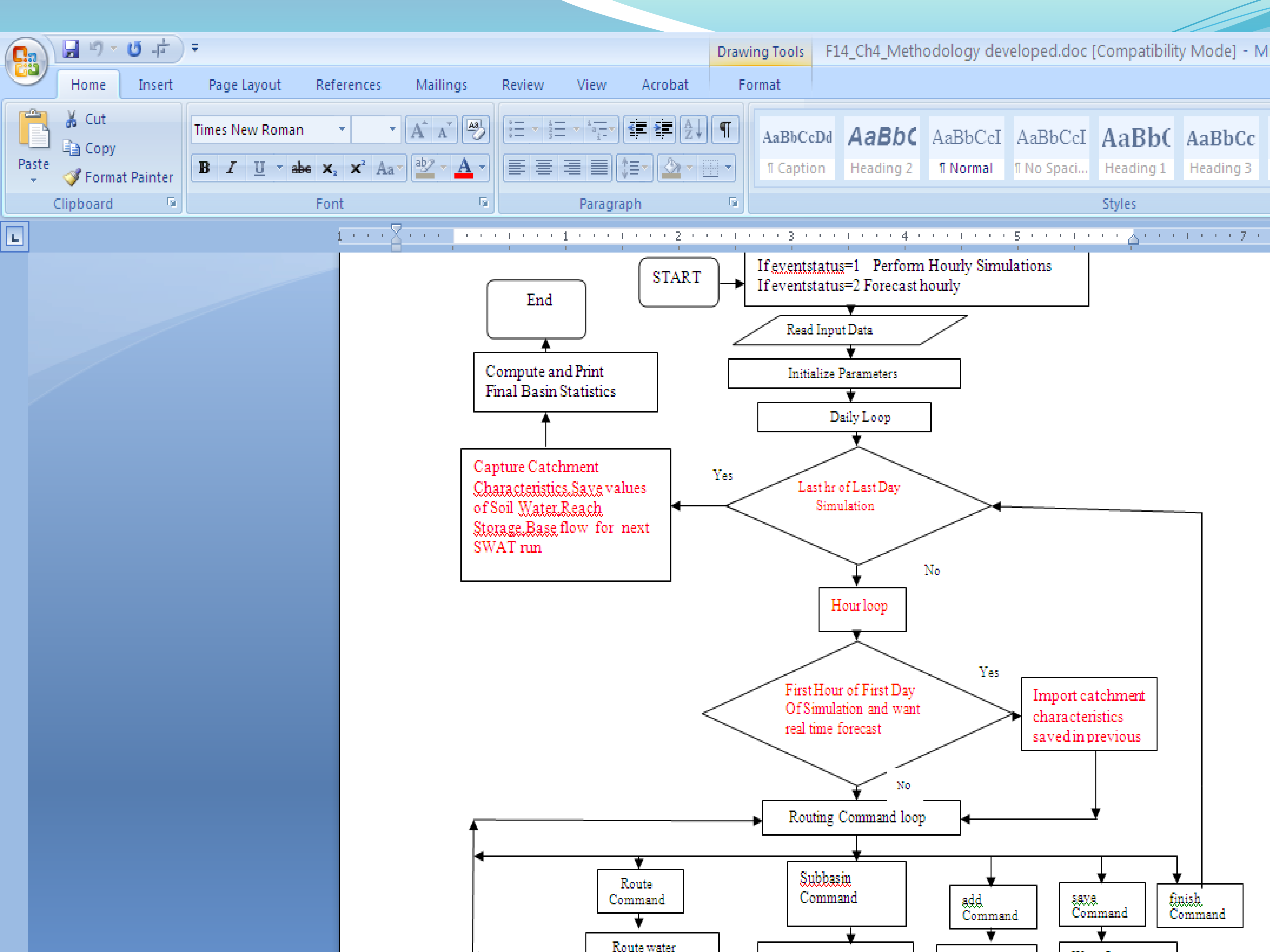
$$V_{stored} = K \cdot \left(X \cdot q_{in} + (1 - X) \cdot q_{out}\right)$$

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


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
Simulation
End
Hour loop
First Hour of First Day Of Simulation and want real time forecast
Yes
Import catchment characteristics saved in previous run
NO
Routing Command loop
Route
Command
Route water hourly through channel
Subbasin
Command
Read Sub –daily Precipitation
add
Command
Add water
save
Command
Write Outputs
to File to be Read by Another SWAT Run
Generate Max/Min Temperature


F14_Ch4_Methodology developed.doc [Compatibility Mode]
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
Import catchment characteristics saved in previous
Routing Command loop
Route Command
Subbasin Command
add Command
save Command
finish Command
Route water

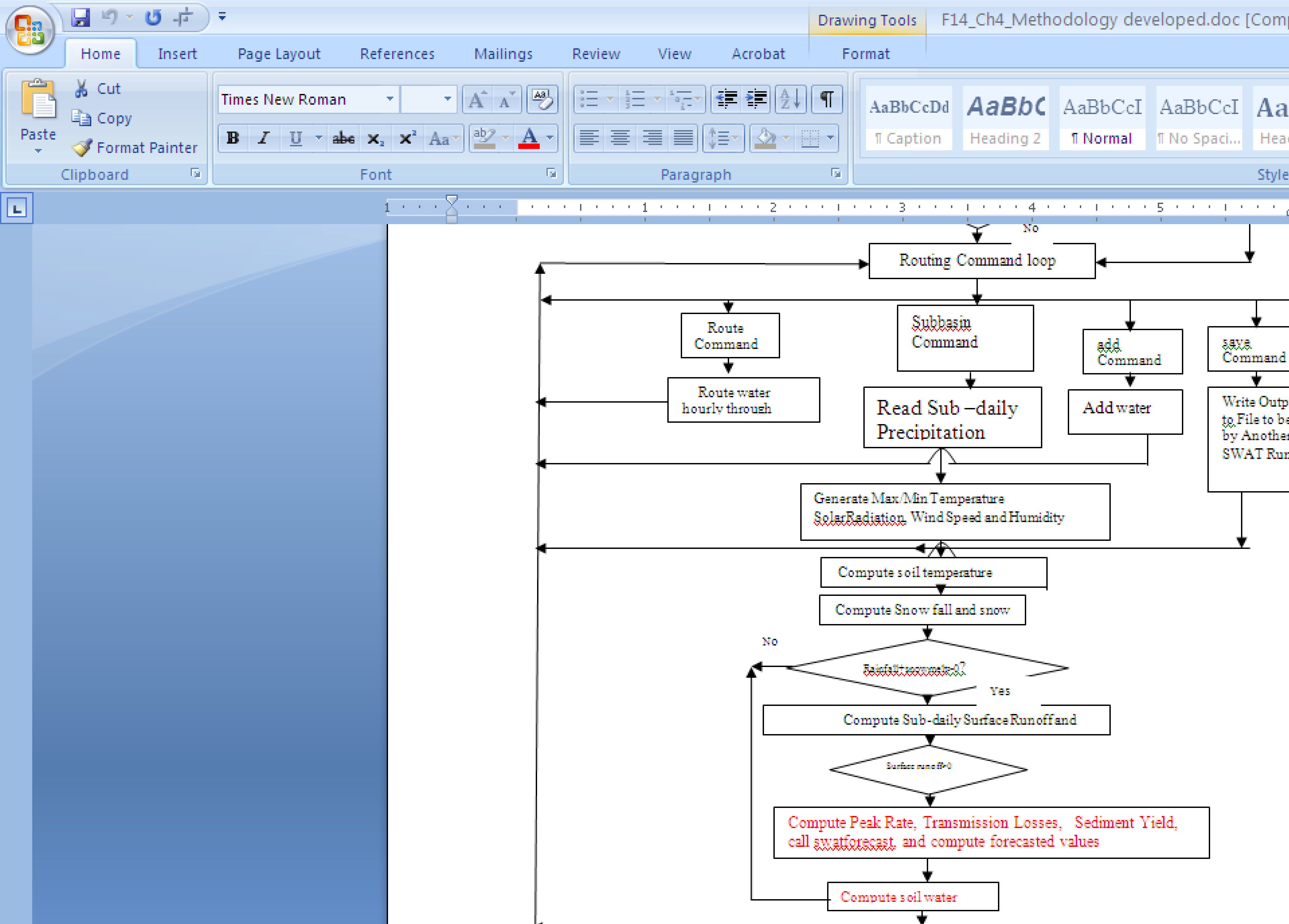
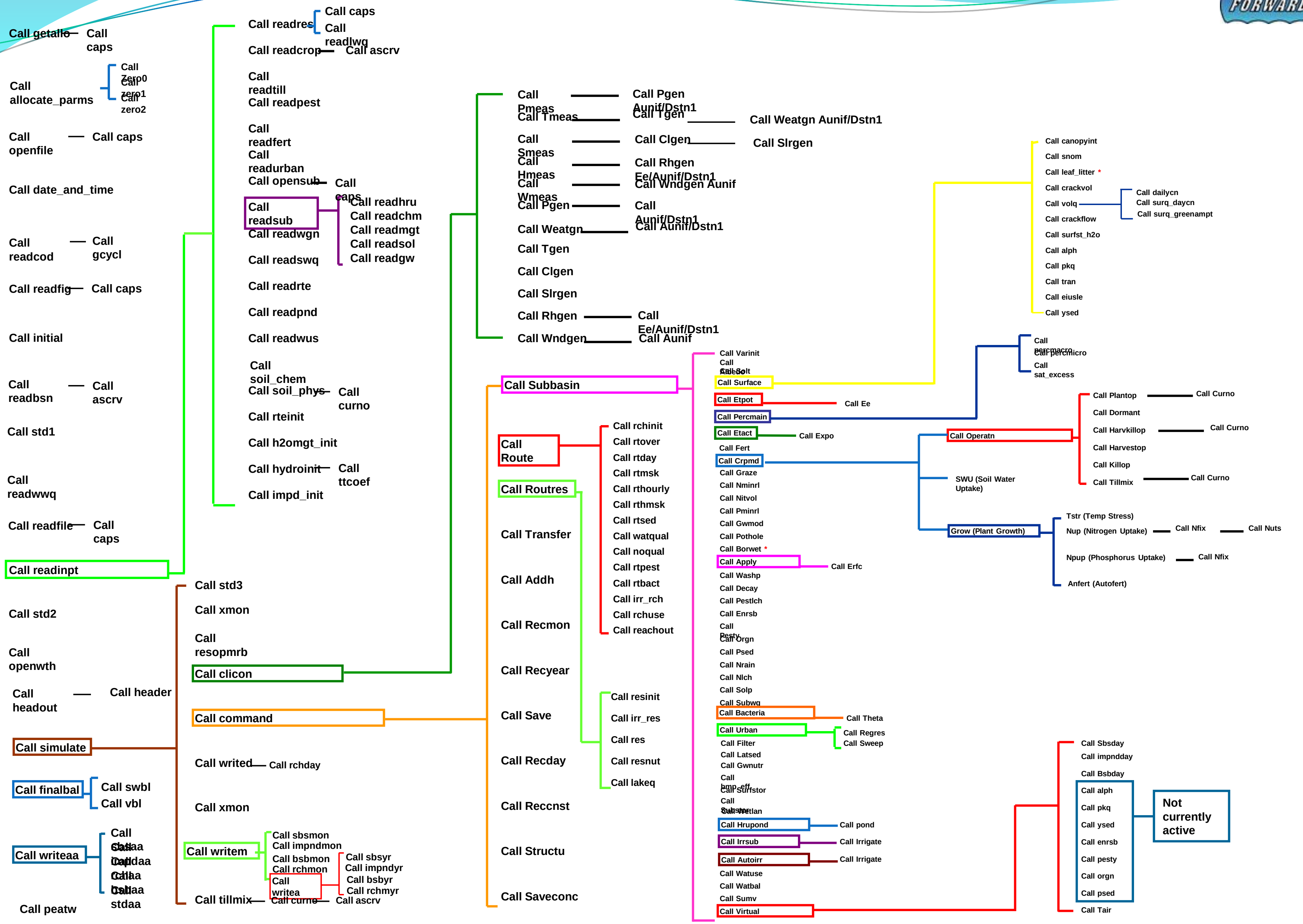


Figure 4.1 Modified Operational Flow Chart of SWAT Model

SWAT FlowChart



4.1.2 Modifications in modelling architecture

All subroutines have been thoroughly studied and modelling architechture
been reviewed. A new parameter "eventstatus" is defined. If "eventstatus" =0, orig
SWAT is run without any modifications. It gives output on daily basis irrespective of
weather data input being daily or sub-daily. This is the modelling design of the
modified version of SWAT. The choices of eventstatus are given to the user during
from program main.f. Next there are two options. The user can get subdaily outpu
providing subdaily input data by putting "eventstatus" =1 or, he/she can use the
conditions water in the reaches, soilwater content, baseflow, snow melt, hydra
conductivity of soil, curve number, wetting front matric potential etc. from a previo
saved file as initial conditions for the new run by putting "eventstatus" =2 and go for
time flood forecast for "eventstatus" =3.

In the pre-modified SWAT, a model must run in daily loop starting with first h
of the first day and ending with 24^{th} hour of the last day of declared simulat

Two new subroutines forecasthourly.f and swatforecast.f have been developed anc integrated into SWAT model and other related subroutines main.f, rout.f, rthourly.f surq_greenampt.f for enabling it for hourly simulation and forecasting flows at outle points of different sub-basins. The new subroutines forecasthourly.f and swatforecast.: are attached with Appendix I and other modified sub routines are attached with Appendix II. Modified version of SWAT takes in sub-hourly rainfall data as input and estimate: infiltration and excess rainfall by GAML (Green and Ampt Mein Larson) excess rainfal method. A dimensionless synthetic unit hydrograph is used for overland routing tc forecast flows at outlet points of different sub-basins. Evapotranspiration, soil wate contents, base flow, lateral flow and snow melt are estimated on a daily basis anc distributed equally for each time step. Subroutines have been modified to capture the fina conditions of the catchment at any desired instant. Catchment station is updated on real- time basis after each time step. In modified SWAT, capability of event modelling has alsc been introduced. First of all the model is run in continuous mode to simulate the characteristics of the basin and validate the model using the historical flow data method. A dimensionless synthetic unit hydrograph is used for overland routing to forecast flows at outlet points of different sub-basins. Evapotranspiration, soil water contents, base flow, lateral flow and snow melt are estimated on a daily basis and distributed equally for each time step. Subroutines have been modified to capture the final conditions of the catchment at any desired instant. Catchment station is updated on real-time basis after each time step. In modified SWAT, capability of event modelling has also been introduced. First of all the model is run in continuous mode to simulate the characteristics of the basin and validate the model using the historical flow data. Subsequently the model is run in real-time mode with the initial conditions captured from the historical simulation. After every time step the modified SWAT captures and stores status of the catchment at the end of the interval to be used as the starting status for the next interval. Also an error forecasting model has been developed by time series analysis of previous forecasts.

it was compulsory to provide rainfall and other input data upto the 24th hour even if it was not available till the end of the last day. Simulation had to be done till 24th hour. This modelling structure did not support event modelling. Two new variables 'starthour' and 'endhour' have been introduced. Starthour is the starting hour of simulation in the first day. Endhour is the last hour of simulation in the last day. The intended values of these two variables should be saved in the file 'simhour.dat' before running the model. Likewise the starting day and ending day of simulation are controlled in file.cio as 'idaf' and 'idal' respectively. The added advantage of this new provision is that simulation is made possible from one hour to another hour within the same day.

