

Report on

**Development of flood forecasting system
based on rainfall estimates obtained from
satellite data**



आपो हिष्ठा मयो भुवः

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Roorkee

2016

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CHAPTER 1

Introduction

1.1 Introduction

Runoff estimation for field condition is a challenging work for the hydrologists especially for ungauged basins where data are scarce or very difficult to obtain. Several approaches have been attempted to estimate the runoff from various formulas, techniques, theories and models. Technology has been advanced these days and the role of GIS (Geographical Information System) and remote sensing is rapidly increasing in the field of hydrology. Engineering measures and research towards runoff estimation have made great progresses in recent years. Simulation through modeling of runoff is thus necessary to understand the problems in the discharge analysis and also to estimate the extent of flooding. Several mathematical models are widely used to model rainfall-runoff and flood generation processes.

Various approaches towards runoff estimation are opted till now like empirical, theoretical, conceptual, static approach, dynamic approaches, Lumped and distributed modeling techniques etc. The figure 1.1 shows the various models for runoff generation.

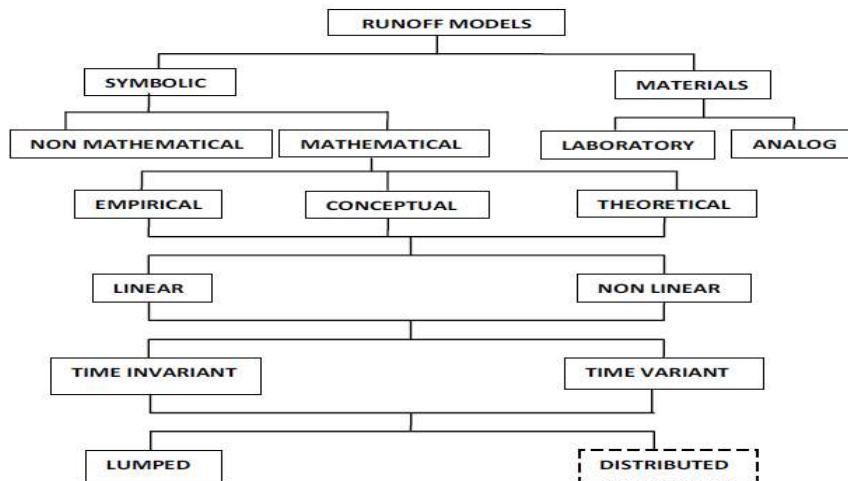


Figure 1.1-Hydrologic model classification (Singh 1988)

IFAS is such a tool that uses various types of rainfall inputs as like satellite rainfall estimates for runoff calculation with tank model approach. IFAS is a distributed hydrologic model which integrates the rainfall data with other parameters like land use, elevation, topography, DEM (Digital elevation model), soil properties to generate discharge for specific conditions. In current scenario the runoff models are extensively used in hydrological studies. In this study distributed hydrologic modeling concept is used and the tool used for runoff generation

is IFAS (integrated Flood Alert System) with the satellite based rainfall data TRMM (Tropical Rainfall Measurement Mission) for the Bagmati basin up to Hayaghat with an area approximately 10550 square kilometers. The IFAS is a tool developed by ICHARM, a research institute in Japan in 1990. The tool has GUI (Graphical User Interface) for Distributed Rainfall-Runoff analysis, which runs on window operated computers. It is a combination of two model approaches-1.Tank Model 2. Kinematic Wave Hydraulic Model. Till now IFAS has developed 3 versions viz. 1, 2 and 3. The version used in this study is IFAS 2.0.The salient features of this software is as following-

1. It is a PWRI-DHM (Public Works Research Institute- Distributed Hydrologic Model).
2. It is a combination of two model approaches-1.Tank Model 2. Kinematic Wave Hydraulic Model.
3. The outflow is determined by Tank Model approach.
4. Parameters are estimated by the use of GIS based datasets like topography, geology, soil and land-use etc. All datasets are in grid format and available online.
5. It is best for small/medium size flood conditions. To calculate the river routing IFAS uses Kinematic Wave Equation

1.2 Objectives

Bagmati basin is a trans-boundary basin for which data is restricted. The actual rainfall data and discharge data for upper part of the basin lays in Nepal is not available. Thus an alternative to replace the actual rainfall data has to be derived. An attempt has been made to use satellite based rainfall estimates such as TRMM for estimating discharge using IFAS. It is also proposed to evaluate the efficiency of the model and to compute the gain in lead time of flood forecast if satellite based rainfall estimates is used for discharge computation.

CHAPTER 2

Literature Review

2 Literature Review

The following studies had been carried out in the previous years for runoff estimation using satellite based rainfall data (TRMM data) and IFAS (Integrated Flood Alert System) for various regions in the world. The main purpose of this literature review is to take guidance from the earlier studies and to make stepwise progress in the project and to evaluate the performance of the dissertation.

Su et al. (2008) in their paper estimates 9 years (1998-2006) rainfall data in the La Plata basin. The work includes the results of TMPA (Tropical Multi-satellite Precipitation Analysis) for the given basin. Various rain gauges are used for the calibration and the validation of the TRMM satellite based rainfall product. It's a good work to show that satellite based rainfall data can be used for hydrologic purpose. They evaluated the rainfall events using VIC method and got the efficiency up to 85% and bias of 2%. So a good step is included in hydrologic research.

Lee et al. (2009) in their technical work had shown how Digital Elevation Model (DEM) resolution affects the physical parameters of the basin and simulated models. Various experiments are done for the DEMs resolution and finding the correct one for the concerned study. The main purpose is that use of perfect resolution of the DEMs lead to a good and accurate result. So for determining the use of hydrologic studies needs to investigate about the resolutions which are best suited for the area of interest.

Nikolopoulos et al. (2010) performed various experiments to find the propagation error related to satellite based rainfall data products. To understand the complexity and errors produced by the two satellites based product TRMM 3B42 and KIDD Radar data is used with distributed modeling process in Bacchiglione basin located in Veneto region. The resolution of KIDD Radar data is finer than TRMM data. The error calculated through the various events is approximately 20% for TRMM and 10-15% for other product. Further the study shows that even TRMM has coarser resolution as compared to other one but it acceptably represents the spatial and temporal variations for the basin. The results evaluated that TRMM products with better resolution or with some corrections are beneficial for hydrologic studies.

GU et al. (2010) showed in their paper that TRMM rainfall data is used for the years 1998 to 2006 using the HEC-HMS software for the discharge calculation. The validation is done over 7000 rain gauge station which lies in the boundary of the basin and the accuracy level is 72-85 %. The conclusion of the study states that satellite based rainfall data needs to be further examined for the use in hydrologic studies.

Sherif et al. (2011) uses spatial data to determine the water storage in lakes of three dams in UAE due to rainfall events. As if UAE is an arid country, thus events are limited and the models are calibrated using the ground data. They choose three areas viz. Ham, Tawiyean and Bih and their physical properties and curve numbers are generated. For runoff estimation

they used Thiessen Polygon method. The calibrated model develops rainfall-runoff curves. The study shows that for limited events TRMM can be used.

Akbari et al. (2012) in their work examines the use of SRTM and TRMM data for practical use in public domain. This study focused on the spatial and temporal pattern of rainfall over Klang watershed. The basin boundaries are delineated using SRTM-DEM by the use of HEC-GeoHMS. TRMM data are used as precipitation dataset and SCS-CN method with $\lambda=0.05$ for tropic region is used. The main finding of this study is that SRTM-DEMs are very less expensive and much more time saving in the hydrologic researches. TRMM is a rough estimates of precipitation and it underestimate (about 35%) of actual gauge data and the peak discharge and peak time are also not accurate by this and it only gives reasonable estimation of volume for the floods in midsize watershed.

Sharma et al. (2012) focused in their work to use TRMM satellite data to predict rainfall amount over Ganga basin. The 3B43 monthly data from January 1998 to December 2011 is used in netCDF format and compare with actual results. At higher altitude overestimations (10-20 %) are found and under-estimation of 5-10% in plain areas likes Varanasi and Raebarely etc. The conclusion of this study was that TRMM rainfall data is not perfect in every case but can be used in ungauged basin.

Hafiz et al (2013) in his research work emphasis on the use of satellite based rainfall estimates for the rainy season (October to January) in which major rainfall occurred in peninsular Malaysia. The Dungun river catchment (1858 square kilometers) is chosen for the study with annual rainfall 2880 mm and great amount of rainfall falling in month of December (19.4%). The GSMaP_NRT, GSMaP_MVK+ and TRMM 3B42RT are used for the runoff calculation with tuned parameters. The satellite data nearly matched the shape of observed hydrograph but truly not represent the actual discharge and also over-estimated the results.

Xue et al. (2013) in this paper the study area is Wangchu basin in Bhutan and TRMM products used are 3B42V7 and 3B42V6. Comparisons for a decade 2001 to 2010 data sets reveals that 3B42V7 is better than 3B42V6 and its also better in frequency. But after all it's not favorable by the scientist but had much more scope after some corrections.

Bennett et al. (2013) in their technical paper examines the effects of TRMM over the hydrological events for sic basins in United States between the year 2004 to 2007 and 2008 to 2010. The model used was SWAT. A great improvement is shown in the accuracy of TRMM when a climatologic bias correction is applied for all the basins over the periods.

Nagesh Kumar et al. (2014) in their research work showed a comparison between various TRMM products like 3A12, 3A13, 3B43 and 3B42 over the Indian subcontinents for the year June 2002 to September 2007 and aimed to improve upon the TRMM rainfall measurements.

Shukla et al. (2014) in their paper had described that TRMM 3B43V7 monthly rainfall data is significantly correlated with gauge rainfall data. Average error is just 5-6 % at Chamoli and Uttarkashi rain station. The lat-lon based average monthly rainfall is used in this study and it is estimated using bilinear interpolation method. The results encouraged the use of TRMM even if no data is acquired in previous years and for poorly gauged and ungauged basins.

Kneiss et al. (2014) in their research paper evaluated the use of TRMM rainfall dataset 3B42 and 3B42RT (7/7A) to examine the quality of satellite based rainfall over Mahanadi basin approximate area 4000 to 16000 square kilometers. The results are evaluated in two ways viz. comparison with ground data and comparison with the discharge. The input model used Nash-Sutcliffe index and the findings that there is a large amount of discrepancy in the results when higher intensity rainfall occurred. But for the other scenario data is not affected much when the hit rate <0.6 mm/day for ground intensity >80 mm/day. The data are useful in the runoff prediction but some complexity arose.

Valeriano et al. (2014) focused in their study which are done in some selected locations in Southeast Asia, that flood simulation can be enhanced by using satellite based rainfall data with the actual rain-gauge measurement. The basins selected in this study are the upper part of Huong river basin in Vietnam and Ping river basin in Thailand. The basins are mostly covered with plants. In the study two satellite based rainfall data GSMaP and TRMM 3B42 V6 are used. The result indicates that these two satellites based rainfall data products slightly just under-estimated the rainfall intensities and discharge but able to predict the temporal and spatial pattern of the rainfall events. The evaluated satellite based rainfall data of TRMM and GSMaP are useful for calculating the discharge and other variables for the basins. This approach can be applied to other basins also where data are lacking or ungauged conditions occurred.

Aziz (2014) had studied about the Kabul river basin in Pakistan for the year 2010 in which high flood occurred and devastation of people and property has seen. The ground data is not available due to the flood for this period of time. In this research paper satellite based rainfall estimates viz. GSMaP_NRT has been used with the software IFAS (Integrated Flood Alert System) by ICHARM Japan. The calculated discharge from the satellite data GSMaP_NRT had shown less error and high efficiency with the observed discharge data. Although GSMaP_NRT data does not match with the peak time and peak discharge and underestimated the situation, it can be used for ungauged basins. the inherent nature of the atmosphere and the parameters are responsible for the errors.

Sugiura et al (2014) propose a method to access the discharge for the Indus river basin in Pakistan for the year 2010 by using IFAS (Integrated Flood Alert System) with input data TRMM and GSMaP_NRT. The model is validated and calibrated using the various parameters of surface tank, aquifer tank and river course tank to match the real conditions. The model performance was also affected by the quality of observed discharge data and spatial variability. Fewer errors are produce with the use of corrected satellite based rainfall estimates.

Kimuara et al (2014) proposed a method to analyze the climatic behavior of Tsengwen reservoir watershed in China on the basis of the use of dimensionless hyetograph with IFAS (Integrated Flood Alert System). 100 years return period hyetograph is taken as rainfall input and simulated in IFAS with tuned parameters for hydrograph generation. The error between the observed and the predicted discharge is approximately 28% for this study area. Extreme weather rainfall data are taken for the simulation at 10 outlet points and compared with the actual data and found to be nearly matched.

Aziz et al (2014) in his research work over upper middle Indus river basin (basin area 476136 square kilometers) and annual flow around 207 cubic kilometers, used IFAS (Integrate Flood Alert System) with TRMM 3B42RT and GSMaP_NRT for runoff prediction and to forecast the time of peak discharge for the people in downstream areas. Tuned parameters for surface tank, aquifer tank, unsaturated tank and river course tank is used for validation and calibration for various points of interest to match the observed discharge. Three error indices viz. wave shape error, volume error and peak discharge error are calculated to check the efficiency of IFAS model for various sites. A correction is also applied in the satellite based rainfall data to reduce the error.

CHAPTER 3

Description of Study Area and Data availability

3 Study Area and Data availability

3.1 Study Area

The Bagmati basin is a midsize basin having the catchment area approximately 3700 square kilometers up-to Dheng Bridge in Sitamarhi district in Bihar. The Kathmandu valley comprise of 15% of the basin area in Nepal. The whole basin can be separated into three parts; the topmost Bagmati basin comprising of the Kathmandu valley plus the upper Dakshinkali area and Nakhkhu khola, the central Bagmati basin including of the remainder of the basin in the hills together with the Kulekhani khola; and the lowermost Bagmati basin comprising of the basin in the Terai, plus few tributaries which originate in the Shivaliks hills. The Bagmati basin uppermost part lies in Nepal and lower part lies in India. The basin characteristic is influenced by the uppermost art which lies in Nepal.

3.2 Hydrology

The areas of Bagmati basin (GOB, 1994) is 14384 square kilometer respectively. Lower portion of basins (45.2 % of the Bagmati basin) lies in India. Basin is extended form in the north-south direction. The length to width ratio is 3.2. It is a 589 km long main river. It is attention-grabbing to note that 54.8 % of the Bagmati basin lying in Nepal is flow out by only 33.1% of the main river.

3.3 Topography

The Bagmati river basin has very sharp gradient in Nepal in close proximity to the origin of the main river which is 16 km north-east of Kathmandu, in Shivpuri range of hills are at an elevation of 1500 km (GOB, 1994). It rapidly decreases starting from 0.08986 (among source, 0 km, and Nayagaon, 8.5 km) to 0.00307 (among Dung-Dungia, 91 km, and Karungi, 101 km). Later on it consecutively decreases to 0.00053 (between Bariya, 154 km and Dheng, 199 km). Between Dheng (the upper point) to Badlaghat (outfall point of the chief river) the gradient is even. Topography of the region can be understood by the contour-map developed using shuttle radar topography mission (SRTM) data (CGIAR- CSI, 2008). The key features of Bagmati are described by Table 3.1

Table 3.1-Key features of Bagmati basin (GOB 1994)

Features	Unit	Bagmati basin	
		Lower part in India	Upper Part In Nepal
Topographical			
1.Basin Area	Km ²	6500	7884
(Percentage of Total)	%	45.2	54.8
River Length	Km ²	394	195
Percentage of Total	%	66.9	33.1
2.Longitudinal Gradient			
Maximum		0.00014	0.08986
Minimum		0.00004	0.00144
Average		0.00009	0.02966
Meteorological			
Normal Rainfall			
Annual		1255	2491 at Garhi
Monsoon	mm	1119	
Hydrological			
Average Discharge	m ³ /sec	204	106
Annual	m ³ /sec	493	232
Monsoon	m ³ /sec	59	48
Peak	m ³ /sec	3033(1975)	2569(1990)

3.4 Land-use

The upper part of the basin which lies in Nepal is mainly covered by the forests but some parts of Terai region is under agriculture. The main crops in the Terai regions are rice, wheat and sugarcane. The lower part in India had no forest cover and it is totally covered by agricultural land. The 20% of the lower parts included roads, residential areas, railways and water bodies.

Figure3.1 shows the Bagmati basin with the existing gauging sites as per Survey of India

3.5 About the Gauge sites

Three gauge sites are marked as outlet to generate runoff and to compare between the results obtained from the observed ground data and satellite based rainfall data. The sites are Dheng Bridge and Hayaghat. The brief descriptions as per CWC India about the sites are discussed below.

3.5.1 Dheng Bridge H.O. 949

The Dheng Bridge lies at the Dheng village in Sitamarhi district of Bihar. The location is 26°73'N-85°33'E. The CWC has set up their gauge site in this village in 1970. It's still in running conditions. The details are shown in table 3.2

Table 3.2-Details of Dheng bridge as per IndiaWRIS

Site Name: Dheng Bridge	Activity: HO
Station Type: GDSQ	Other Activities: Rf/temp
Operational Status: Existing	Bank: Left
State: Bihar	District: Sitamarhi
Basin: Ganga	Independent River: Ganga
Tributary: Kosi	Sub Tributary: Baghmata
Local River: Bagmati	Circle: HOC,Patna
Division: M Ganga Div. IV, Patna	Sub-Division: BurhiGandak SD, Muzaffarpur
Drainage Area (Sq. km.): 3790	Zero of Gauge(m): 65

3.5.2 Hayaghat H.O. 968

The Hayaghat site lies in Darbhanga district of Bihar. The location of the site is 25°59'N-85°56'E. the CWC has set up their gauge site in 1956 and it is still in running conditions. The details are shown in table 3.3

Table 3.3-Details for Hayaghat as per IndiaWRIS

Site Name: Hayaghat	Activity: HO/FF
Station Type: GDSQ	Other Activities: Ff/Rf/
Operational Status: Existing	Bank: Right
State: Bihar	District: Darbhanga
Basin: Ganga	Independent River: Ganga
Tributary: Kosi	Sub Tributary: Baghmata
Local River: Bagmati	Circle: HOC,Patna
Division: M Ganga Div. IV, Patna	Sub-Division: Bagmati Kamala B SD. Darbhanga
Drainage Area (Sq. km.): 12973	Zero of Gauge(m): 35

3.6 Data availability

The data available and used in this study are described in this section. The IFAS uses various types of GIS data for runoff computation like DEM (Digital Elevation Model) soil data, rainfall data etc.

3.6.1 DEM data

The digital elevation model (DEM) used in this study is GTOPO30. It is produced by United States Geological Survey (USGS) and available freely. The GTOPO30 file which is downloaded for the study area is E060N40.

3.6.2 Land use

Global Land Cover Characterization (GLCC) land use is obtained from USGS for the land characteristics determination of the study area. The main area including in the study area are Urban and Built-Up Land, cropland, mountainous regions with snow, water bodies etc.

3.6.3 Soil Data

The global soil data set had been derived from FAO-UNESCO world soil map by various agencies such as USGS, UNEP (United Nations Environment Programme) in gridded data format for whole world. The data which are downloaded are soil classification, soil depth and soil water holding capacity features for the respective area. Table 3.4 shows the technical specification for the data downloaded for the requirement to complete the study.

Table 3.4-Technical details for the data downloaded for the study area

Division	Name	Creator	Spatial Resolution	Coordinate	Data Format
DEM	GTOPO30	USGS	1 KM	WGS84	
LANDUSE	GLCC	USGS	1 KM	WGS84	Raster file(img), binary
SOIL GEOLOGY	Soil Classification	UNEP	1 Degree	90 N - 180 W	bil
	Soil Depth	GESDISC, NASA	1 Degree		bil, sol
	Soil Water Holding Capacity	UNEP	1 Degree	90 N – 180 W	bil

3.6.4 Rainfall Data

The rainfall data used for this project is satellite based rainfall estimates which is TRMM (Tropical Rainfall Measurement Mission) rainfall data. TRMM is a cooperative endeavor of NASA (USA) and JAXA (Japan) started in the year 1997 to study precipitation in the tropical regions and the associated release of energy. TRMM products 3B42 and 3B43 are available in 0.25° spatial resolution, covering 50°N to 50°S for 1998-present. The table 3.5 shows technical details for TRMM. (Source TRMM website)

Table 3.5-Technical details of TRMM

Years of Record	1998/01 to 2013/12
Formats	netCDF, HDF, bin
Time-step	Sub-daily, Daily, Monthly
Data Time Period Extended?	Yes
Domain	Tropics and Subtropics

Spatial Resolution	0.25x0.25 , ~40S - 40N and ~50S - 50N
Missing Data Flag	Missing data present
Vertical Levels	Surface Data Set
Input Data	Satellite microwave and IR; Gauge (for calibration)
Earth system components and main variables	Atmosphere, Precipitation

Data Source-<ftp://trmmopen.gsfc.nasa.gov/pub/merged/mergeIRMicro/V6 or V7>

CHAPTER 4 Methodology

4 Methodology of IFAS

IFAS is a tool developed by ICHARM, a research institute in Japan in 1990. The tool is accomplished with GUI (Graphical User Interface) by Distributed Rainfall-Runoff analysis, which runs on window operated computers. Till now IFAS has developed 3 versions viz. 1, 2 and 3. The version used in this study is IFAS 2.0. IFAS is using the distributed hydrologic modeling approach and tank model concept to simulate the discharge for given dataset.

4.1 Tank Model Approach

The tank model consists of four tanks laid vertically name as surface tank, sub-surface tank, aquifer tank and river tank in IFAS. All the tanks are connected to each other for every possible flood condition. The table4.1 shows the tanks and their functions respectively.