Two subroutines forcasthourly.f and swatforecast.f have been developed and integrated into SWAT for enabling it for hourly simulation and forecasting flows at outlet points of different subbasins. Modified version of SWAT takes in sub-hourly rainfall data as input and estimates infiltration and excess rainfall by GAML (Green and Ampt Mein

Two subroutines forcasthourly.f and swatforecast.f have been developed anc integrated into SWAT for enabling it for hourly simulation and forecasting flows at outlet points of different subbasins. Modified version of SWAT takes in sub-hourly rainfall data as input and estimates infiltration and excess rainfall by GAML (Green and Ampt Mein Larson) excess rainfall method. A dimensionless time area diagram is used for overland routing to forecast flows at outlet points of different subbasins. Evapotranspiration, soil water contents, base flow, lateral flow and snow melt are estimated on a daily basis and distributed equally for each time step. This assumption is valid in view of the small contribution made by these components to the flood events.

If "eventstatus"=1 event modelling is done which acts as the first run of event modelling. This run is for a slightly longer duration which can help generate initial condition. Here modified subroutines surq_greenamptNKT.f, forcasthourly.f swatforecast.f, rthourlyNKT.f are used for generating simulated/forcasted flows. Routing points of different subbasins. Modified version of SWAT takes in sub-hourly rainfall data as input and estimates infiltration and excess rainfall by GAML (Green and Ampt Mein Larson) excess rainfall method. A dimensionless time area diagram is used for overland routing to forecast flows at outlet points of different subbasins. Evapotranspiration, soil water contents, base flow, lateral flow and snow melt are estimated on a daily basis and distributed equally for each time step. This assumption is valid in view of the small contribution made by these components to the flood events.

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Muskingum river routing method). During this run some important parameters suc

soil water, discharge values in the reaches at the endhour of last day, baseflows etc

stored in "StoreSoilWater.dat", "EndWater.dat" and baseflow.dat respectively.

storing helps in quick generation of more realistic results in consecutive short r

Generally the values 1 and 24 can be entered in the simhour.dat file. In the rare ca

total data upto 24th hour is not available even for the first run, the endhour value ca

put as desired specially in case of real time flood forecasting.

"eventstatus"=2 is given for the consecutive/following runs (i.e., 2nd,3rd,4th ,

when the final situation has already been captured from a previous run. Here st

values of soilwater and endwater are imported from previously saved files. After the

run (eg: 2nd) the files "StoreSoilWater.dat" and "EndWater.dat" are overwritten with

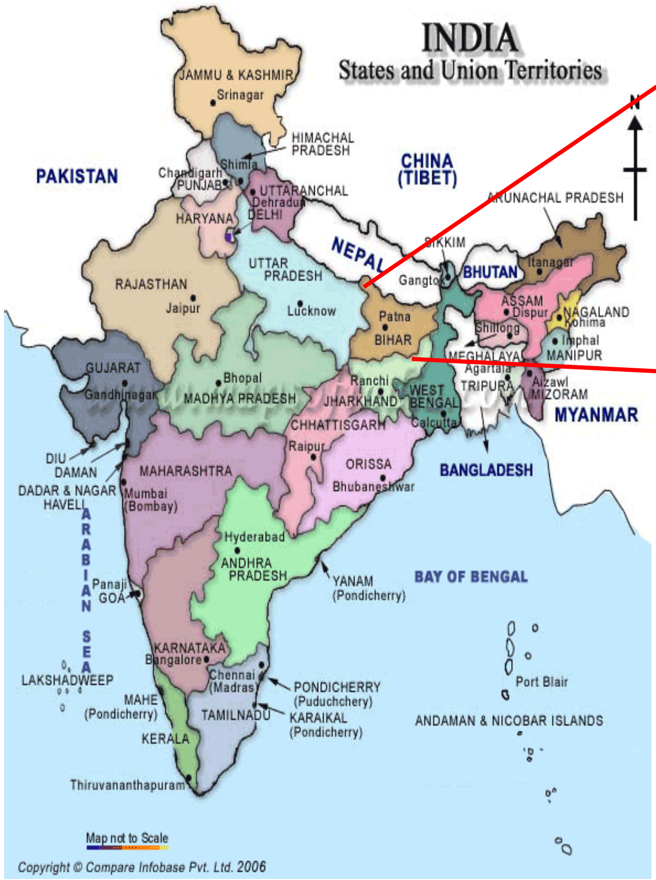
final values generated from the present run. These values are again used as in

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

Study Area


INDIA
States and Union Territories
JAMMU & KASHMIR
Srinagar
HIMACHAL PRADESH
Shimla
PAKISTAN
CHINA (TIBET)
Chandigarh
PUNJAB
UTTARANCHAL
Dehradun
DELHI
HARYANA
ARUNACHAL PRADESH
NEPAL
SIKKIM
Gangtok
BHUTAN
Itanagar
RAJASTHAN
Jaipur
UTTAR PRADESH
Lucknow
Patna
BIHAR
ASSAM
Dispur
NAGALAND
Kohima
Shillong
Imphal
MANIPUR
MEGHALAYA
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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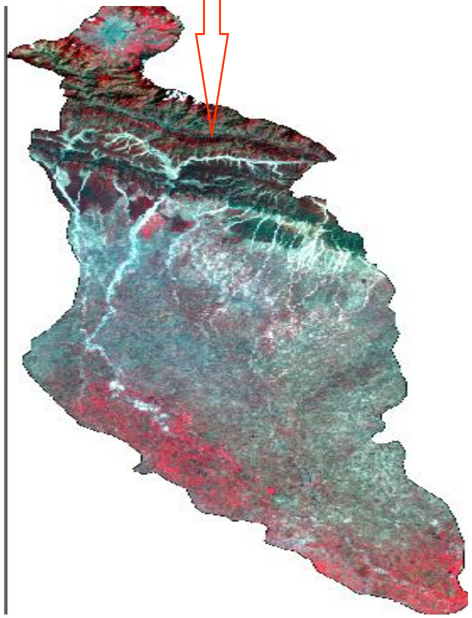
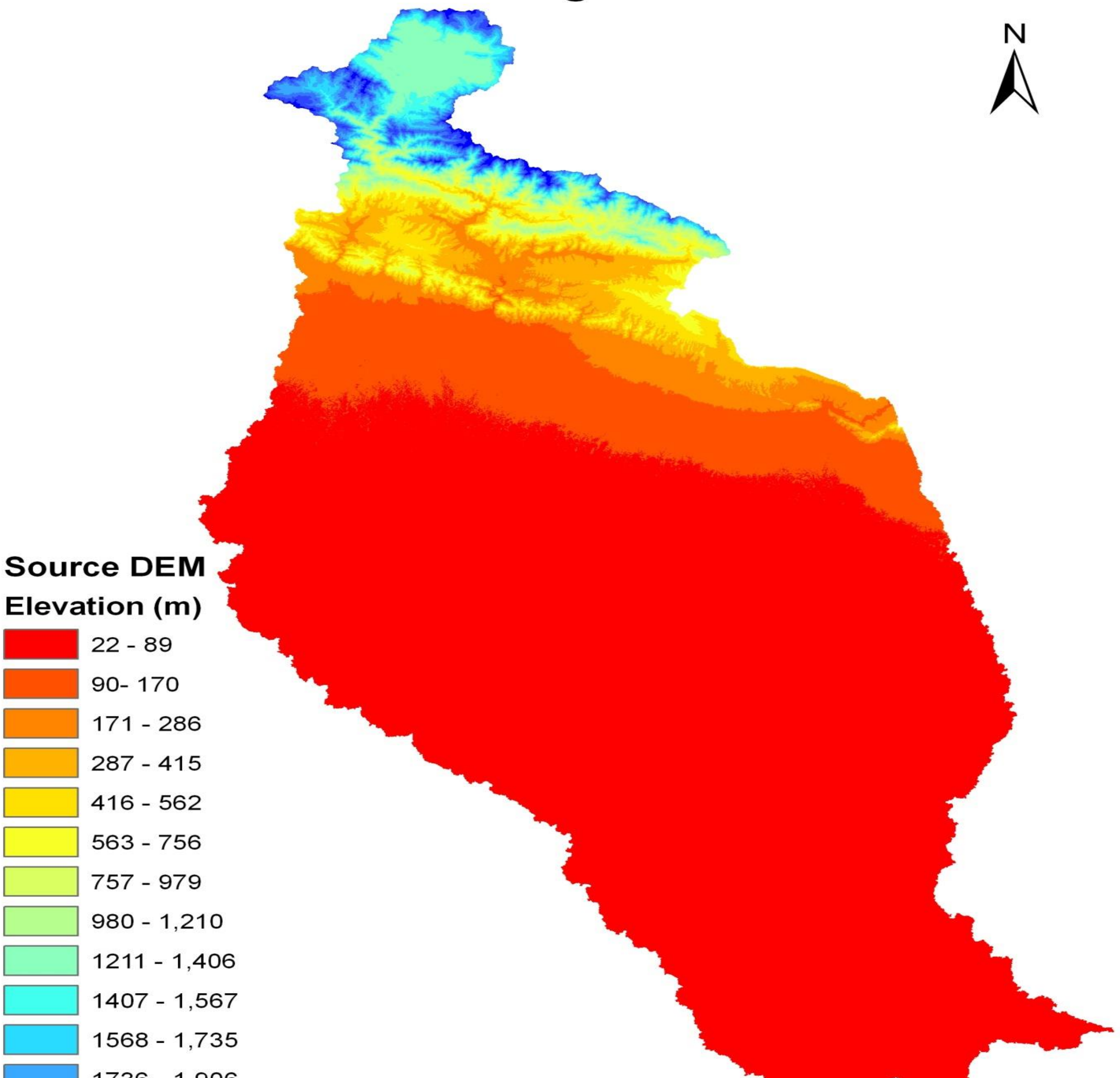
BIHAR
2001
Pashchim Champaran
Purba Champaran
Sitamarhi
Gopalganj
Sheohar
Madhubani
Siwan
Muzaffarpur
Darbhanga
Supaul
Araria
Kishanganj
Saran
Vaishali
Samastipur
Madhepura
Saharsa
Purnia
Buxar
Bhojpur
Patna
Khagaria
Begusarai
Katihar
Rohtas
Jehanabad
Nalanda
Lakhisarai
Sheikhpura
Bhagalpur
Kaimur (Bhabua)
Munger
Nawada
Jamui
Aurangabad
Gaya
Banka




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

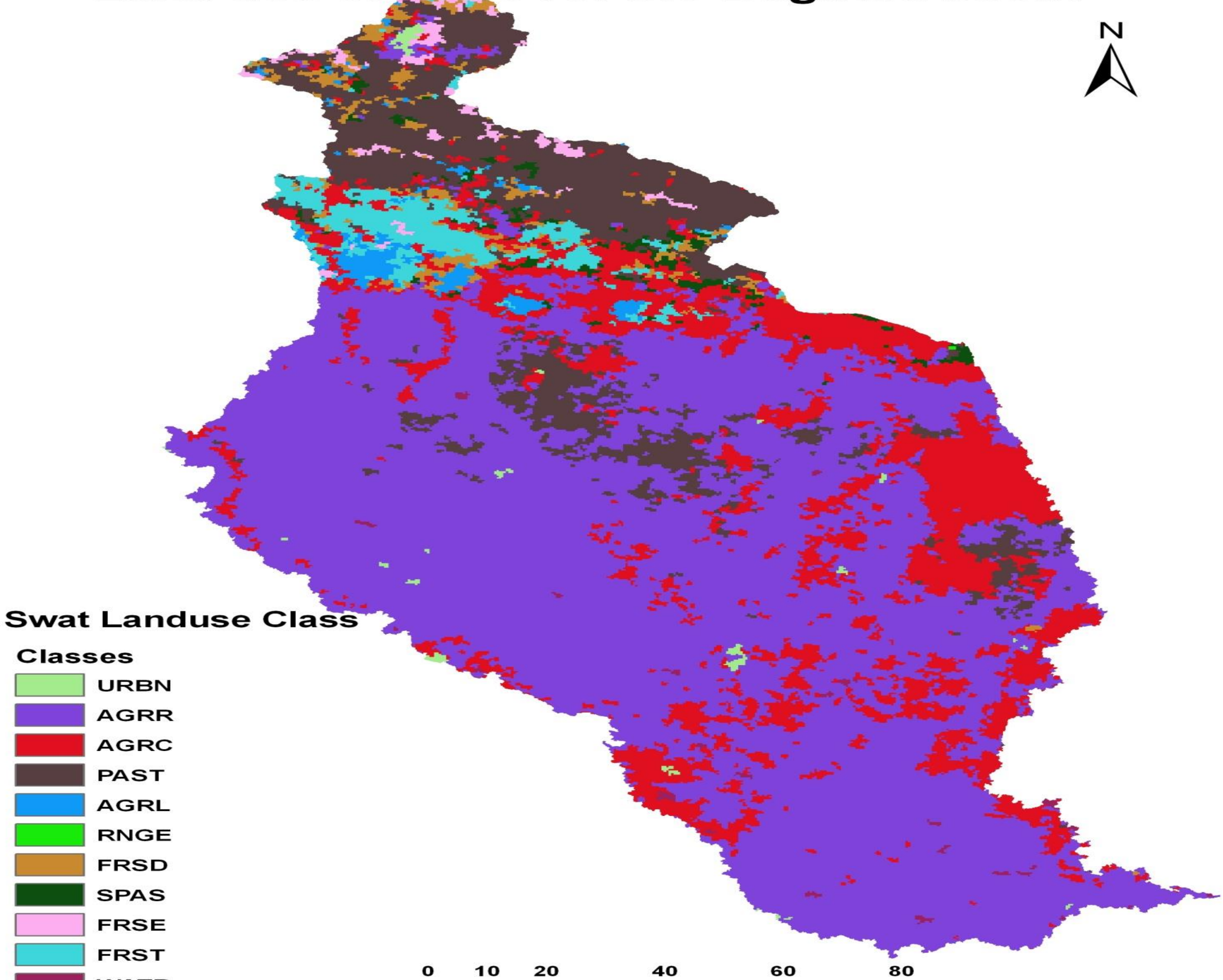
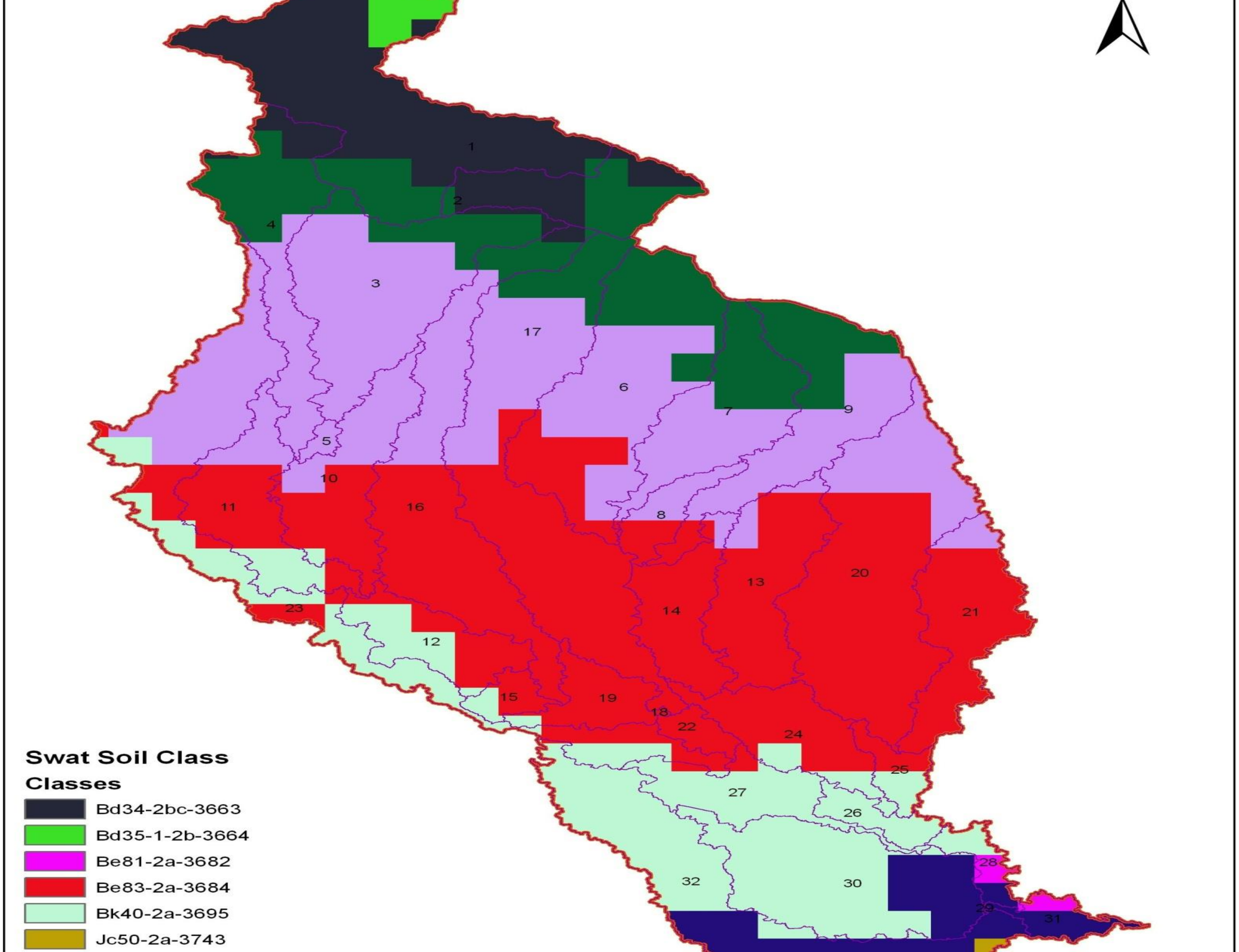