Table 0.1-Tank types and their function

Model	Functions
Surface tank model	Infiltration to unsaturated layer, surface runoff, surface storage, evapotranspiration, rapid intermediate flow
Subsurface tank model	Infiltration to aquifer, subsurface runoff, subsurface storage, low intermediate flow
Aquifer tank model	Outflow from aquifer, aquifer loss
River tank model	River course discharge

4.1.1 Surface Tank Model

The surface tank model separates the precipitation to surface flow, fast intermediate flow and infiltration flows. The figure 4.1 shows the three outflows of the surface tank model. The surface outflow Q_{sf} is deliberate as a fraction $3/5$ of the storage capability based on Manning rules. The fast subsurface flow Q_{ri} is also estimated as a portion of storage capacity. The infiltration flow Q_0 is calculated as a part of storage capacity based on the Darcy law. The figure 4.1 shows the surface tank with the possible outflows and factors

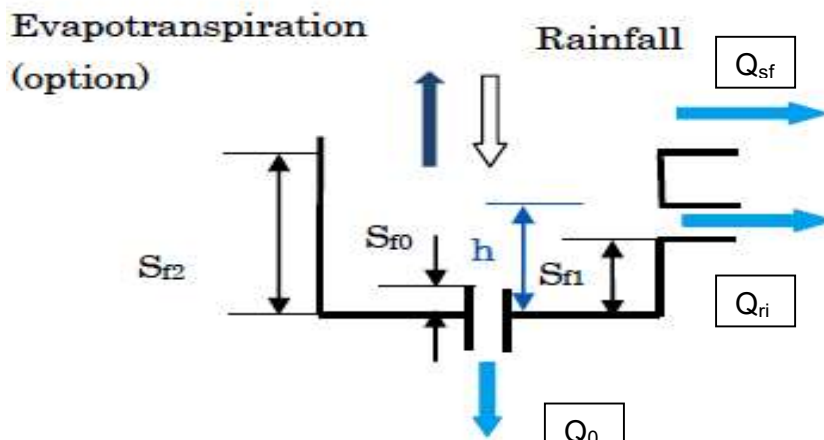


Figure 0.1-Surface tank

$$\text{Surface flow } Q_{sf} = L \frac{1}{N} (h - S_{f2})^{3/5} i^{1/2} \quad 4.1$$

$$\text{Rapid subsurface flow } Q_{ri} = \alpha_{ri} A f_0 \frac{h - S_{f1}}{S_{f2} - S_{f1}} \quad 4.2$$

$$\text{Infiltration flow } Q_0 = A f_0 \frac{h - S_{f0}}{S_{f2} - S_{f0}} \quad 4.3$$

If $h \geq S_{f2}$, then

$$\frac{\partial h}{\partial t} = R - E_{ps} - Q_0 - Q_{sf} - Q_{ri} \quad 4.4$$

If $S_{f1} \leq h < S_{f2}$, then

$$\frac{\partial h}{\partial t} = R - E_{ps} - Q_0 - Q_{ri} \quad 4.5$$

If $S_{f0} \leq h < S_{f1}$, then

$$\frac{\partial h}{\partial t} = R - \frac{E_{ps}}{S_{f1} * h} - Q_0 \quad 4.6$$

If $h \leq S_{f0}$, then

$$\frac{\partial h}{\partial t} = R - \frac{E_{ps}}{S_{f1} * h} \quad 4.7$$

Where, R= rainfall

E_{ps} = Evapotranspiration

Q_0 = Infiltration to lower tank

Q_{sf} = Surface outflow

Q_{ri} = rapid subsurface flow

h = water height for the tank

S_{f2} = height from which saturated excess overland flow occurs

S_{f1} = height from which rapid subsurface flow occurs

S_{f0} = height where ground infiltration occurred

L= length of the mesh

N= manning's coefficient

i = gradient

4.1.2 Subsurface tank model

The subsurface tank model deals with the low flow conditions when the precipitation values are very less in the surface tank model and the input to the intermediate zone is almost negligible. The figure 4.2 shows the subsurface tank model with the possible outflow discharges.

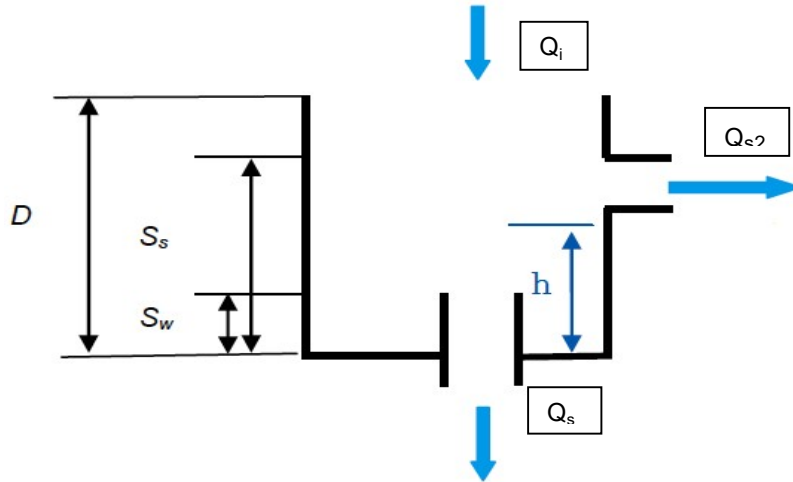


Figure 0.2- Unsaturated tank

$$\text{Unsaturated lateral flow } Q_{S1} = K_X * D * I \quad 4.8$$

$$\text{Unsaturated vertical flow } Q_{S2} = K_Z * I \quad 4.9$$

If $S_s > h \geq S_w$, then

$$\theta_s \frac{\partial h}{\partial t} = Q_{in} - E_{ps} - Q_{S1} - Q_{S2} \quad 4.10$$

If $h < S_w$, then, there is no slow intermediate flow nor infiltration to the aquifer

$$\theta_s \frac{\partial h}{\partial t} = Q_{in} - \frac{E_{ps}}{S_w} h \quad 4.11$$

Where, E_{ps} = Evapotranspiration

Q_{in} = flow coming from the surface tank

Q_{S1} = unsaturated lateral flow

Q_{S2} = unsaturated vertical flow

D = total height of water for the unsaturated tank

h = height of water for this tank

θ = soil moisture content ($=h/D$)

S_s = height when $\theta = \theta_s$

θ_s = soil moisture content at saturation ($=S_s/D$)

S_w = height when $\theta = \theta_w$

θ_w = soil moisture content at wilting point ($=S_w/D$)

K_X = hydraulic conductivity (horizontal) at θ

K_Z = hydraulic conductivity (vertical) at θ

$$K_X = \frac{K_{SX}}{100} \frac{\exp(b\theta) - \exp(b\theta_w)}{\exp(b\theta_s) - \exp(b\theta_w)} \quad 4.12$$

$$K_X = K_{ZX} \frac{\exp(b\theta) - \exp(b\theta_w)}{\exp(b\theta_s) - \exp(b\theta_w)} \quad 4.13$$

Where, K_{SX} = horizontal hydraulic conductivity at θ_s

K_{ZX} = vertical hydraulic conductivity at θ_s

b = constant depending upon the total porosity of soil ranging from 0-100

4.1.3 Aquifer tank model

The aquifer tank model deals with the aquifer zone of the flow. The possible outflows are unconfined aquifer outflow and confined aquifer outflow from this tank. The figure 4.3 shows the aquifer tank model. The outflow is considered as a fraction of confined aquifer to h , and unconfined aquifer to h^2 .

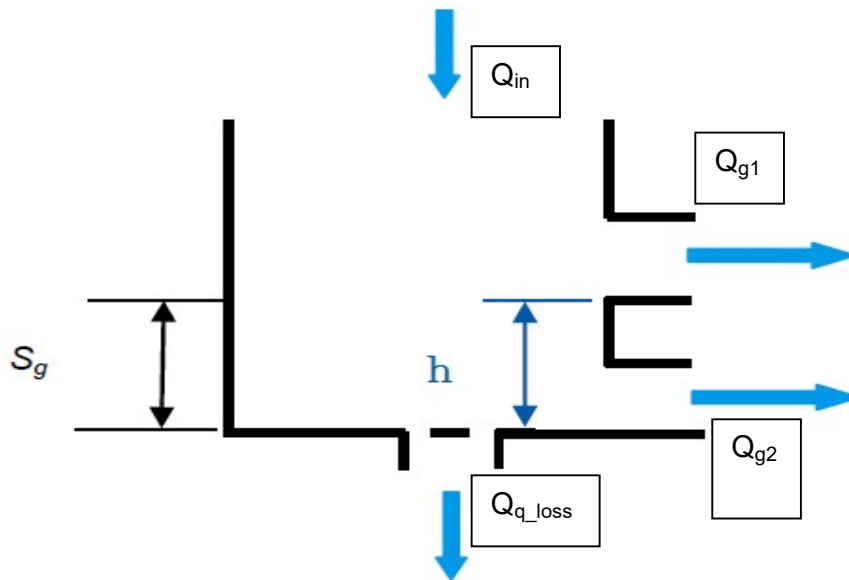


Figure 0.3-Aquifer tank

If $h \geq S_g$, then

$$\frac{\partial h}{\partial t} = Q_{in} - Q_{g1} - Q_{g2} - Q_{q_loss} \quad 4.14$$

If $h < S_g$, then

$$\frac{\partial h}{\partial t} = Q_{in} - Q_{g2} - Q_{q_loss} \quad 4.15$$

Where Q_{in} = inflow from infiltration model tank

h = water height of model

Q_{g1} = unconfined aquifer outflow

Q_{g2} = confined aquifer outflow

Q_{q_loss} = accountable aquifer loss

The outflows are described as follows

$$Q_{g1} = A_u^2 (h - S_g)^2 A \quad 4.16$$

$$Q_{g2} = A_g h A \quad 4.17$$

Where, A_u =coefficient for the unconfined outflow.

A_g =coefficient for the confined outflow

$$Q_{g_loss} = \alpha_{g_loss} Q_2 \dots\dots\dots 4.18$$

4.1.4 River tank model

The river tank model represents the river and its discharge which is calculated on the base of manning equation. The river tank model is shown in figure 4.4

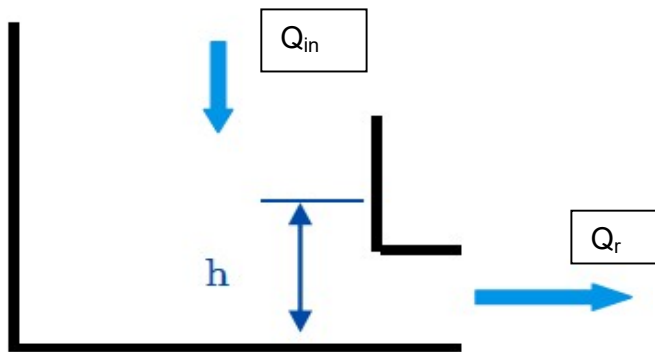


Figure 0.4-River course tank

$$LB \frac{\partial h}{\partial t} = Q_{in} - Q_r \quad 4.19$$

Where

Q_{in} = inflow from the aquifer model

Q_r = outflow from the river tank model

L = length of river course

B = breadth of river course calculated as the resume law

$$B = cA^s \quad 4.20$$

Where c and s are constant (generally $S < 1$)

The model consider the time delay function and the basic equation are as follow

$$\frac{\partial A}{\partial t} + \frac{\partial Q}{\partial x} = 0 \quad 4.21$$

$$Q = \frac{1}{n} B h^{5/3} I^{1/2} \quad 4.22$$

Where Q =flow

A =area of cross section= Bh

I = gradient of riverbed

n =coefficient of roughness

x = spatial variable in flow direction

t=time

The river routing method used is the kinematic wave method using the difference method for the cell type.

$$\frac{\partial Q}{\partial t} + C \frac{\partial Q}{\partial x} = 0 \quad 4.23$$

$$C = \frac{\partial Q}{\partial A} \quad 4.24$$

The differential equation is solved as per the difference method shown by the following steps

$$\frac{1}{2\Delta t} (Q_i^{n+1} + Q_{i+1}^{n+1} - Q_i^n - Q_{i+1}^n) + \frac{C}{2\Delta x} (Q_{i+1}^n + Q_{i+1}^{n+1} - Q_i^n - Q_i^{n+1}) = 0 \quad 4.25$$

Where i= spatial increment, n=time increment

$$\text{Then } Q_{i+1}^{n+1} = \frac{\left(\frac{1}{2\Delta t} + \frac{C}{2\Delta x}\right) Q_i^n + \left(\frac{1}{2\Delta t} - \frac{C}{2\Delta x}\right) Q_{i+1}^n + \left(-\frac{1}{2\Delta t} + \frac{C}{2\Delta x}\right) Q_i^{n+1}}{\frac{1}{2\Delta t} + \frac{C}{2\Delta x}} \quad 4.26$$

This model conducts computation by treating Δx as the cell length and by shortening the Δt . In addition, river course with compound sections also can be calculated within this model. Furthermore, the model assumes that the flow rate of flood channel is 0 m³/hour or day, and calculates the discharge of low flow channel section only. Because the sectional area contains also the flood channel, a storage effect considering the flood channel has been included in the model. Finally, the storage effect of flood channel (considered as flood area) around the river can be optionally selected.

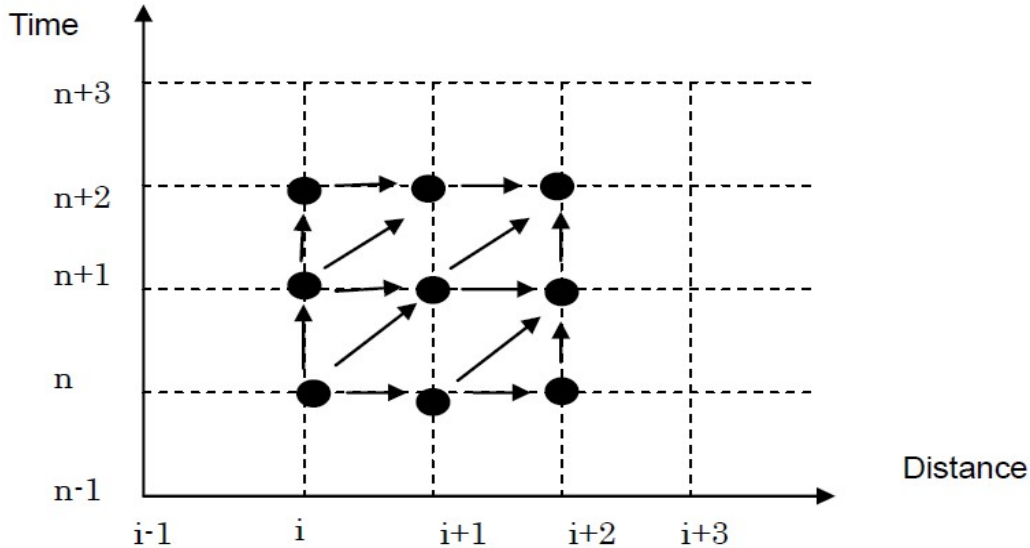


Figure 0.5-Image for kinematic wave method

CHAPTER 5

Description of Procedure

5 Application of IFAS

The following schematic flow chart describes the schematic way to deal with the tool IFAS (Source IFAS Manual)

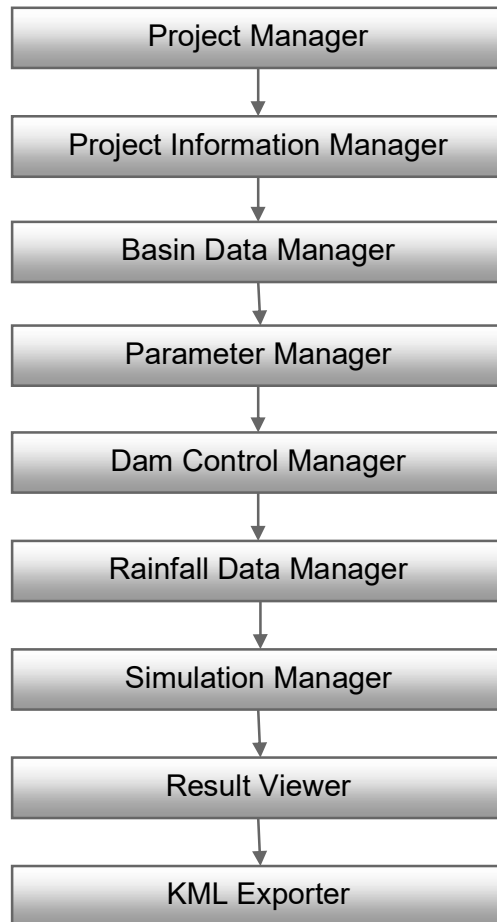


Figure 5.1-Flow chart for IFAS procedure

5.1 Procedure

The procedure to accomplish this study for runoff generation by the use of IFAS and TRMM data is described as below

5.1.1 Project Manager

The project manager consist the name of the project for which simulation has to take place. It can create a project, copy a project and also can delete a project. The project name for this study is “Bagmati”.

5.1.2 Project information Manager

Project information manager sets the fundamental information about the project which has to be carried out. The following inputs are required for this step

1. Location of the basin i.e. latitude and longitude for the area covering the basin. in this study the area covering the basin extent is given below in table

Table 5.1-Location of Bagmati basin

	Lower left	Upper Right
Latitude	25 ⁰ 58'41''	27 ⁰ 50'46''
Longitude	85 ⁰ 00'30''	85 ⁰ 59'27''

2. Input cell size for GTOPO30 is 0.01 degree.
3. Input target period for the rainfall events. In this project 5 events are taken whose date is as follow-
 - a) 01 July 2010 to 20 July 2010
 - b) 31 August 2010 to 04 September 2010
 - c) 23 august 2009 to 28 August 2009
 - d) 25 July 2008 to 31 July 2008
 - e) 31 July 2007 to 03 August 2007
4. Input time interval which is 60 minute for the project
5. **Data Importing-** The following data described in table5.2 are imported in IFAS which are required for the analysis of the project.

Table 5.2-Data downloaded for the project

Division	Name	Creator	Spatial Resolution	Coordinate	Data Format
DEM	GTOPO30	USGS	1 KM	WGS84	
LANDUSE	GLCC	USGS	1 KM	WGS84	Raster file(img), binary
SOIL GEOLOGY	Soil Classification	UNEP	1 Degree	90 N - 180 W	bil
	Soil Depth	GESDISC, NASA	1 Degree		bil, sol

	Soil Water Holding Capacity	UNEP	1 Degree	90 N – 180 W	bil
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5.1.3 Basin Data Manager

Basin data manager is done for river course modeling. It creates drainage course on the basis of elevation data. The steps performed for this is shown in the figure 5.2

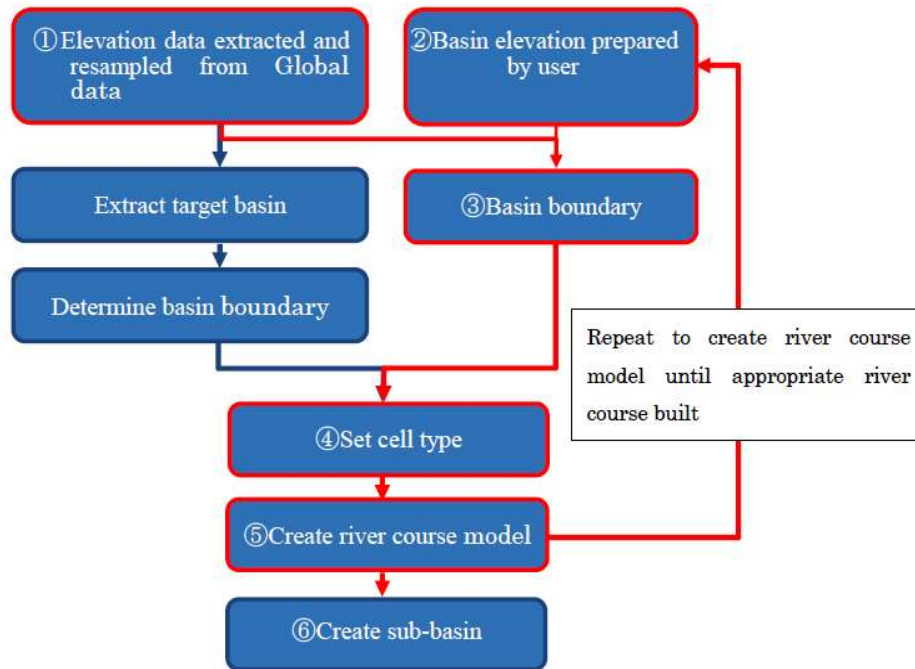
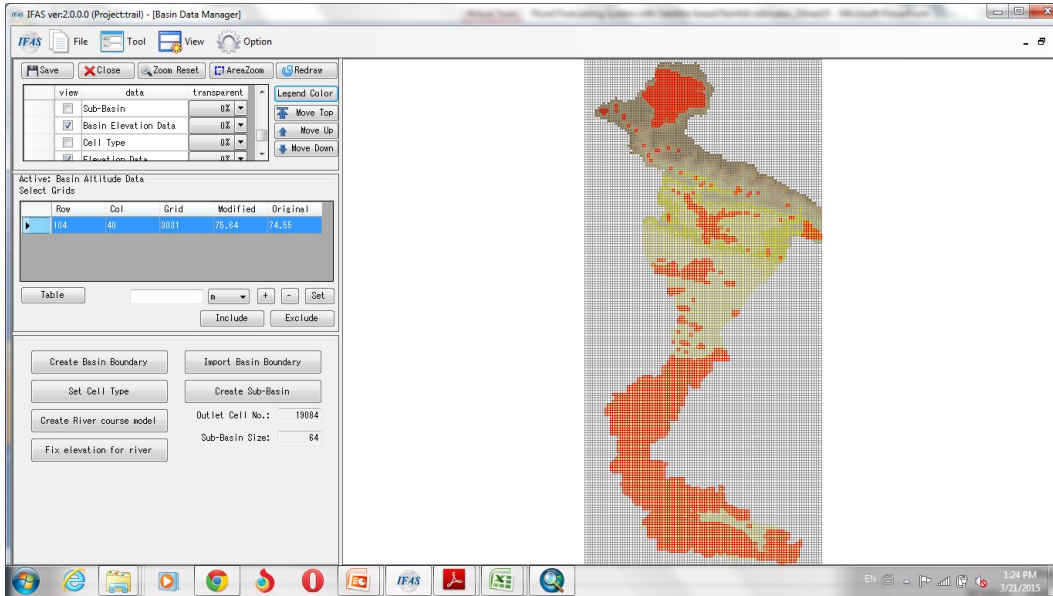
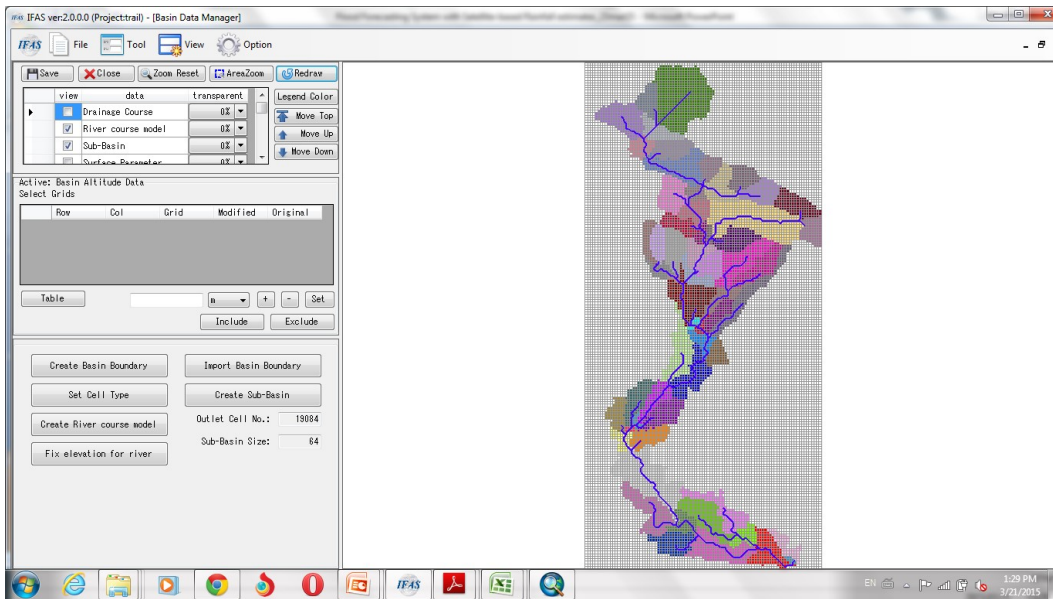