Table 6.4 Details of landuse

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
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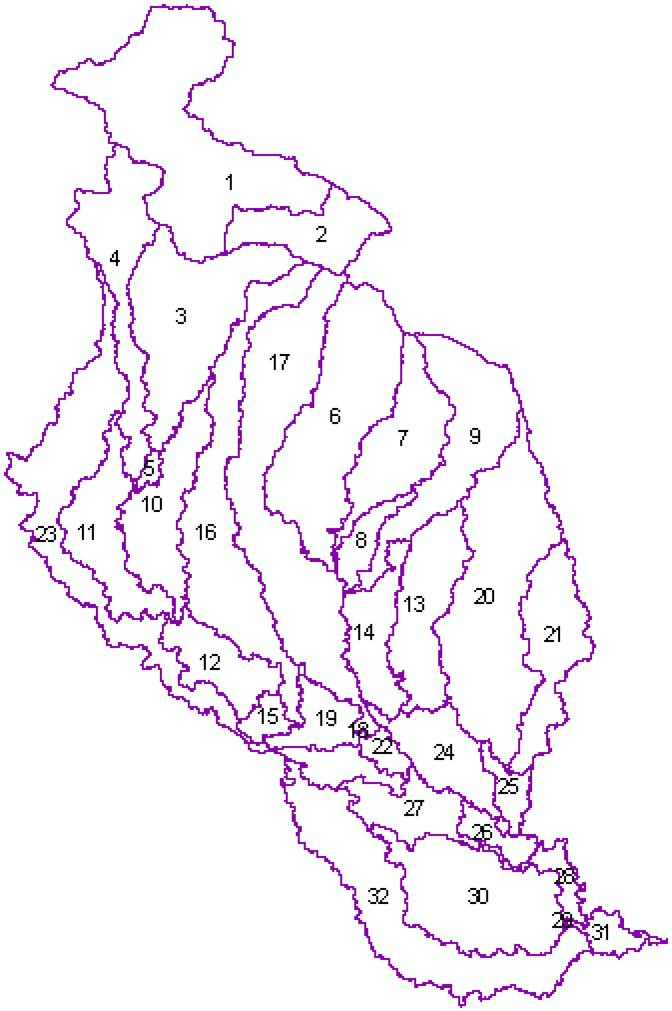
Division into subbasins



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

GAUGE STATIONS

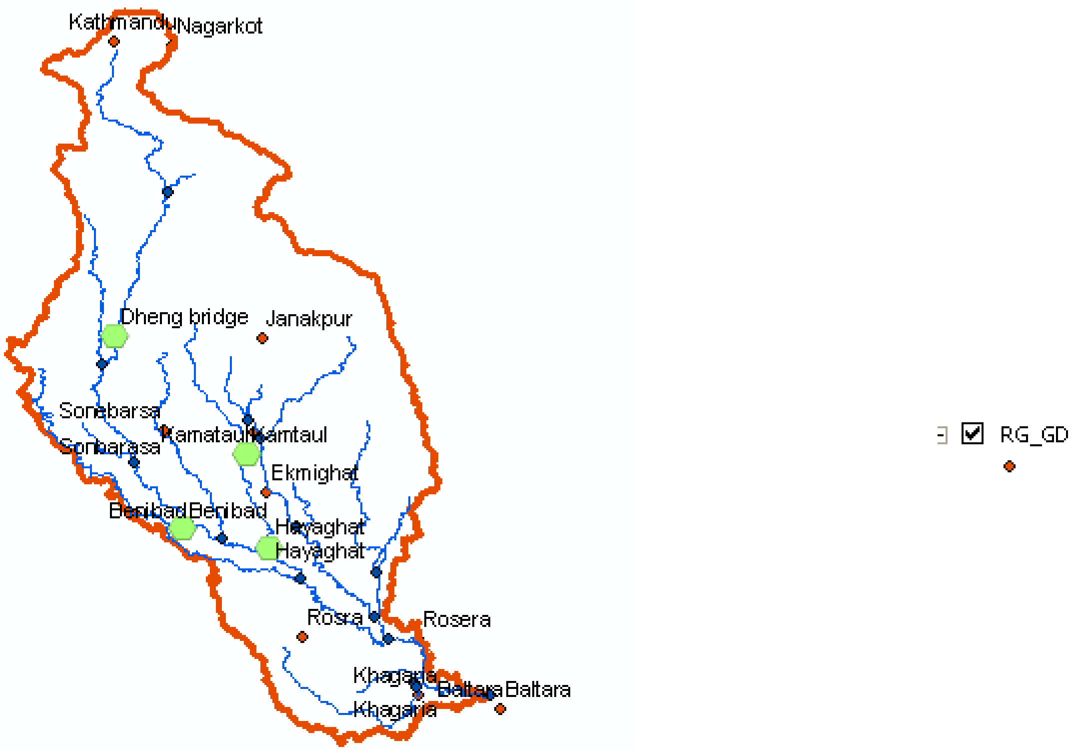


Table 5.3 Daily Rainfall, Temperature and Wind speed of 13-14 Sept-12 of Hayaghat (source: www.imdaws.com)

DATE	TIME [UTC]	RAINFALL [mm]	TEMPERATURE [Deg C]	DEW POINT [Deg C]	WIND SPEED [Kt]	WIND DIR [Deg]
13-Sep-12	0:00:00	0	26.7	26.5	2	100
13-Sep-12	1:00:00	0	27	26.8	2	100
13-Sep-12	2:00:00	0	27.3	27.1	3	100
13-Sep-12	3:00:00	0	27.5	27.3	3	110
13-Sep-12	4:00:00	0	28.8	28.6	2	140
13-Sep-12	5:00:00	0	30.6	30.4	2	120
13-Sep-12	6:00:00	0	31.9	31.7	6	120
13-Sep-12	7:00:00	0	31.5	31.3	3	140
13-Sep-12	8:00:00	0	32	31.6	2	150
13-Sep-12	9:00:00	0	30.7	30.4	3	110
13-Sep-12	10:00:00	0	30.3	30.1	1	120
13-Sep-12	11:00:00	0	30.3	30.1	1	140
13-Sep-12	12:00:00	0	28.7	28.5	3	230
13-Sep-12	13:00:00	0	27.7	27.5	3	210
13-Sep-12	14:00:00	9	25.2	25	9	150
13-Sep-12	15:00:00	13	25	24.8	1	60
13-Sep-12	16:00:00	15	24.9	24.6	1	30
13-Sep-12	17:00:00	15	24.8	24.5	2	60
13-Sep-12	18:00:00	17	24.9	24.6	3	0
13-Sep-12	19:00:00	57	24.8	24.5	2	60
13-Sep-12	21:00:00	139	24.1	23.8	2	100
13-Sep-12	23:00:00	146	25.2	25	1	120

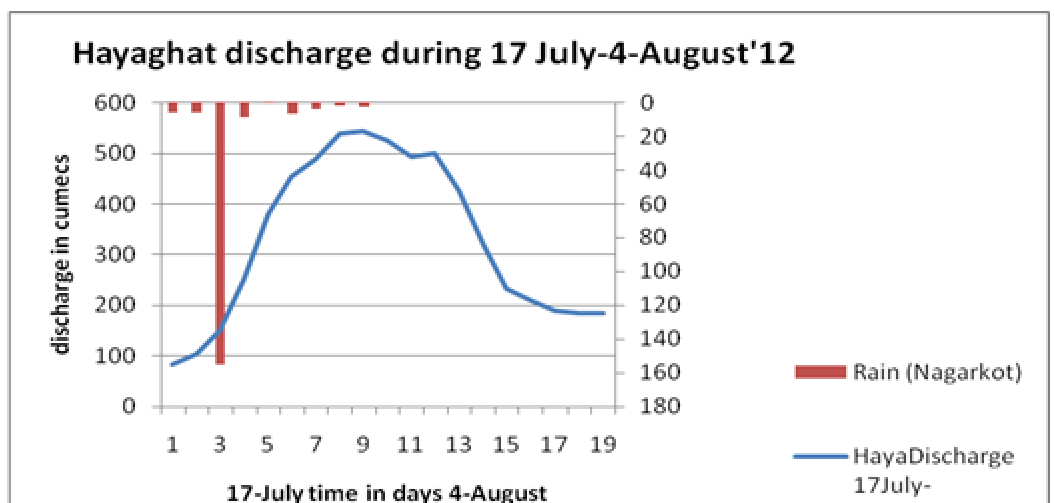
14-Sep-12	0:00:00	149	25.3	25.1	1	80
14-Sep-12	1:00:00	150	25.3	25.1	2	90
14-Sep-12	2:00:00	150	25.1	24.9	4	110
14-Sep-12	3:00:00	150	25.5	25.2	3	110
14-Sep-12	4:00:00	0	25.8	25.6	2	110
14-Sep-12	5:00:00	0	26.8	26.6	3	120
14-Sep-12	6:00:00	0	27.6	27.4	4	100
14-Sep-12	7:00:00	0	27.6	27.4	5	100
14-Sep-12	8:00:00	0	29	28.8	4	120
14-Sep-12	9:00:00	0	28.1	27.9	3	160
14-Sep-12	11:00:00	0	27.4	27.2	2	100
14-Sep-12	12:00:00	0	27.1	26.9	1	110
14-Sep-12	13:00:00	0	26.9	26.7	2	140
14-Sep-12	14:00:00	0	27.1	26.9	3	120
14-Sep-12	15:00:00	0	26.7	26.5	4	110
14-Sep-12	16:00:00	0	26.3	26.1	5	110
14-Sep-12	17:00:00	0	25.9	25.7	5	110
14-Sep-12	18:00:00	0	25.9	25.7	4	110
14-Sep-12	19:00:00	0	25.9	25.7	3	110
14-Sep-12	20:00:00	0	25.6	25.4	3	100
14-Sep-12	21:00:00	0	25.4	25.2	5	100
14-Sep-12	23:00:00	3	25	24.8	2	110

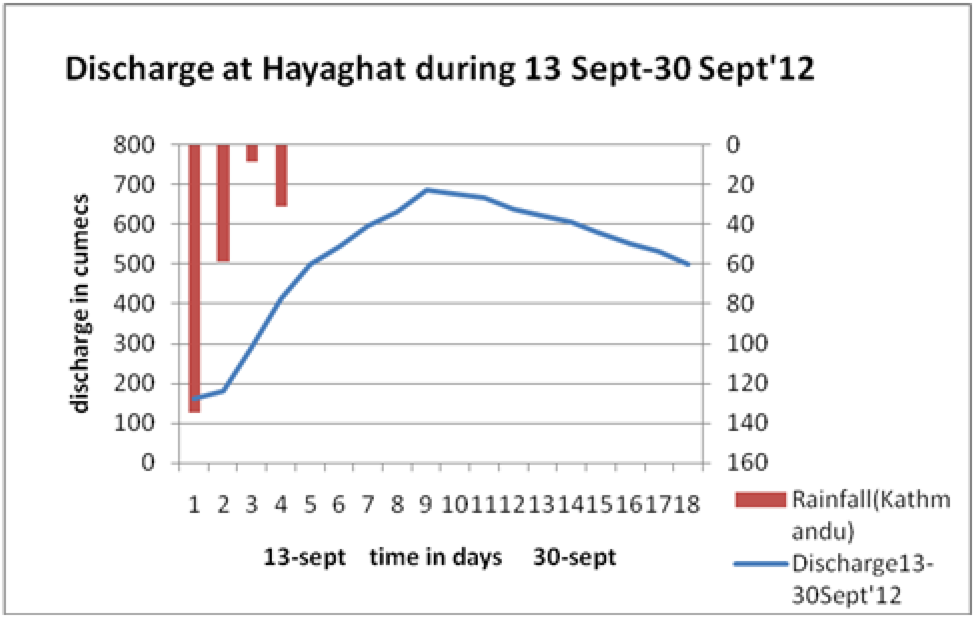
Table 5.8 Real time hydrological data for year 2012 downloaded from websites (17July-4August)

Date	Discharge (Hayaghat) (cumecs)	WL (meters)	Rainfall (Nagarkot) (mm)
17-Jul-12	83.047345	39.93	6.2
18-Jul-12	103.07675	40.27	6.2
19-Jul-12	149.41263	40.95	155.2
20-Jul-12	251.59863	42.15	8.8
21-Jul-12	379.84863	43.35	0.4
22-Jul-12	453.74763	43.95	7
23-Jul-12	487.79411	44.21	4.2
24-Jul-12	536.95535	44.57	1.8
25-Jul-12	542.56251	44.61	2.8
26-Jul-12	524.44512	44.48	0
27-Jul-12	493.14063	44.25	0
28-Jul-12	498.5161	44.29	0
29-Jul-12	424.64952	43.72	0
30-Jul-12	319.99122	42.82	0
31-Jul-12	231.83458	41.94	0
1-Aug-12	210.2245	41.7	0
2-Aug-12	189.65698	41.46	0
3-Aug-12	183.85451	41.39	0
4-Aug-12	183.85451	41.39	0

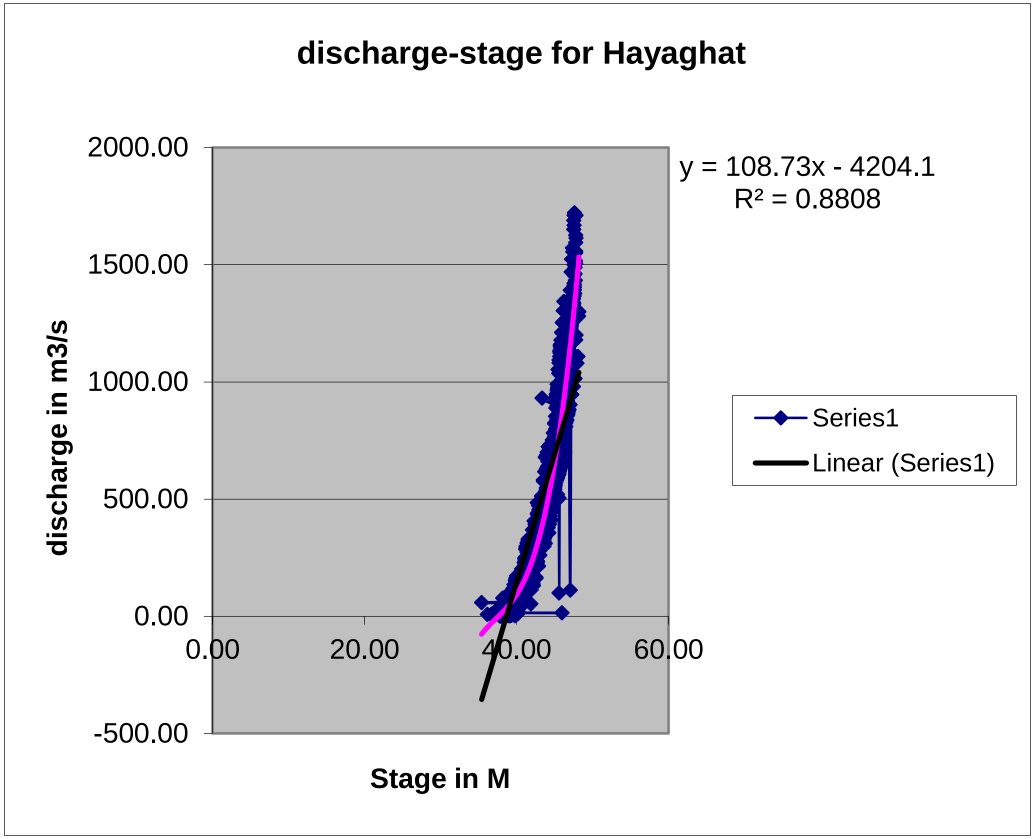
Analysis of web based real time hydrological data of year 2012

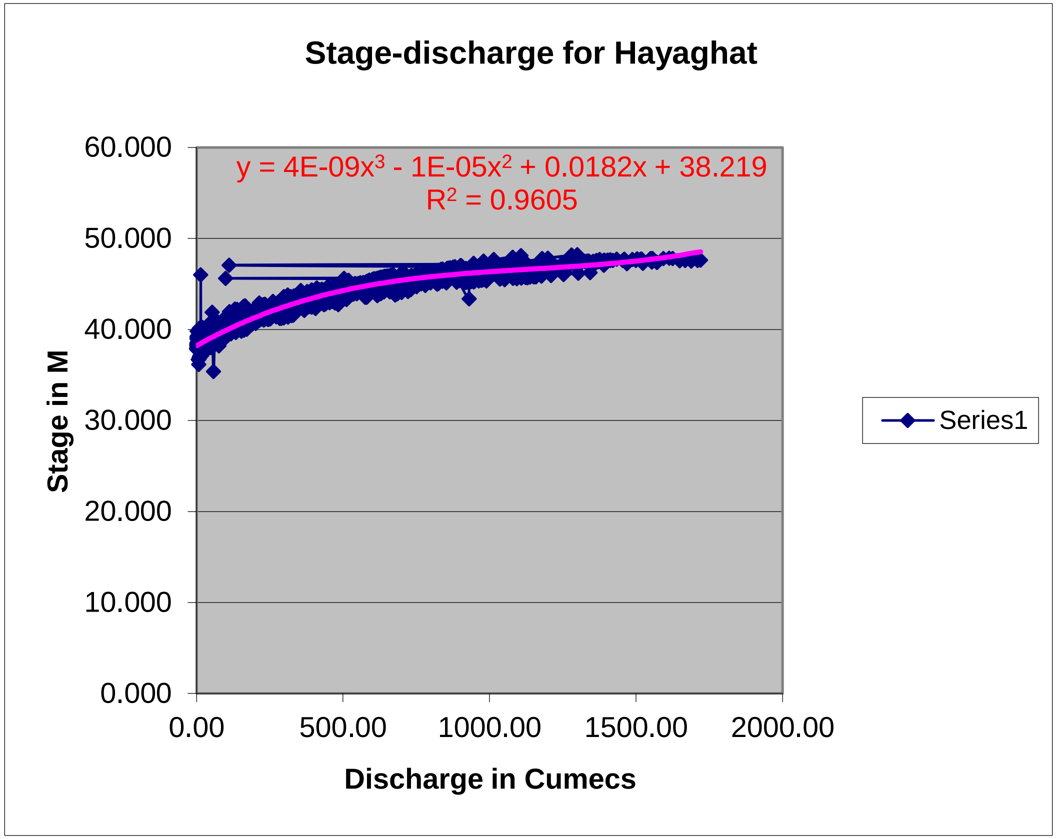
Rainfall and water levels of Hayaghat gauge station for September 2012 w downloaded from websites www.imdaws, www.hydrology.gov.np. www.fmis.bih.nic (Table 5.8-5.10). Discharge was calculated using stage disch relationship of Hayaghat. It can be concluded that rainfall of Nepal portion produces p discharge at Hayaghat after 10 days. Hence correlation between rainfalls of Nepal por and runoff of Hayaghat is very interesting. The lead time at Hayaghat for rainfall of N portion is very high 4-8 days.

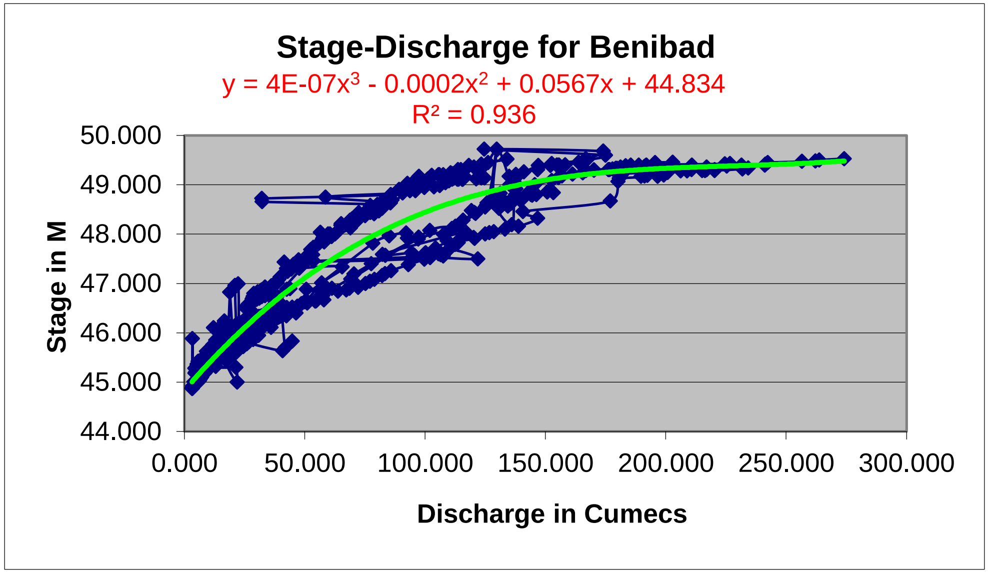




Discharge at Hayaghat during 13 Sept-30 Sept'12
discharge in cumecs
800
700
600
500
400
300
200
100
0
0
20
40
60
80
100
120
140
160
1 2 3 4 5 6 7 8 9 101112131415161718
13-sept time in days 30-sept
Rainfall(Kathmandu)
Discharge13-30Sept'12


discharge-stage for Hayaghat
discharge in m3/s
2000.00
1500.00
1000.00
500.00
0.00
-500.00
0.00
20.00
40.00
60.00
Stage in M
y = 108.73x - 4204.1
R² = 0.8808
Series1
Linear (Series1)

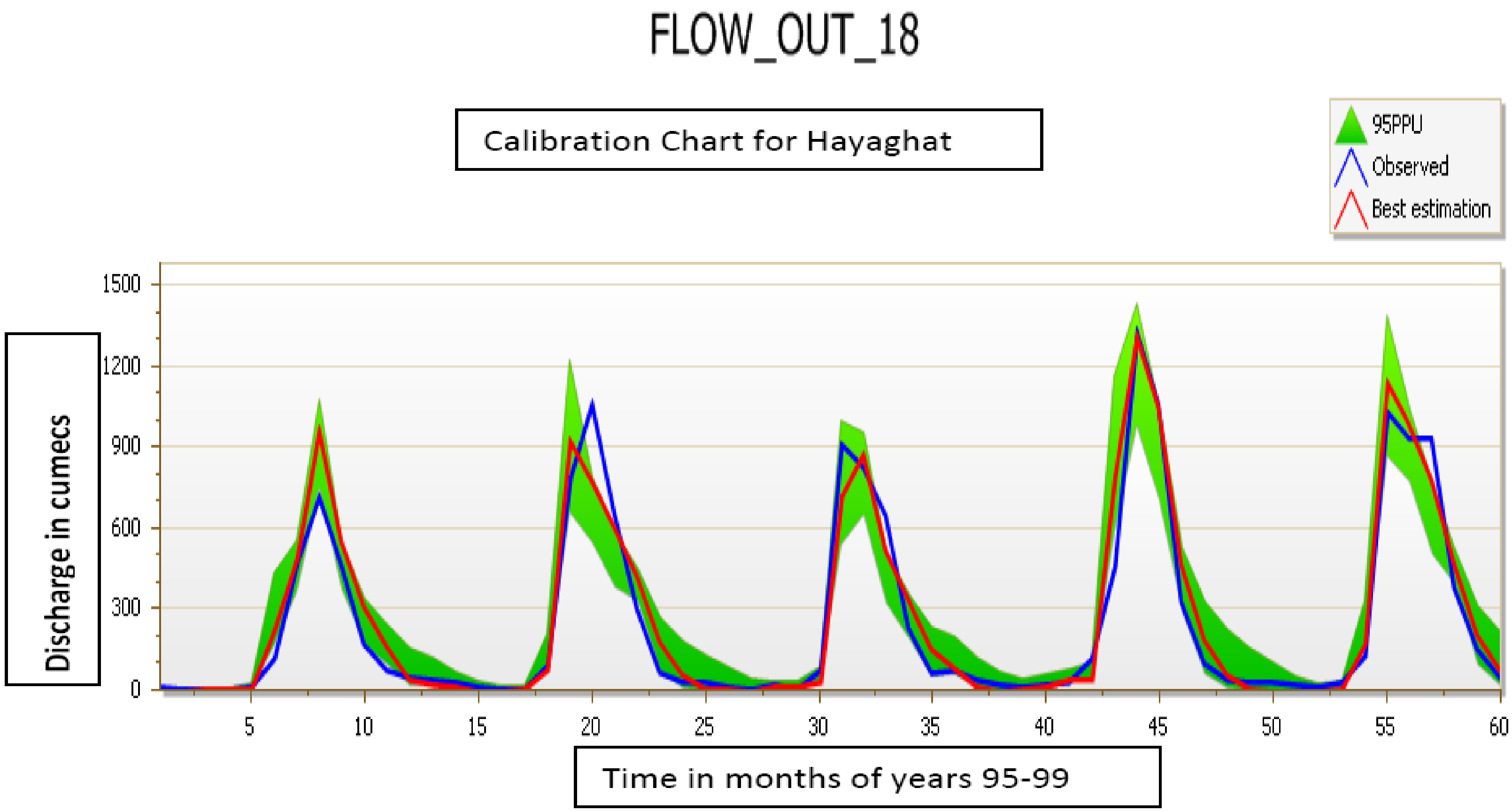

Stage-discharge for Hayaghat
y = 4E-09x3 - 1E-05x2 + 0.0182x + 38.219
R2 = 0.9605
60.000
50.000
40.000
30.000
20.000
10.000
0.000
Stage in M
0.00
500.00
1000.00
1500.00
2000.00
Discharge in Cumecs
Series1


Stage-Discharge for Benibad
y = 4E-07x3 - 0.0002x2 + 0.0567x + 44.834
R² = 0.936
50.000
49.000
48.000
47.000
46.000
45.000
44.000
Stage in M
0.000
50.000
100.000
150.000
200.000
250.000
300.000
Discharge in Cumecs

Results

Calibration - Output

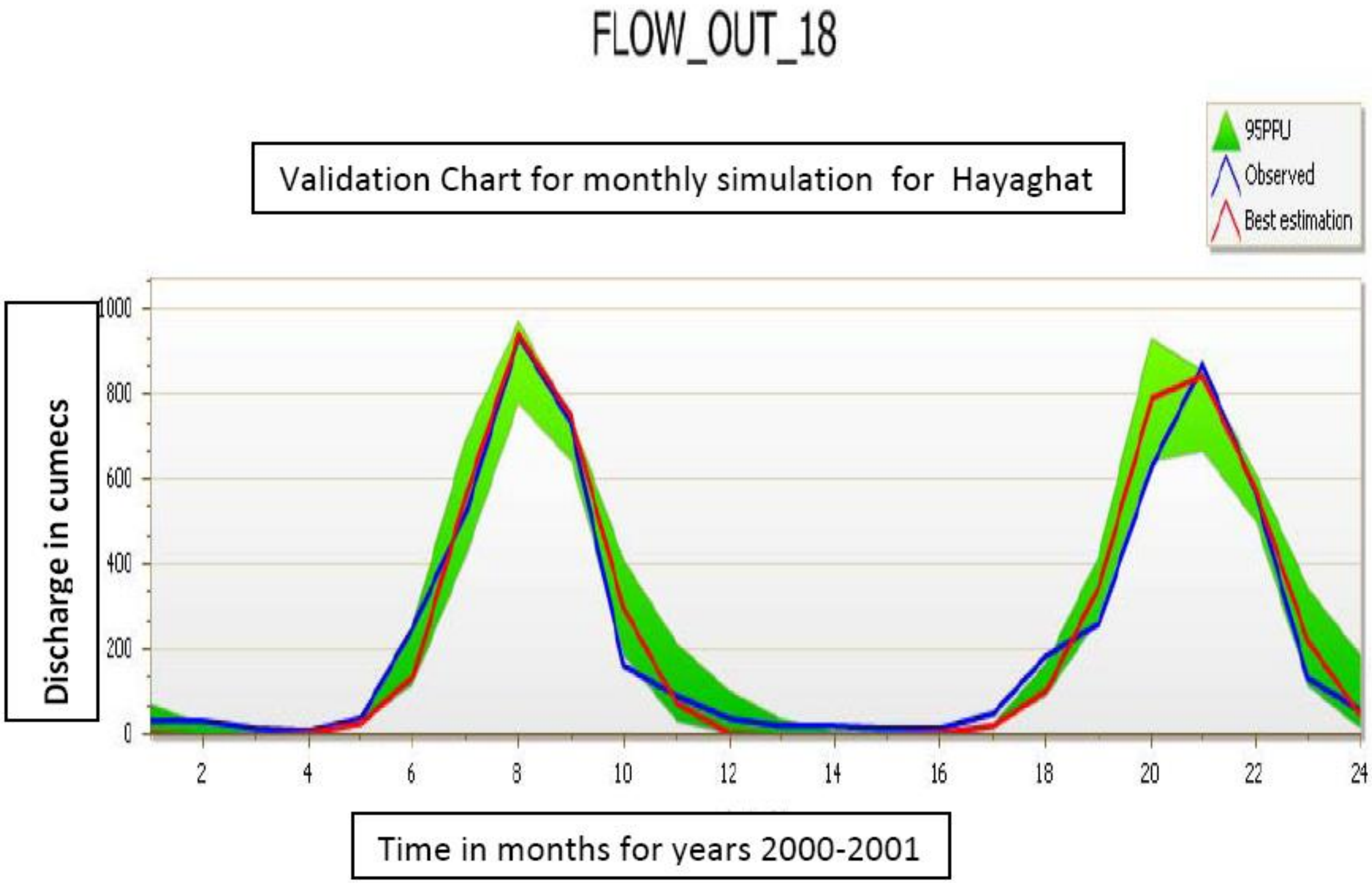
Discharge m^3/s



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. Seventy four percent observed and simulated values lie in 95PPU. P-