Figure 5.2-Basin data manager process

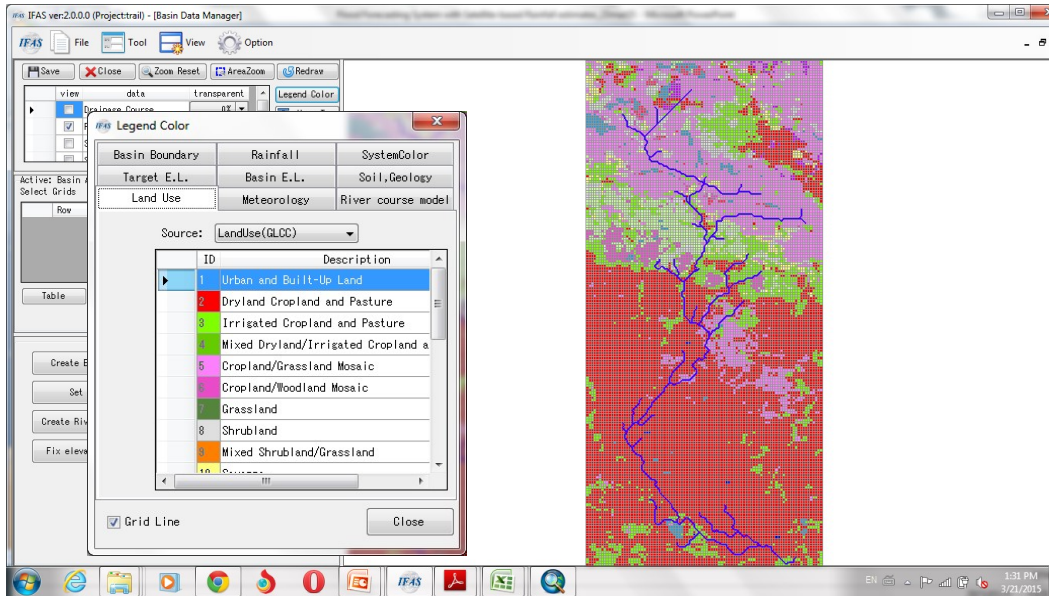
The basin boundary and stream network delineated from online DEM (SRTM data) and online landsue class for the study area are shown in Figure 5.3.



DEM of study area



Basin delineation



Land use class

Figure 5.3- Delineation of basin boundary, stream network and land use class from on line data

5.1.4 Parameter Manager

Parameters are set for the surface, subsurface, aquifer and river course for the discharge calculation in IFAS. The parameters are set by analysis of the area and other study carried out in the project area. The description and the value taken for the study area are discussed in this section. Four tank parameters are described in the IFAS which are described in this section as per the IFAS technical manual.

5.1.4.1 Parameters for Surface Layer Tank

The surface layer tank is the topmost tank laid vertically in the tank model. Three outflows are possible from the surface layer tanks which are surface flow, subsurface flow and infiltration. The figure 5.3 shows the parameters for the surface layer tank as per the IFAS manual.

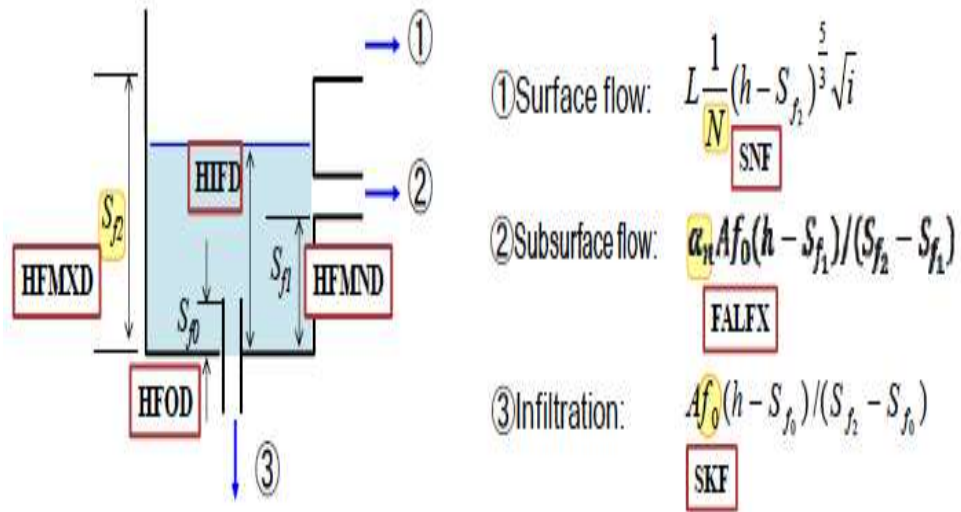


Figure 5.4-Surface tank and its parameters

The table 5.3 shows the parameters and their functions for the surface layer tank as per IFAS manual

Table 5.3-Parameters for surface tank

Symbol	Notation	Unit	Explanation
S_{f_2}	HFMXD	m	Maximum storage height of surface layer. Estimated as maximum storage height of A0 layer of the surface. 10-40mm is recommended.
S_{f_1}	HFMND	m	Height to generate fast runoff. 5-10mm is recommended.
S_{f_0}	HFOD	m	Height to generate infiltration. 5mm is recommended. $S_{f_1} > S_{f_0}$.
f_0	SKF	cm/sec	Final infiltration capacity.
α_{ri}	FALFX	non	Coefficient to specify the sub-surface runoff. $f_0 * \alpha_{ri}$ is the maximum runoff α_{ri} is equal to runoff/impervious area
N	SNF	$m^{-1/3}s^{-1}$	Roughness coefficient of surface
	HIFD	m	Initial value for calculation

The parameters for surface tank used in this study is described in table 5.4

Table 5.4-Tuned parameters for surface tank

No	SKF	HFMXD	HFMND	HFOD	SNF	FALFX	HIFD
1	0.0016	0.05	0.01	0.005	4.0	0.60	0.00
2	0.004	0.1	0.01	0.005	1.4	0.80	0.00
3	0.00008	0.05	0.01	0.005	4.0	0.50	0.00
4	0.000008	0.001	0.005	0.0001	0.2	0.90	0.00
5	0.00008	0.05	0.01	0.0005	4.0	0.50	0.00

5.1.4.2 Parameters for unsaturated Layer Tank

This tank lies below surface layer tank in the tank model and represent the unsaturated zone of the model. Two outflows are possible in this tank. The parameter for this tank is shown in figure 5.4 as per IFAS manual.

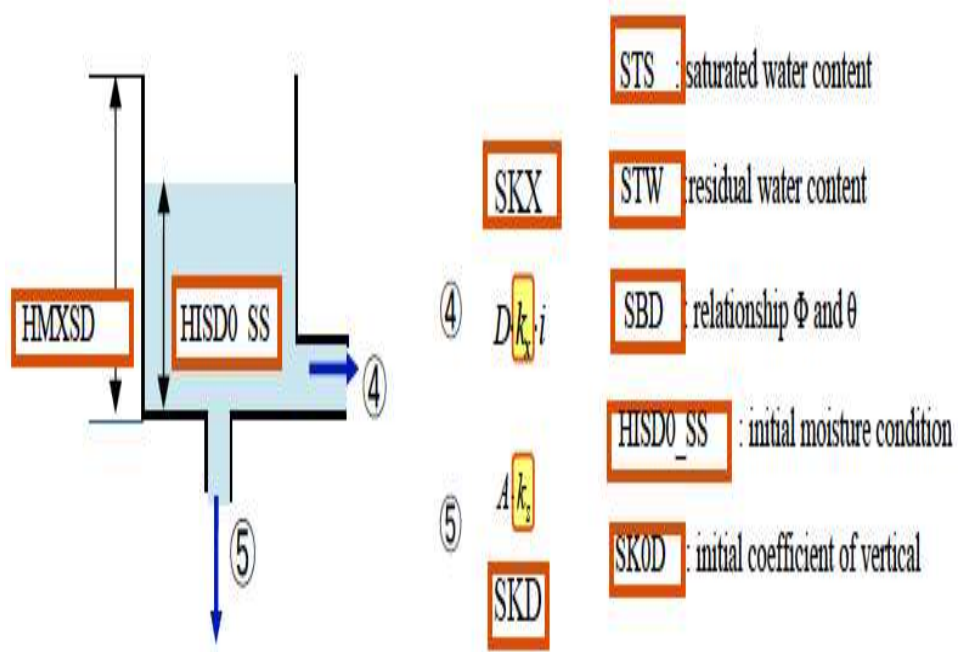


Figure 5.5-Unsaturated tank and its parameters

The table 5.5 shows the parameters for the subsurface tank and their function as per IFAS manual.

Table 5.5-Parameters for subsurface tank

Symbol	Notation	Unit	Explanation
	SKD	cm/sec	Horizontal permeability
	SKX	cm/sec	Vertical permeability
	HMSXD	m	Height of tank
	STS		Saturated water content
	STW		Residual water content
	SBD		Constant value of b (Hillel constant)
	HISD0_SS	m	Initial water depth for calculation
	SK0D	cm/sec	Initial horizontal permeability for calculation

The parameters used for subsurface tank is described in table5.6

Table 5.6-Default parameters for unsaturated tank

No	SKD	SKX	HMXSD	STS	STW	SBD	HISS0_SS	SK0D
1	0.0004	0.2	0.6	0.6	0.3	12	0.3	0.000001
2	0.0005	0.2	0.6	0.6	0.3	12	0.3	0.000001
3	0.0006	0.2	0.6	0.6	0.3	12	0.3	0.000001
4	0.0007	0.2	0.6	0.6	0.3	12	0.3	0.000001

5.1.4.3 Parameters for Aquifer Layer Tank

The aquifer layer tank lies below the subsurface layer tank vertically in the tank model. The aquifer layer tank represents the aquifer characteristics of the model. Two possible outflows are generated from the aquifer layer tank. The figure 5.5 shows the aquifer layer tank as per IFAS manual.

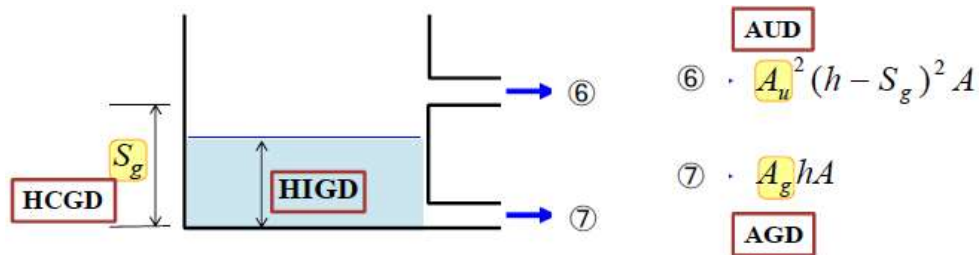


Figure 5.6-Aquifer tank and its parameters

The parameters for the aquifer layer tank are shown in the table 5.6 as per the IFAS manual.

Table 5.7-Parameters for aquifer tank

Symbol	Notation	Unit	Explanation
S_g	HCGD	m	Storage height for generate unconfined groundwater
A_u	AUD	$(1/\text{mm}/\text{day})^{1/2}$	Runoff coefficient of unconfined groundwater
A_g	AGD	1/day	Runoff coefficient for confined groundwater
	HIGD	m	Initial value for calculation

The parameters used in aquifer tank are described in table

Table 5.8-Tuned parameters for aquifer tank

No	AUD	AGD	HCGD	HIGD
1	0.20	0.003	2.0	2.0
2	0.22	0.003	2.0	2.0
3	0.24	0.003	2.0	2.0
4	0.26	0.003	2.0	2.0
5	0.28	0.003	2.0	2.0
6	0.30	0.003	2.0	2.0
7	0.32	0.003	2.0	2.0
8	0.34	0.003	2.0	2.0
9	0.36	0.003	2.0	2.0

10	0.38	0.003	2.0	2.0
11	0.40	0.003	2.0	2.0

5.1.4.4 Parameters of river course

This is the last tank laid vertically below the aquifer layer tank in the tank model. This tank generates the river discharge by using the kinematic wave method. The figure 5.6 shows the river course details as per IFAS manual.

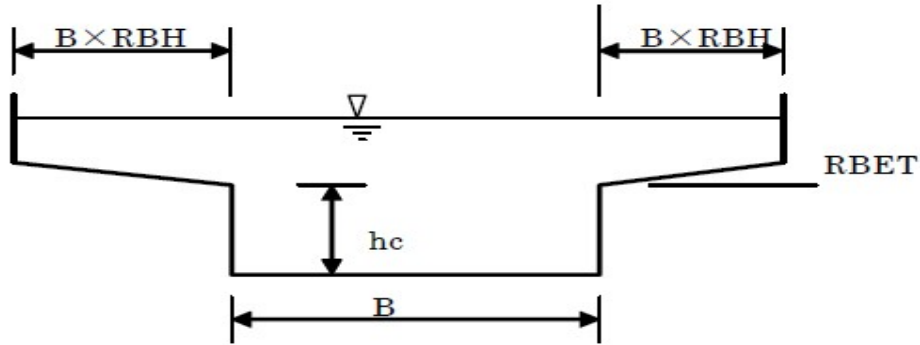


Figure 5.7-River course tank and its parameters

The table 5.6 shows the parameters for the river course described as per IFAS manual.

Table 5.9-Parameters for river course tank

Symbol	Notation	Unit	Explanation
c	RBW		Coefficient set from actual river width Unit for river width is m and catchment area in square km
s	RBS		Coefficient (approx. 0.3-0.5)
n	RNS		Manning coefficient
	RRID		Initial value for calculation
	RGWD		Infiltration coefficient from river to aquifer layer tank
	RHW		Water table for submerge high water channel is calculated as $hc=RHW \cdot RHS$
	RHS		Refer to RHW
	RBH		River width of high water channel/low water channel
	RBET		Slope gradient for high water channel
	RLCOF		Collection coefficient of river channel

The table shows the parameters for the river course used in this study

Table 5.10-Tuned parameters for river course tank

No	RBW	RBS	RNS	RRID	RGWD	RHW	RHS	RBH	RBET	RCOLF
1	7	0.5	0.035	0.2	0.00	9999	1.0	0.5	0.05	1.4

2	7	0.5	0.036	0.2	0.00	9999	1.0	0.5	0.05	1.4
3	7	0.5	0.037	0.2	0.00	9999	1.0	0.5	0.05	1.4

5.1.5 Rainfall Data Manager

IFAS can use this rainfall data for runoff analysis

- a) 3B42RT (Satellite based rainfall estimates)
- b) GSMap (Satellite based rainfall estimates)
- c) QMorph (Satellite based rainfall estimates)
- d) CMorph (Satellite based rainfall estimates)
- e) GPV (Forecast rainfall)
- f) Any kind of CSV data

In this project the TRMM 3B42RT V6/V7 satellite based rainfall is used. The schematic diagram for rainfall analysis is given below in figure5.7

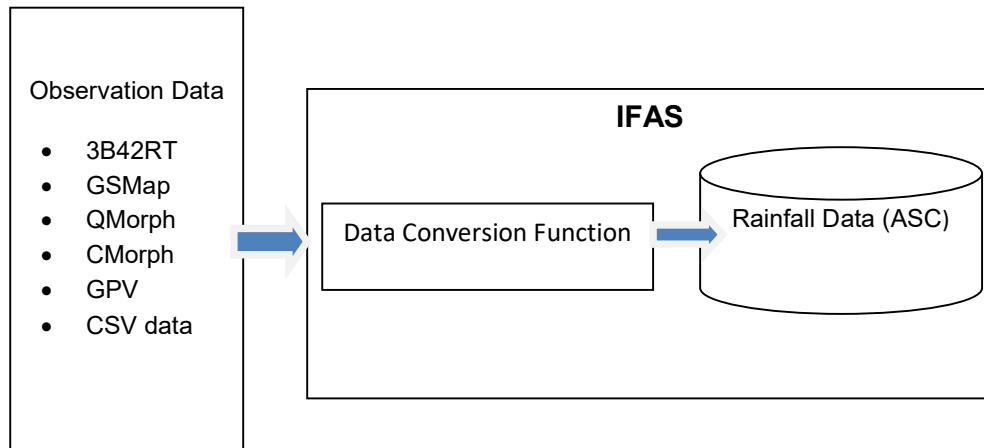


Figure 5.8-Rainfall data manager

5.1.6 Simulation Manager

Simulation in IFAS means the combination of data like rainfall and parameters for runoff analysis. Its main aim is to simulate the model. The schematic figure5.8 shows the process for simulation manager

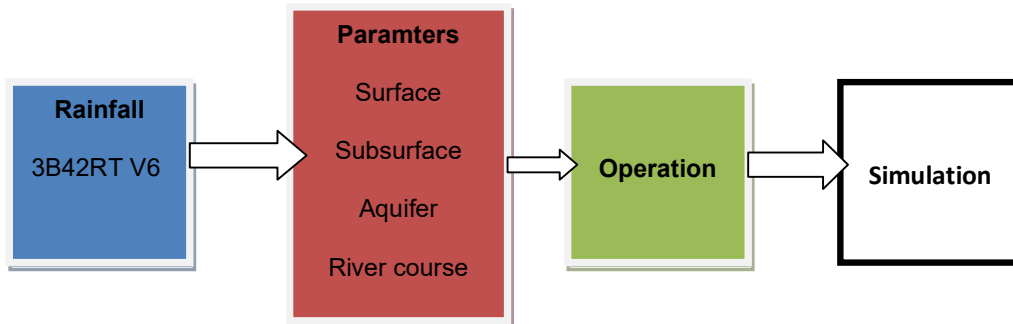


Figure 5.9-Simulation manager

5.1.7 Result Viewer

All the results are shown in the result output display function such as model information and analysis result.

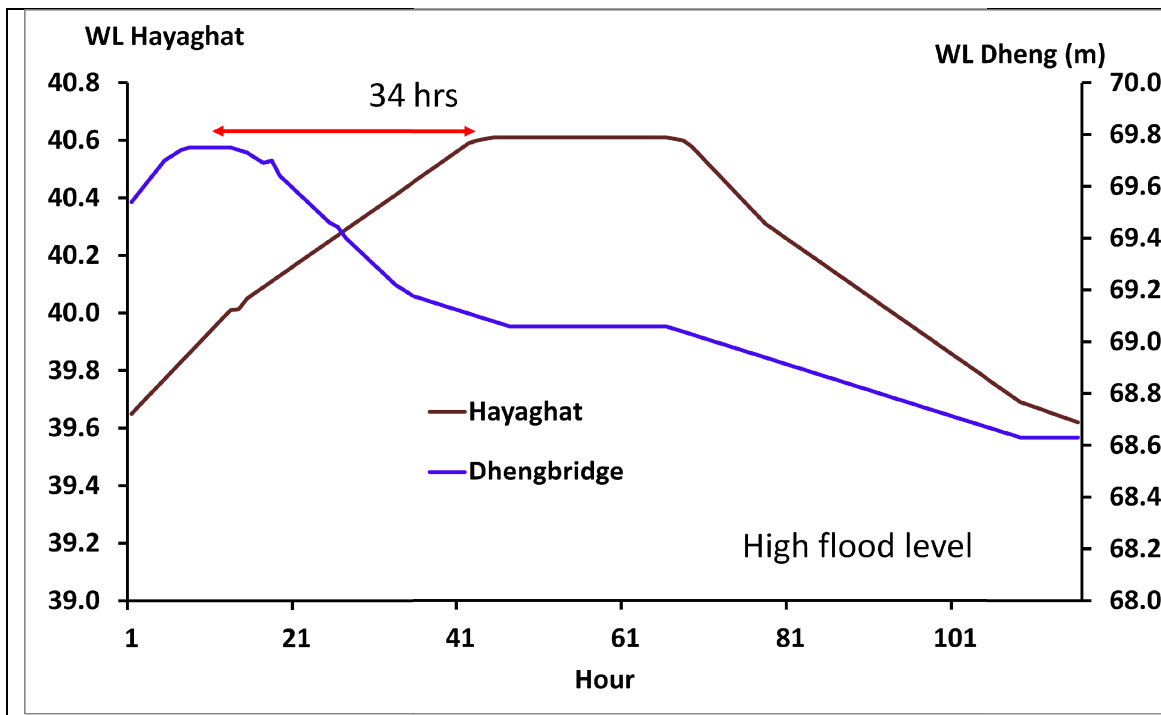
5.2 Calibration and validation

The default values of the parameters for the 4 tanks viz. surface tank, unsaturated tank, aquifer tank and river course tank with the TRMM 3B42RT V6 rainfall data is not giving reliable results. So the parameters have to change to match the proper field observations. The IFAS is then simulated with the tuned parameters and simulated discharge is obtained. The observed data at Hayaghat is used for calibration as the H-Q relationship was available. The H-Q relation is used to derive the equation for which the discharge calculated from IFAS is transformed to water level. The tuned parameters are described in each parameter sections. After using the tuned parameters the results shows good response for the hourly water level observed data at Hayaghat site. Thus the model is calibrated for this study by trial and error method using the IFAS manual. Therefore the tuned parameters are used for the discharge calculation for both the sites Dheng Bridge and Hayaghat. The validation is done for other events and approximately matched the hourly water level for the Hayaghat site.

Chapter 6 Results

6 Results and Discussion

1. The observed water level at Dheng bridge site and Hayaghat are analysed to estimate the lag time of peak flood between two gauging sites. Figure 1.1 shows the stage hydrographs at two GD site for high and low flood. The lag time is estimated as 34 to 60 hours between the two GD sites.