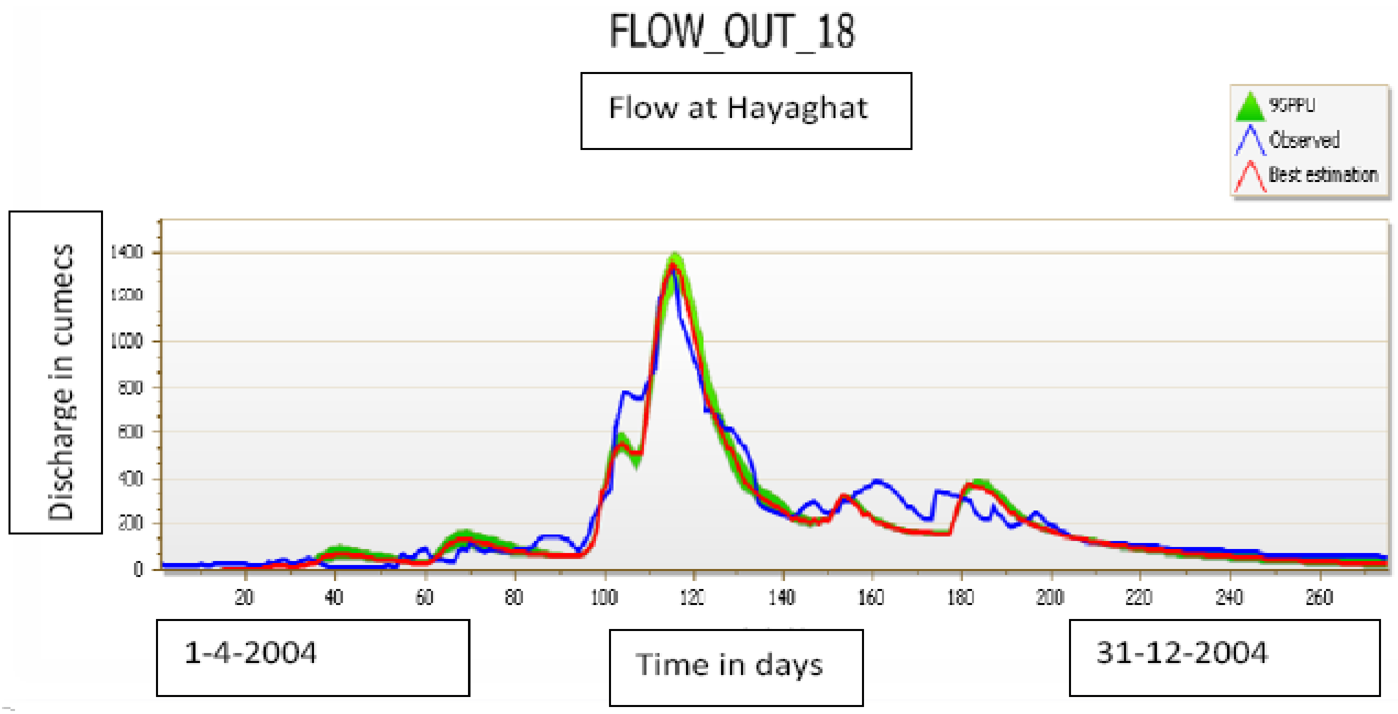
Validatio for monthly flow



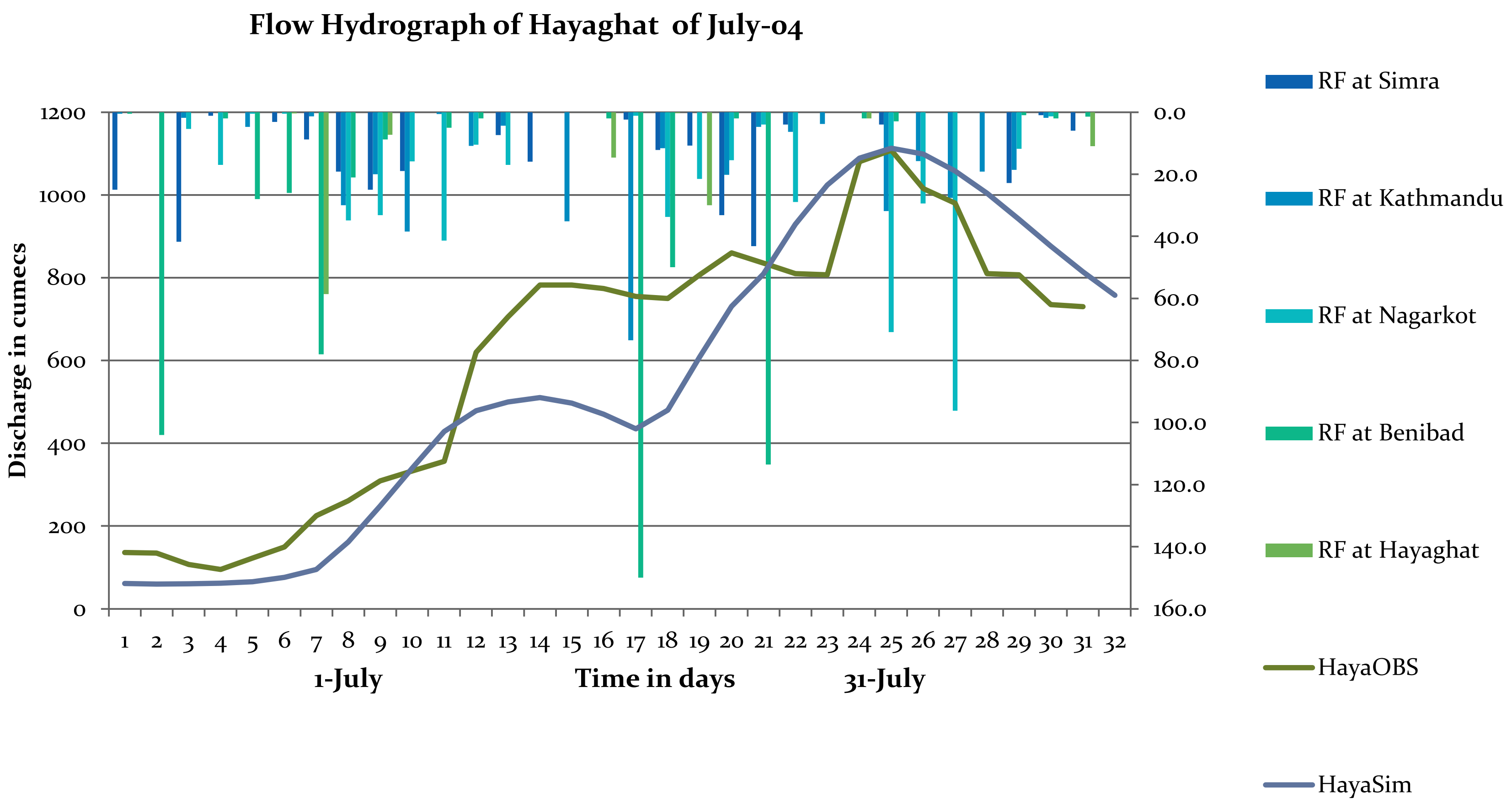
Model Performance Test

- 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.
- $R^2 = \quad = 0.96$
- 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.