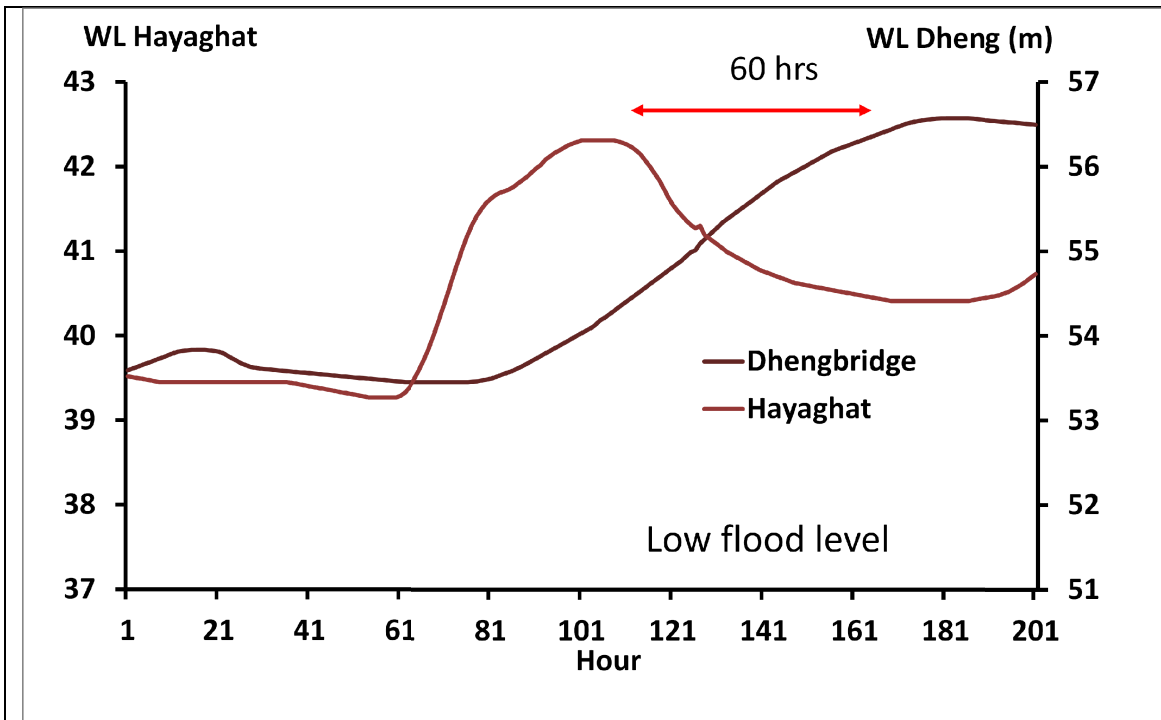
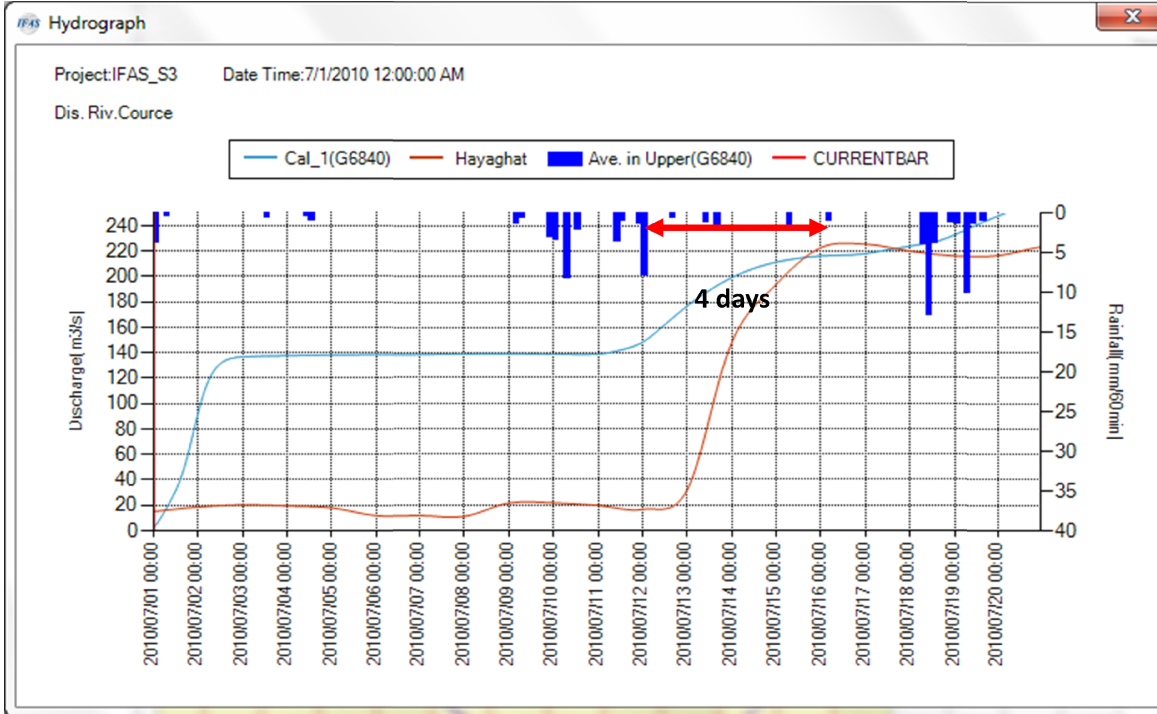


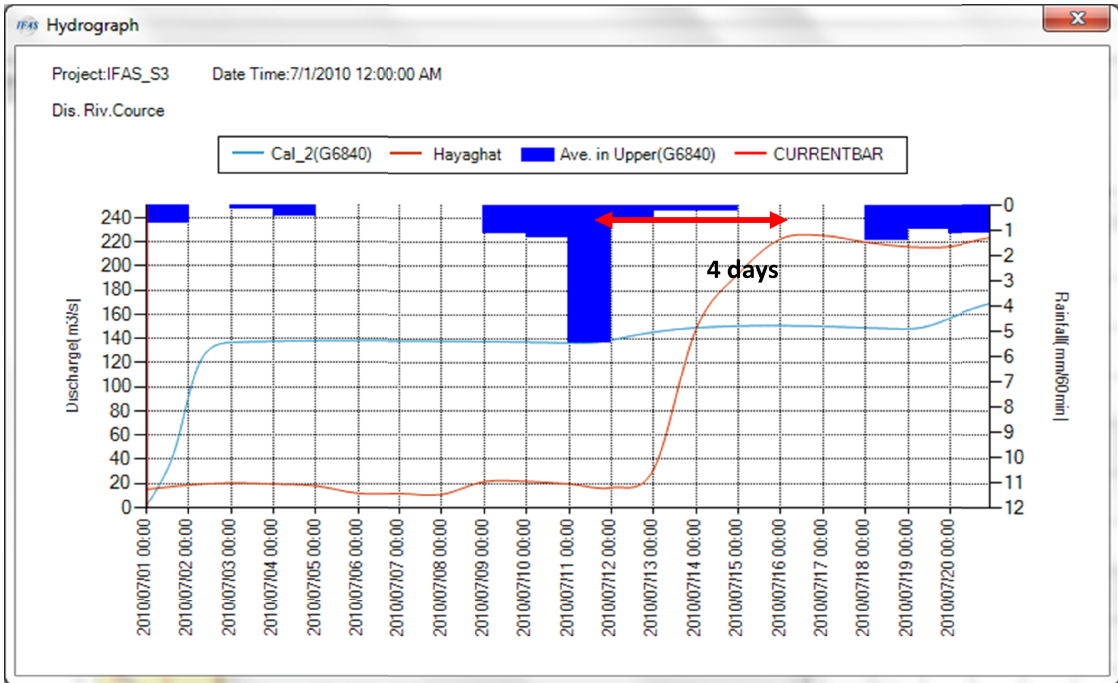
Figure 1.1-Estimation of lag time of peak flood between Dheng bridge and Hayaghat site.

2. Using IFAs model, the discharge is computed at Hayaghat site. The observed rainfall data in the basin (ground rainfall) at Hayaghat and Dheng bridge is used to compute the discharge using the IFAS setup. Subsequently, satellite rainfall estimate for the entire basin is used to compute the discharge. Further, the satellite rainfall estimate is corrected using the observed rainfall data and again used to compute the discharge at Hayaghat site. Using the GD rating curve of Hayaghat, the flood level is computed. Figure 1.2 shows the flood level at Hayaghat computed from various rainfall estimates for two flood events of August 2009 and July 2010. The red line shows the observed flood level and used for comparing the simulated flood level.

Ground Rainfall



Satellite Rainfall



Satellite Rainfall (correc)

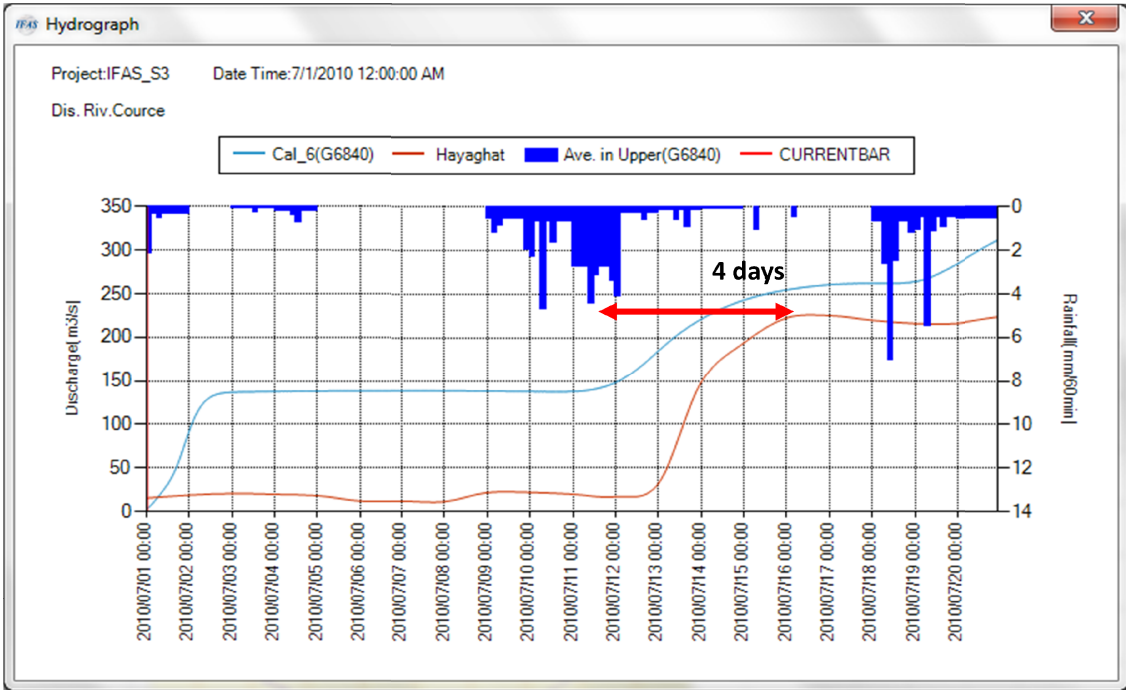
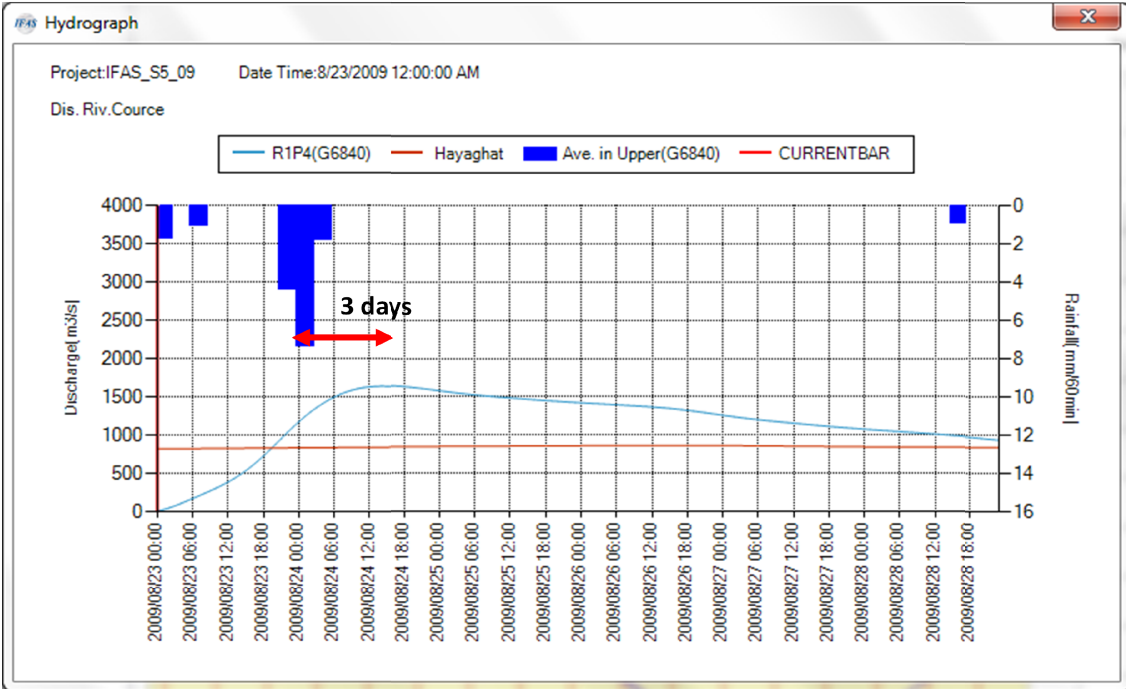