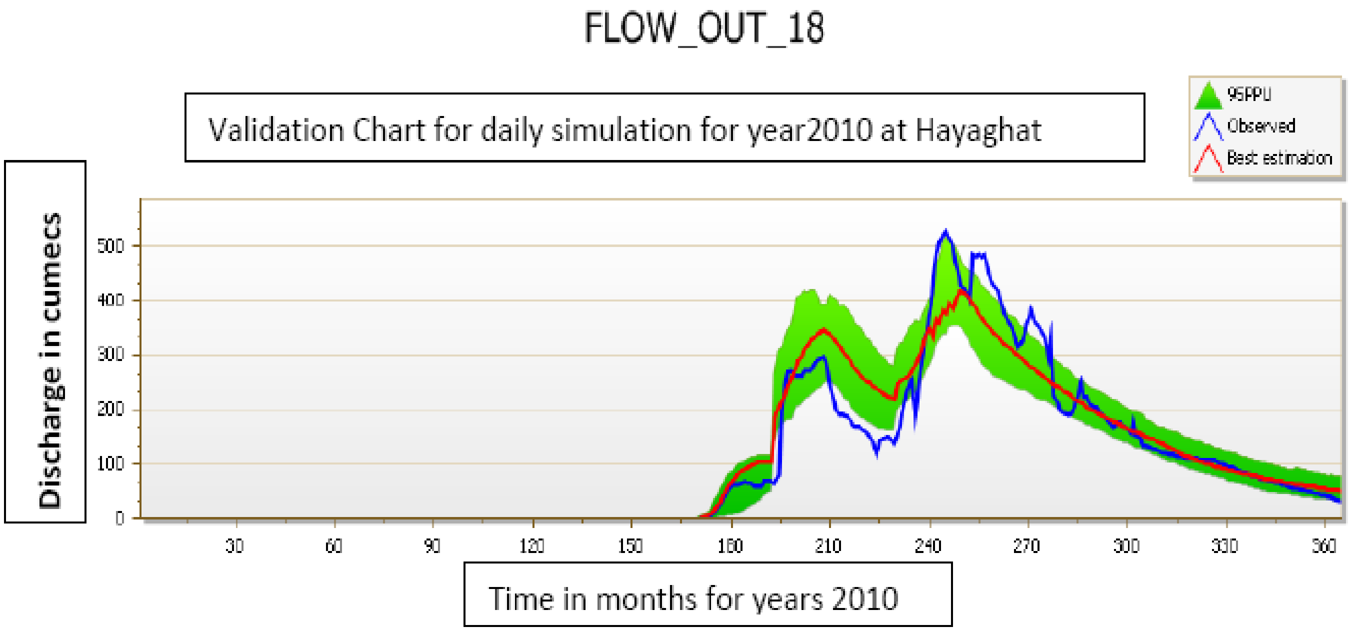
Daily Flow Valdation



Flow Hydrograph Daily Simulation

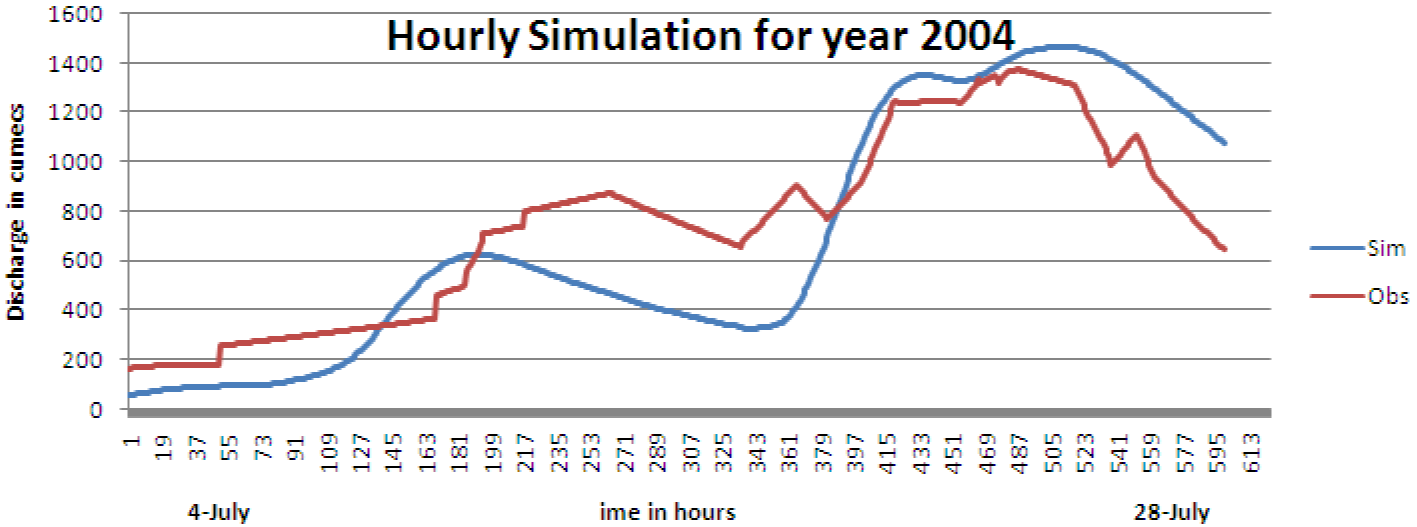


Valdation for daily flow 2010

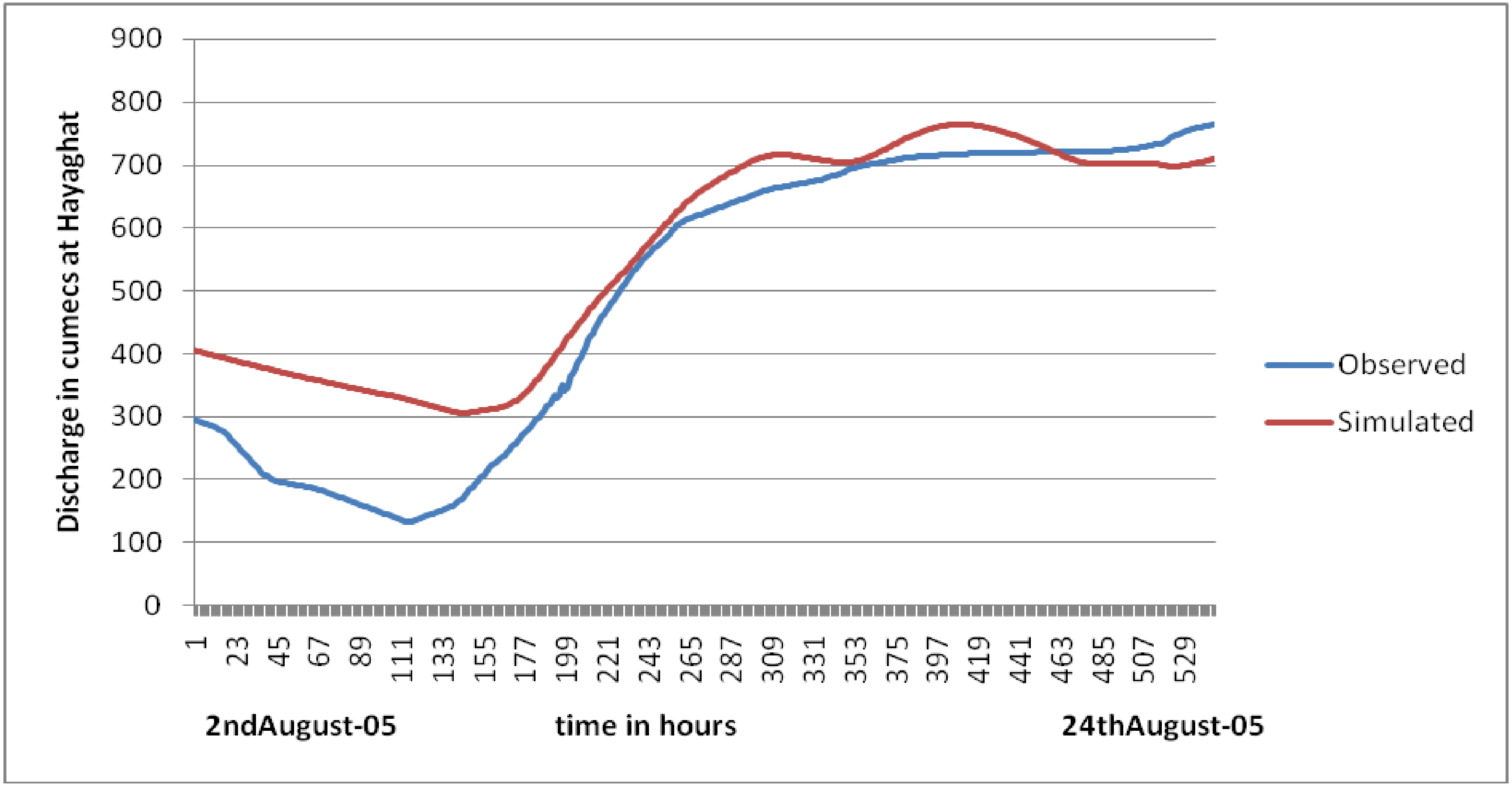


Validation for hourly flow

NE = 0.72



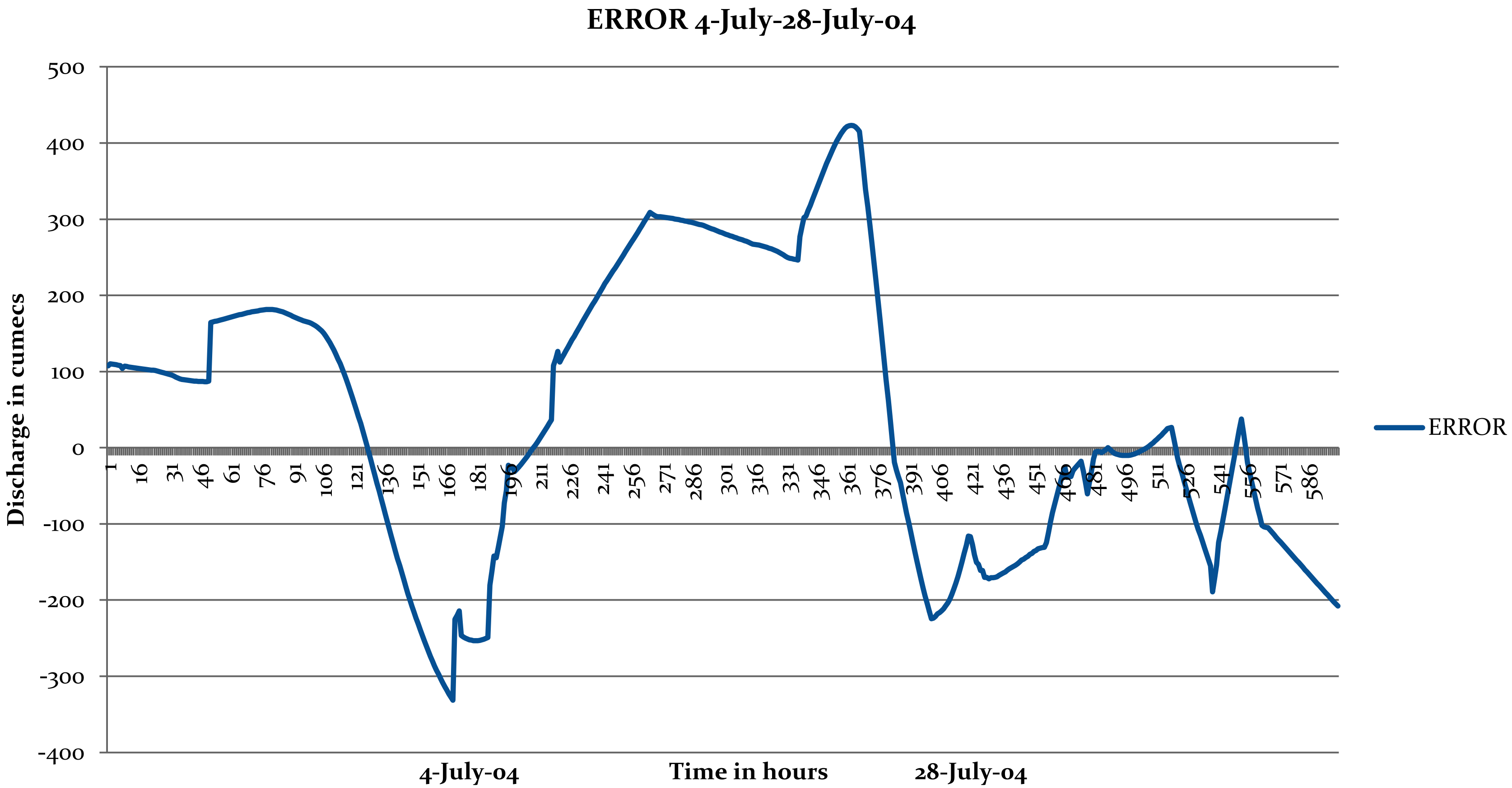
Validation Graph



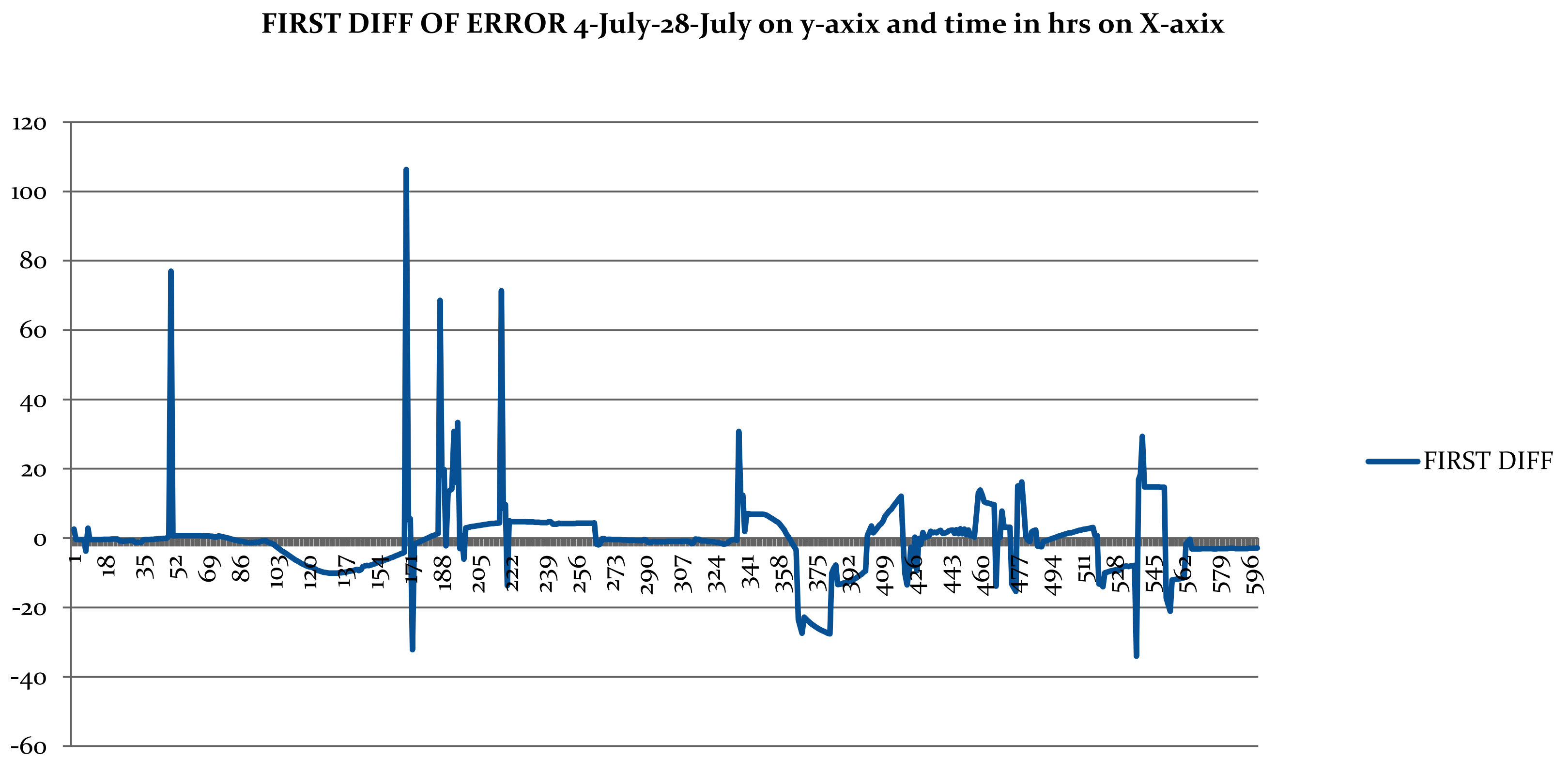
ERROR ANALYSIS

- Time series analysis of errors in hourly simulations/forecasts has been performed. An ARIMA model developed for forecasting error has been deployed for correcting simulated/forecasted hourly flows. Integration of simulation capability of SWAT model and error forecasting capability by time series analysis has been done for solving the problem of real-time flood forecasting

Error 2004 Simulation



Error 2004 hourly simulation



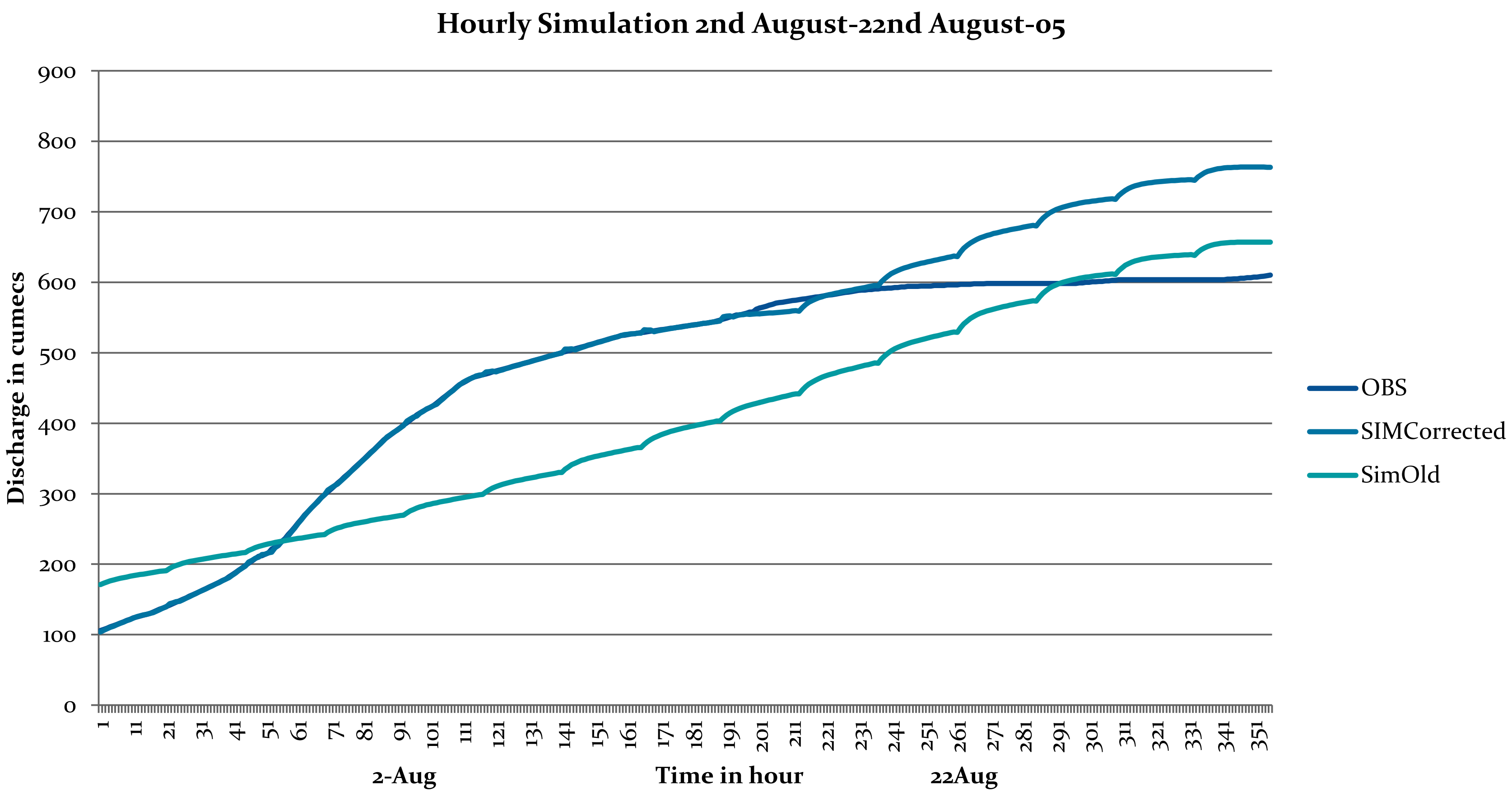
Error analysis of 2004 flood event

ARIMA Model Parameters for error analysis for hourly simulation of year 2004

- ARIMA Parameters
- B1(LAG1)= 1.3153
- B2(LAG2)= -0.0162
- B3(LAG3)=-0.3013

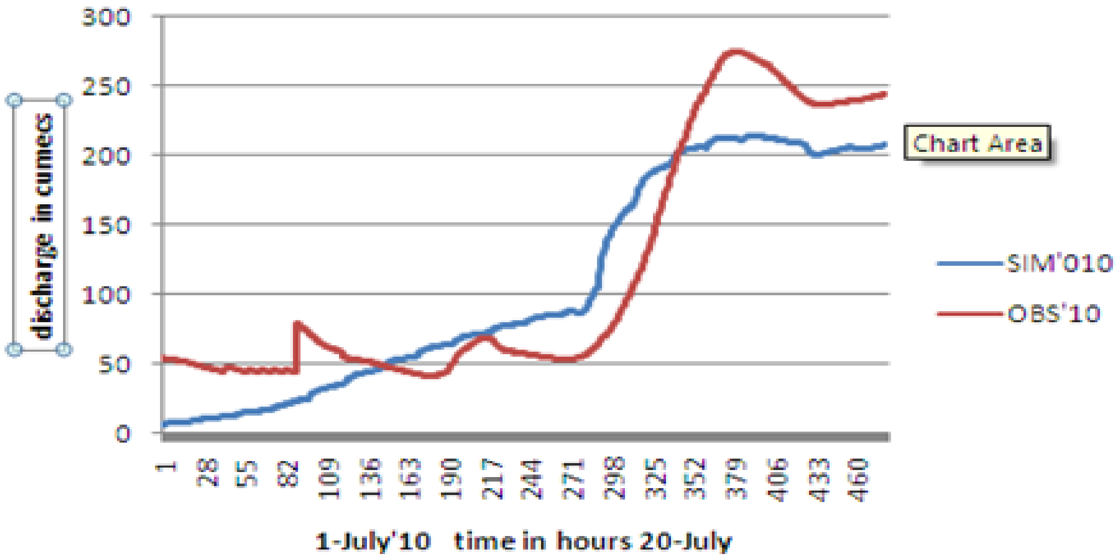
Error Analysis

- There are 600 observed and simulated values. Four hundred data have been used for determining ARIMA model parameter and two hundred forecasted errors have been determined. Nash Sutcliffe coefficient before correction for forecasted period of error was 0.64 and after error correction it is 0.795.ARIMA model parameters are given below.
-
- b = 1.3153, -0.0162, -0.3013
- Z(t)= 1.3153*Z(t-1)-0.0162*Z(t-2)-0.3013*Z(t-3)

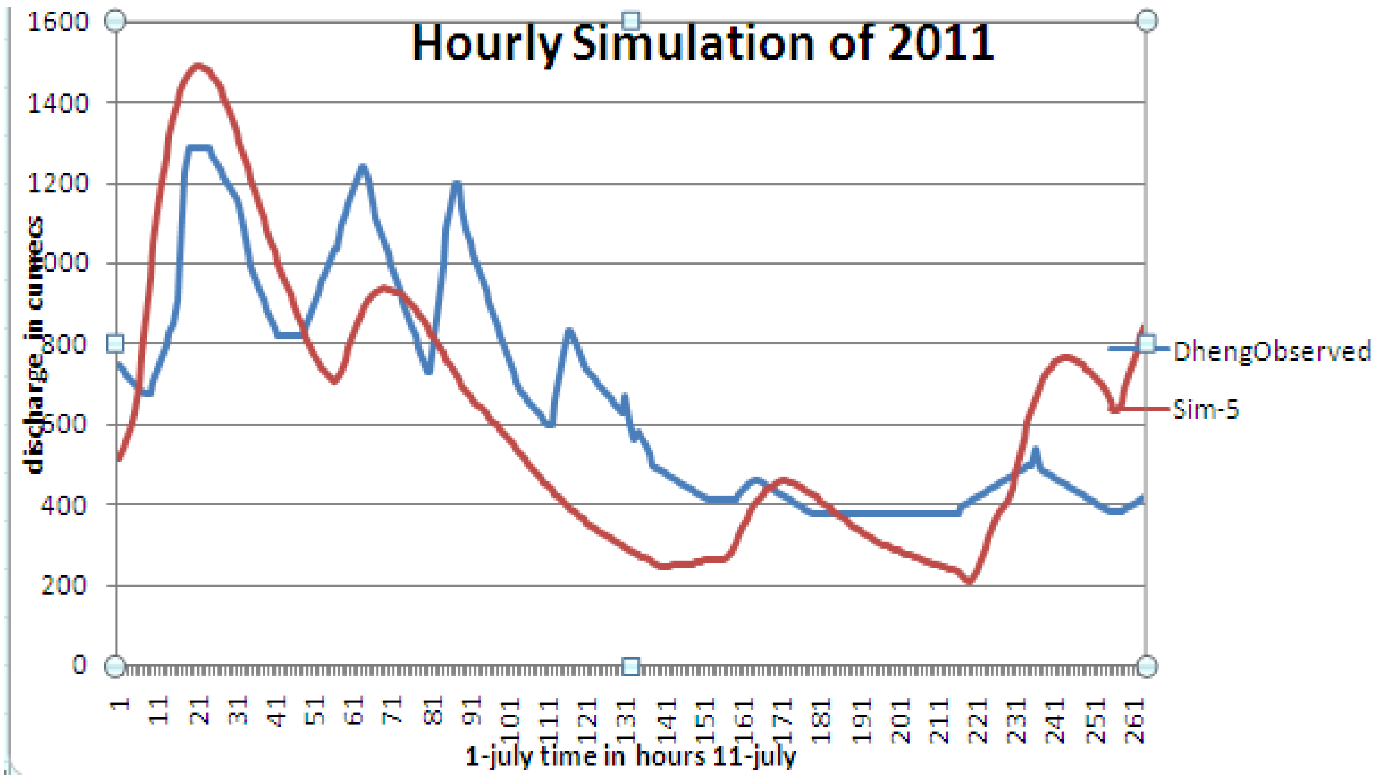

Hourly Simulation 2nd August-22nd August-05
Discharge in cumecs
900
800
700
600
500
400
300
200
100
0
1
11
21
31
41
51
61
71
81
91
101
111
121
131
141
151
161
171
181
191
201
211
221
231
241
251
261
271
281
291
301
311
321
331
341
351
2-Aug
Time in hour
22Aug
OBS
SIMCorrected
SimOld

Hourly 2005

- ARIMA Model Parameters for error analysis for hourly simulation of year 2005
- ARIMA Parameters
- B1(LAG1)= 0.6056
- B2(LAG2)= 0.1792
- B3(LAG3)=0.0988

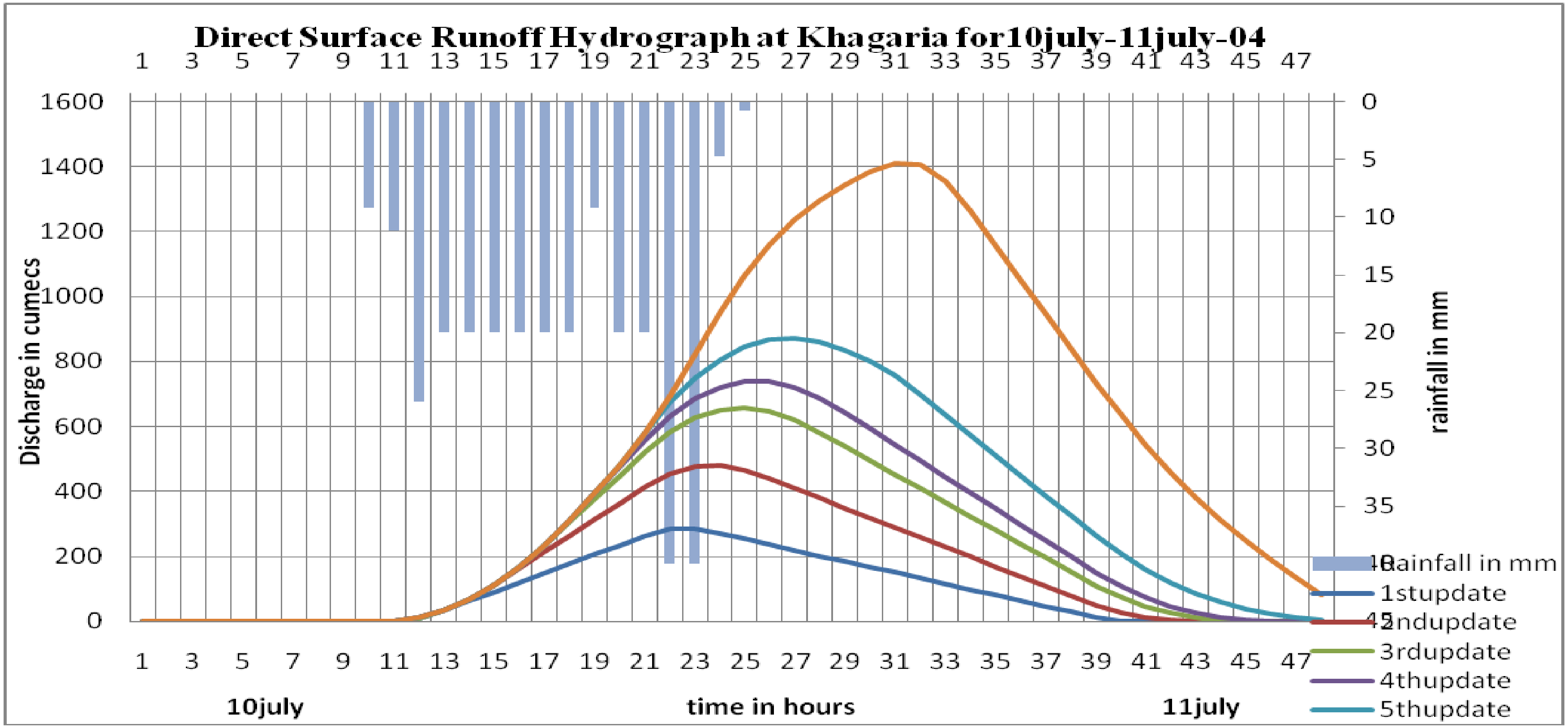


300
250
200
150
100
50
0
discharge in cumecs
1
28
55
82
109
136
163
190
217
244
271
298
325
352
379
406
433
460
1-July'10 time in hours 20-July
Chart Area
SIM'010
OBS'10

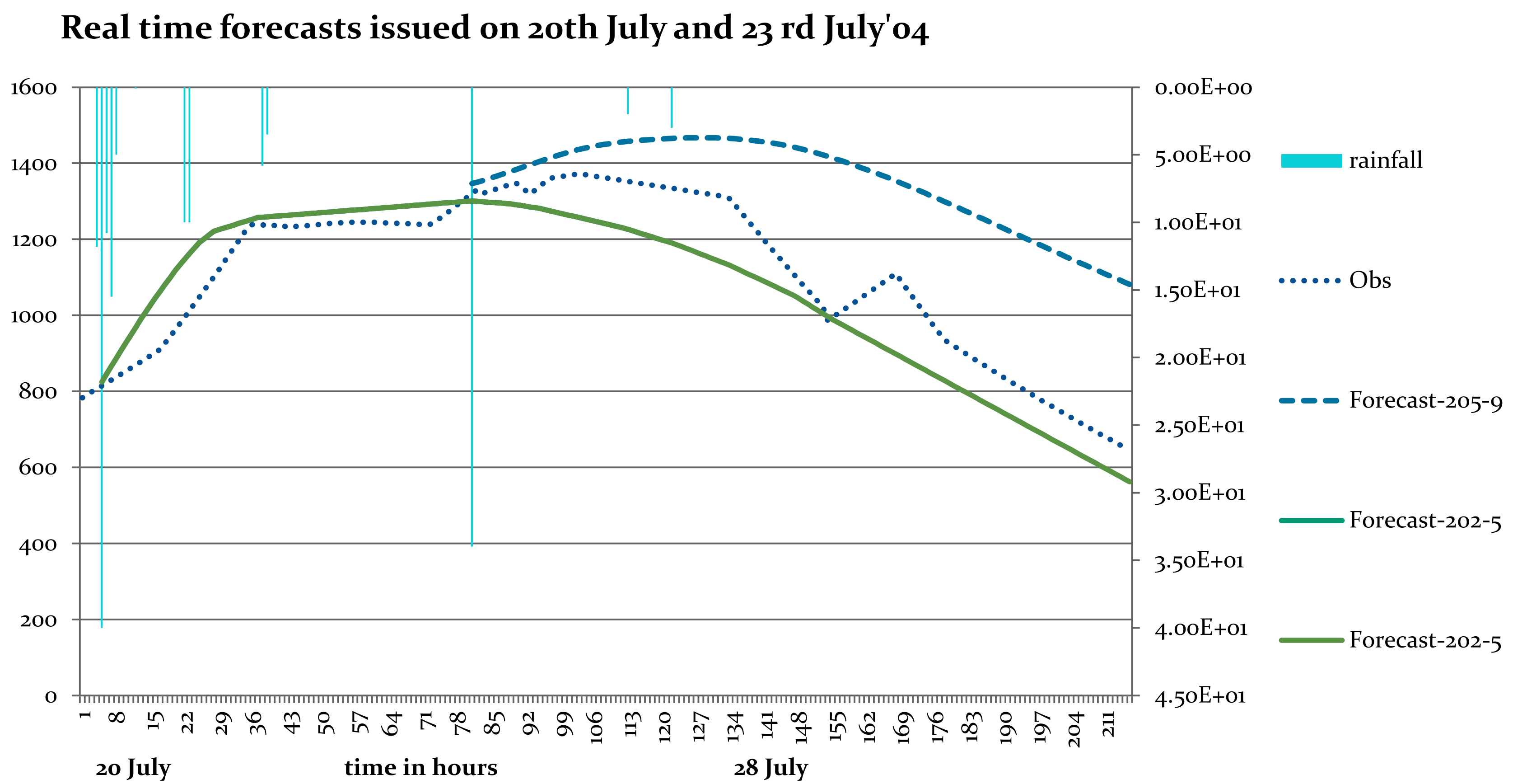


Hourly Simulation of 2011
discharge in cumecs
1600
1400
1200
1000
800
600
400
200
0
1 11 21 31 41 51 61 71 81 91 101 111 121 131 141 151 161 171 181 191 201 211 221 231 241 251 261
1-july time in hours 11-july
DhengObserved
Sim-5

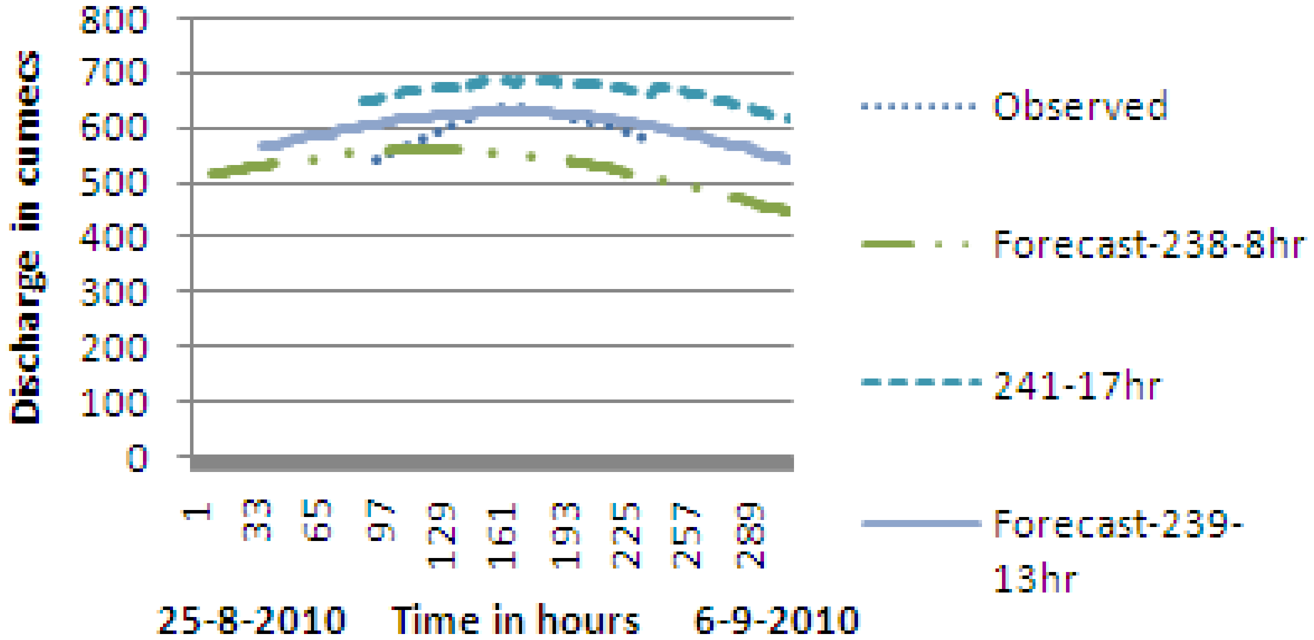
Real time flood forecasting graph



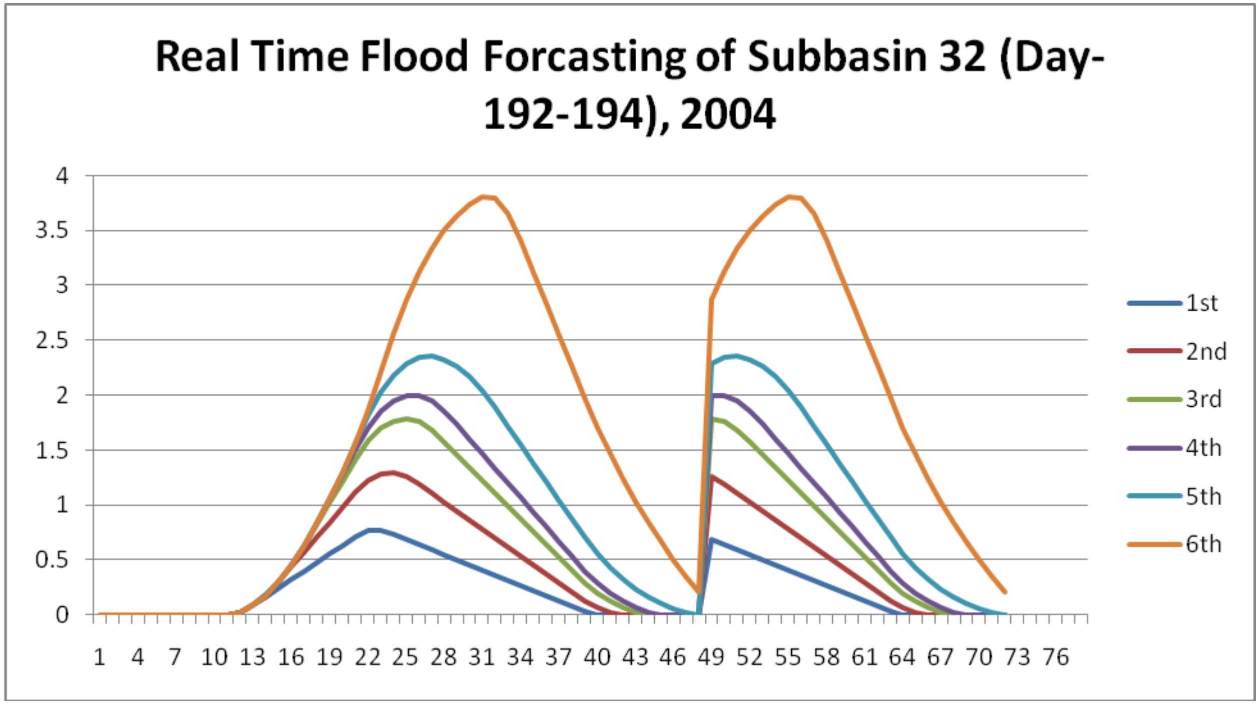
Real time forecasting graphs



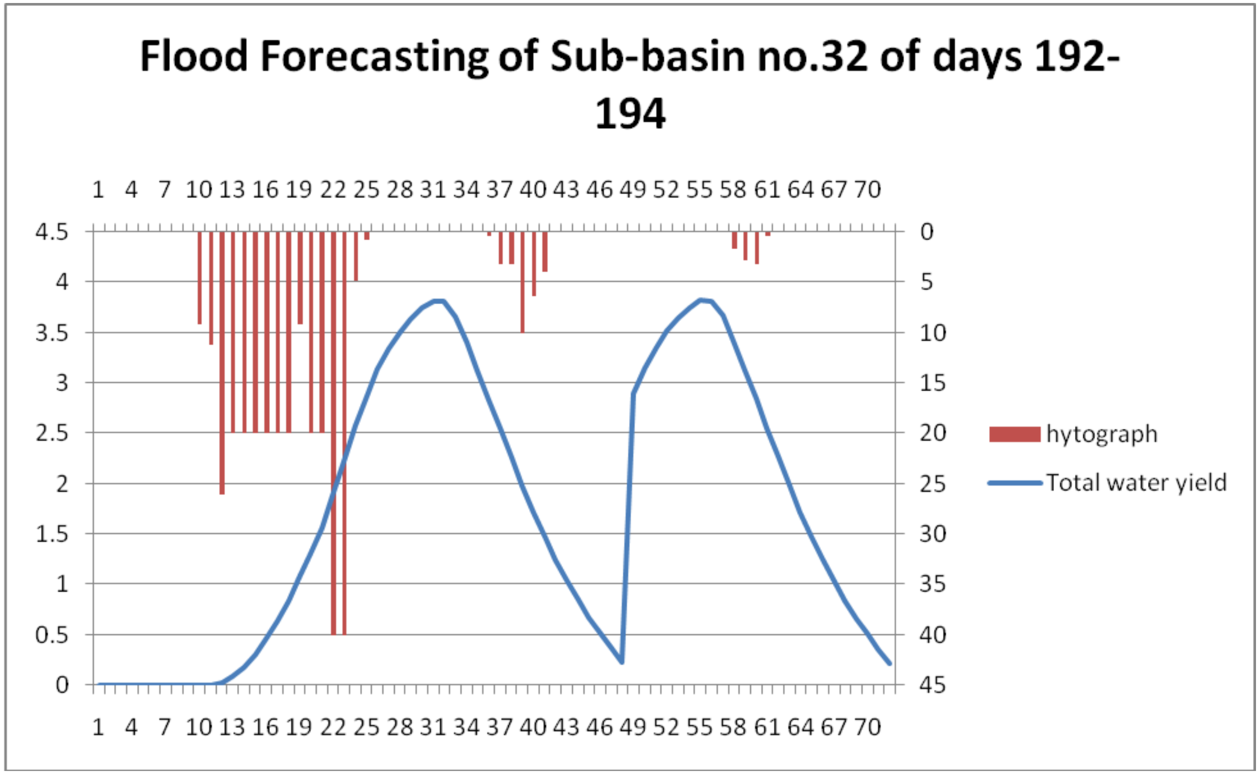
Real time forecast



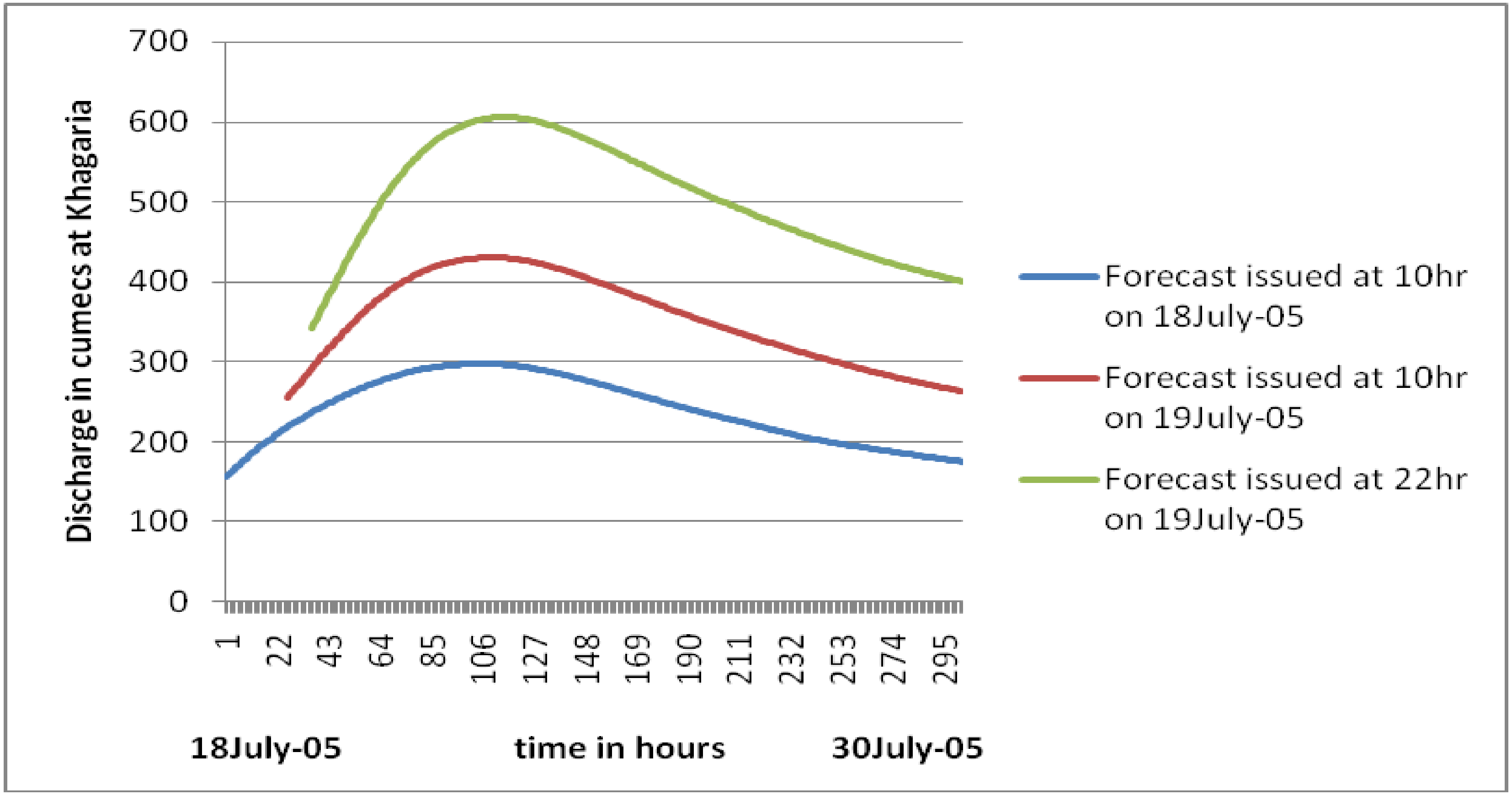
Forecast generated at Benibad for July 2004 event



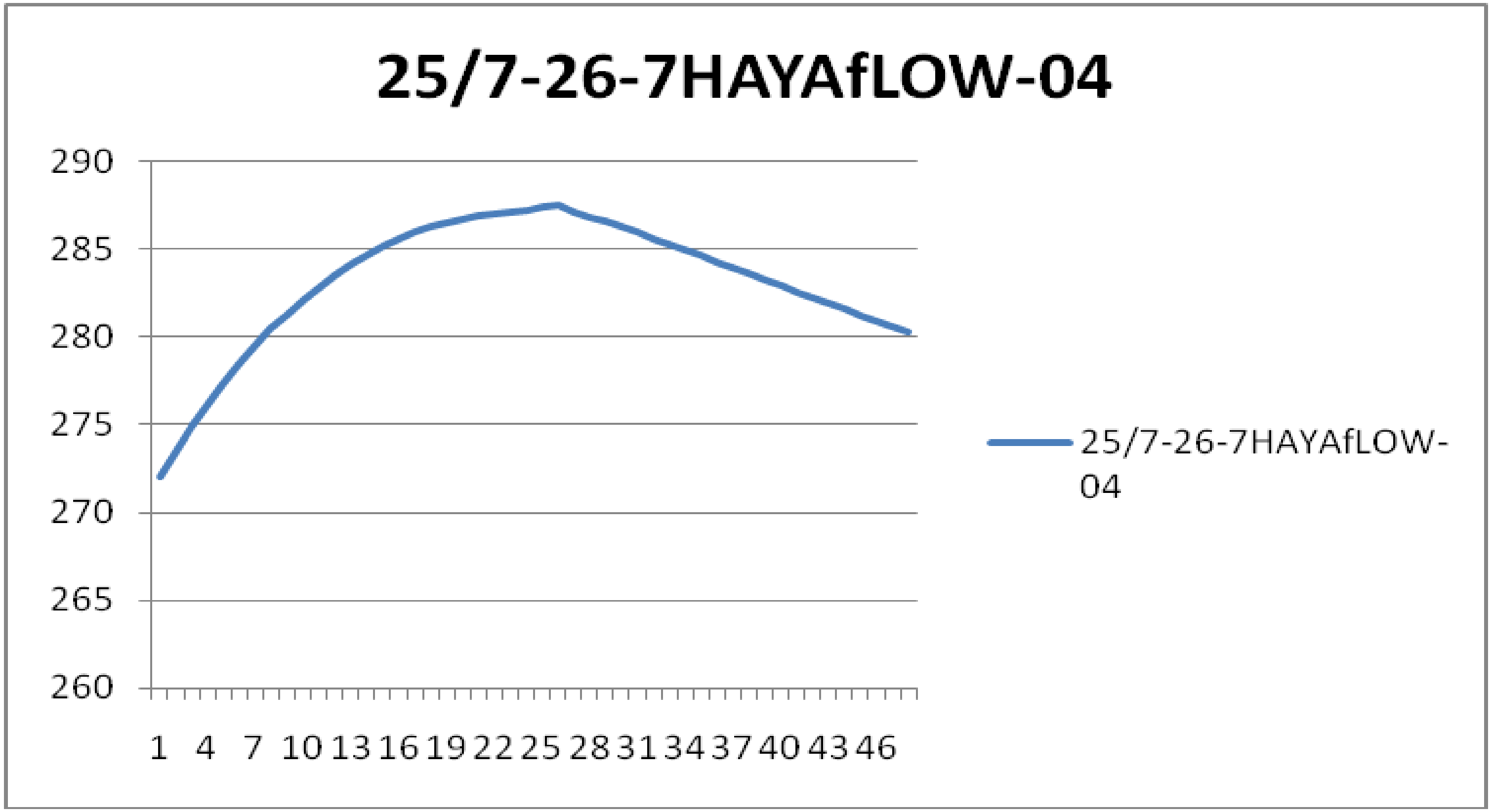
Forecast generated at Benibad for July 2004 event



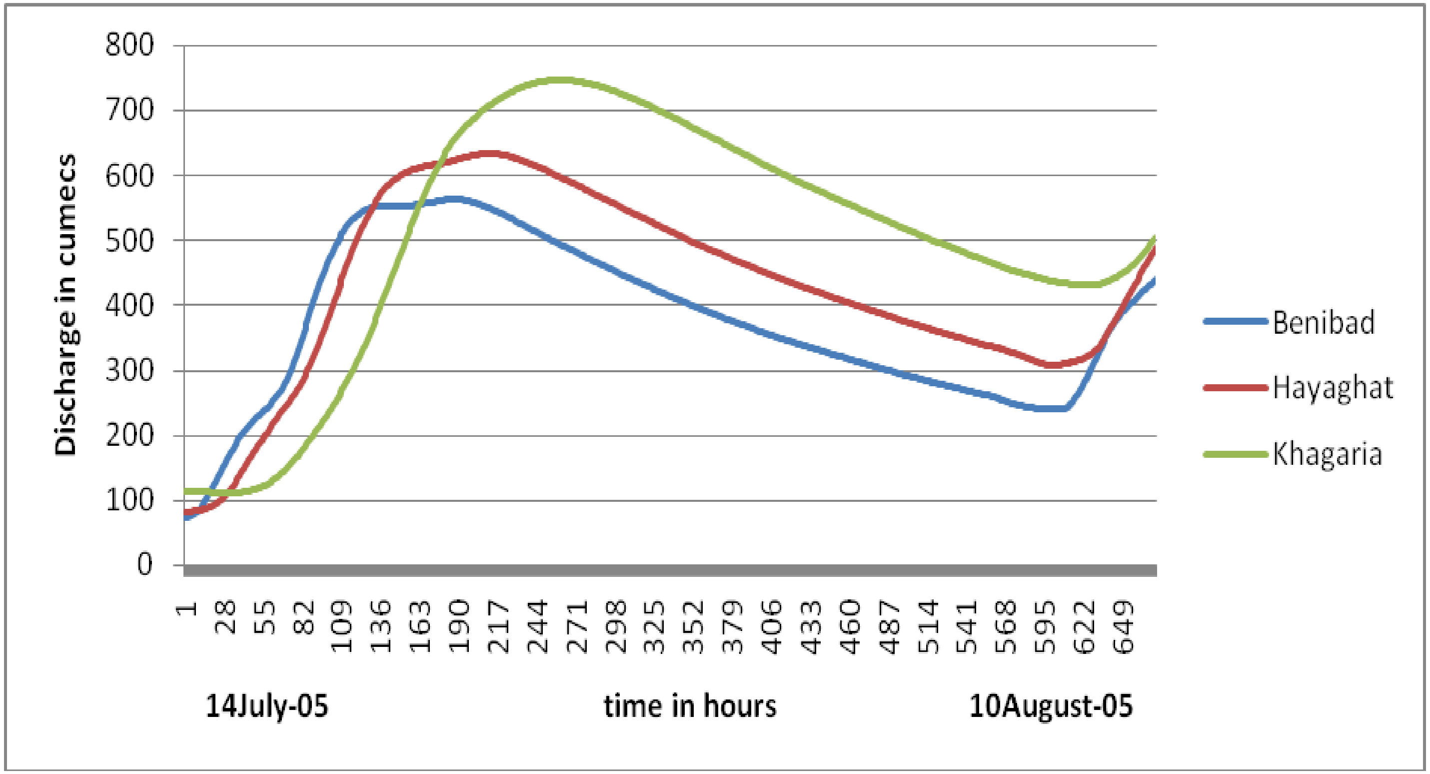
Real time flood forecasting Graph



Real time flood forecasting of Haya



Hourly Discharge



SUMMARY AND CONCLUSIONS

(1)Increase in lead time(cathment response delay+travel time in channel)
(2)Application possible in ungauged cathments also
(3)Sediments,water quality and land use can be modelled on real time basis simultaneously
(4)Physically based
(5)Easy in adaptability
(6)Capable of modelling snow melt, percolation, lateral flow and base flow
(7)Parsimonious
(8)GIS based
(9)Inundation mapping and flood zonation easily possible
(10)Easy updating of catchment characteristics
(11)Capable to incorporate rain fall forecast of IMD and increase lead time
(12)Increase in accuracy
(13)Capable of generating synthetic sub-hourly hydrographs

CONCLUSIONS

As outcome of the present research work it can be concluded that Modified SWAT model combined with time series error forecasting ARIMA model and HEC-RAS hydraulic model can be used as an efficient tool for real-time flood forecasting and inundation mapping. Modified SWAT model reproduces stream flow hydrographs reasonably under multiple storm events and can be used as a real-time flood forecasting tool with enhanced lead time. Rainfall forecast can further increase the forecast lead time.

END

Thank You