Figure 1.2-Rainfall runoff simulation at Hayaghat with various rainfall inputs for July 2010 event

Satellite Rainfall



Ground rainfall

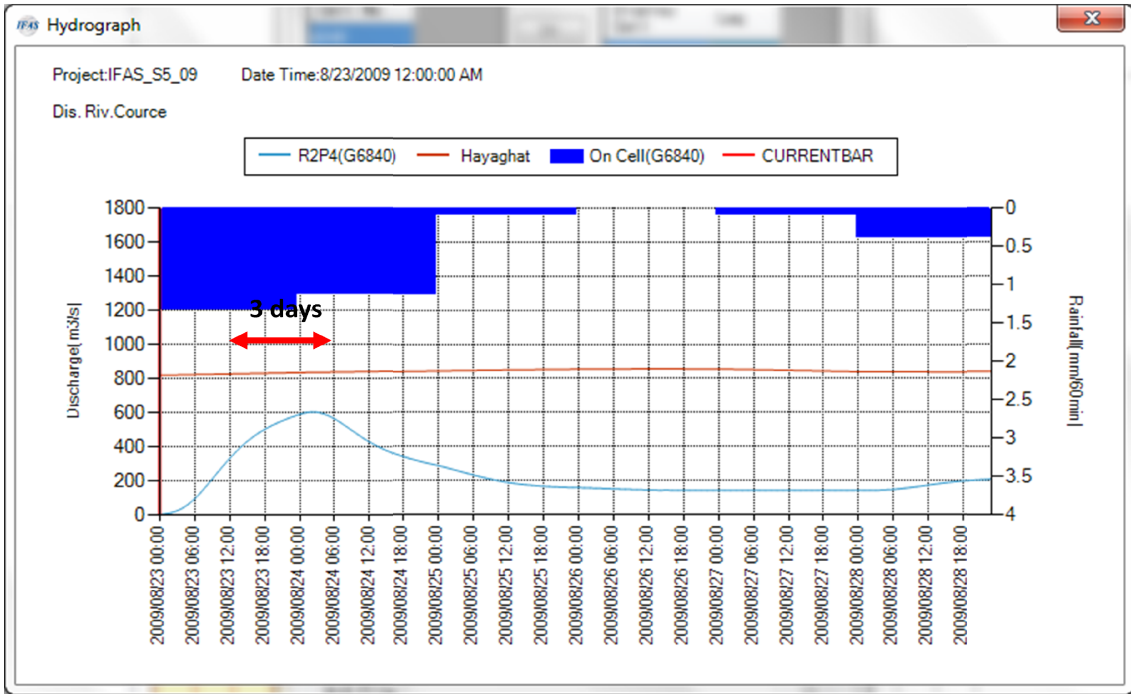
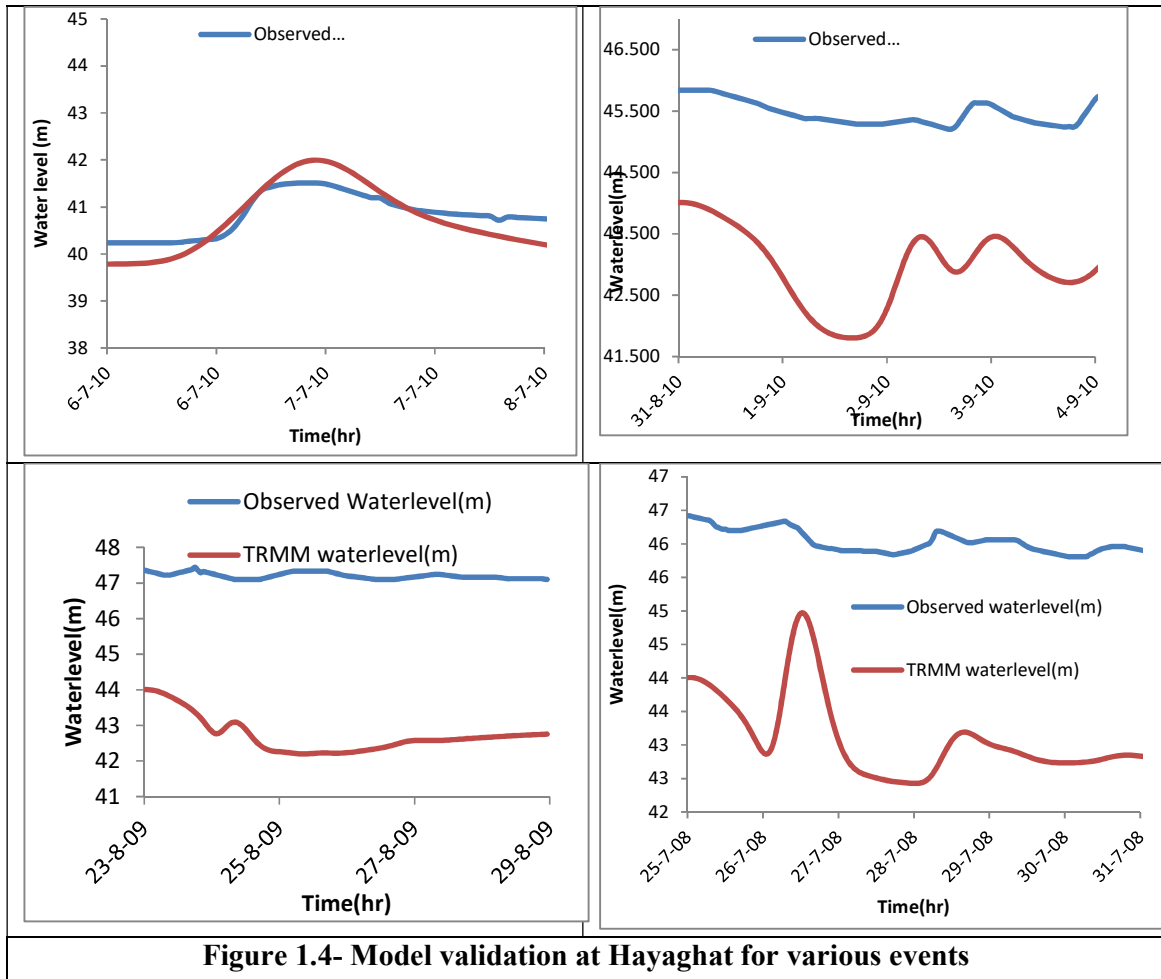


Figure 1.3-Rainfall runoff simulation at Hayaghat with various rainfall inputs for Aug 2009 event.

3. Figure 1.4 shows the comparison between the observed ground data and the simulated water level computed by IFAS model with the integration of TRMM rainfall estimates for Hayaghat site. The rainfall event for which the results are compute is 01/07/2010 to 20/07/2010



6.1 Error Analysis

The evaluation of the results is very necessary to check the adequacy of the project. The error analysis provides the quantitative estimates of the model's capability in dealing with the watershed. The efficiency criteria used in this study are coefficient of determination, Nash-Sutcliffe efficiency, index of agreement, Nash-Sutcliffe efficiency with logarithmic values. the brief description is given below for the above efficiency.

6.2 Systematic Errors

6.2.1 Coefficient of determination r^2

According to Bravais Pearson, the coefficient of determination r^2 is squared value of coefficient of correlation. It is evaluated as

$$r^2 = \left(\frac{\sum_{i=1}^n (O_i - O_{avg})(P_i - P_{avg})}{\sqrt{\sum_{i=1}^n (O_i - O_{avg})^2} \sqrt{\sum_{i=1}^n (P_i - P_{avg})^2}} \right)^2 \quad 7.1$$

Where O=observed values

P=predicted value

Value of r^2 lies between 0 and 1

6.2.2 Nash-Sutcliffe efficiency E

This efficiency is proposed by Nash and Sutcliffe in the year 1970. It is evaluated as

$$E = 1 - \frac{\sum_{i=1}^n (O_i - P_i)^2}{\sum_{i=1}^n (O_i - O_{avg})^2} \quad 7.2$$

Value of E lies between 1 and $-\infty$

Where O=observed values

P=predicted value

6.2.3 7.1.3 Index of agreement d

The index of agreement d was invented by Wilmott in 1981. It is calculated as

$$d = 1 - \frac{\sum_{i=1}^n (O_i - P_i)^2}{\sum_{i=1}^n ((Abs(P_i - O_{avg}) + Abs(O_i - O_{avg}))^2)} \quad 7.3$$

Where O=observed values

P=predicted value

Value of d lies between 0 and 1

6.2.4 Nash-Sutcliffe efficiency with logarithmic values in E_{log}

The Nash-Sutcliffe efficiency deals with the squared difference between the observed and predicted values resulting to sensitivity in the model. The logarithmic values are calculated and keep in the formula to get the efficiency in reduced form.

The various efficiency are calculated for the Hayaghat gauging site for which the observed water level and discharge are obtained from Central Water Commission of India in Table 1.1.

Table 1.1-Estimated efficiency for IFAS model

Event Date	Efficiency			
	r^2	E	d	E_{log}
01july2010-20july2010	0.96638	-0.5691	0.8698	-0.6265
31aug2010-04sep2010	0.75122	-14.8754	0.805149	-146.700
23aug2009-28aug2009	0.4378	-11.7346	0.4031	-3.3773
25jul2008-31jul2008	0.63673	-305.6280	0.70275	-328.925
31jul2007-03aug2007	0.56304	-2.19	0.504480	-0.6823

6.3 Hydrologic error

According to Japan Institute of Construction Engineering the performance of IFAS is also evaluated on three indices such as wave shape error, volume error and peak discharge error. The indices are calculated as

6.3.1 Wave Shape Error E_W

The wave shape error is calculated as

$$E_W = \frac{1}{n} \sum_{i=1}^n \left(\frac{O_i - P_i}{O_i} \right)^2 \quad 4$$

6.3.2 Volume Error E_V

The volume error is calculated as

$$E_V = \frac{\sum_{i=1}^n O_i - \sum_{i=1}^n P_i}{\sum_{i=1}^n O_i} \quad 5$$

6.3.3 Peak error E_P

The peak discharge error is calculated as

$$E_P = \frac{O_{\max} - P_{\max}}{O_{\max}} \quad 6$$

Where O=observed value

P=predicted value

Table 1.2 show the error indices for Hayaghat site

Table 1.2-Computed hydrologic indices

Events	Efficiency		
	E_W	E_V	E_s
01july2010-20july2010	4.046E-5	.0106	-.01598
31aug2010-04sep2010	3.058E-3	.06086	1.0408
23aug2009-28aug2009	9.15E-3	.09	.070
25jul2008-31jul2008	4.17E-3	.0637	.03196
31jul2007-03aug2007	1.46E-3	.07146	.0345

CHAPTER 7

Conclusion

7 Conclusion

1. In this study an effort has been made to compute the discharge for Bagmati basin at Hayaghat (Darbhanga) by Integrated flood Alert System (IFAS) using ground based rainfall, satellite based rainfall estimates (TRMM 3B42RT V6/V7) and corrected satellite based rainfall estimates.
2. The Bagmati basin is a trans-boundary basin for which data are restricted or not available. Hence it is considered as ungauged basin. The calibration is done on trial and error basis by tuning the parameters for surface, unsaturated, aquifer and river tank to match the observed results obtained from Central Water Commission of India. The validated results shows good agreement with observed ground data and errors computed are found to be very less in case of water level. Thus the model can be setup using limited data.
3. The discharge estimates can be improved if ground rainfall data is available to improve the satellite rainfall estimates. In the present study, available ground rainfall data is limited to lower part of basin only. Still it improves the flow estimation when combined with satellite data.
4. Presently the flood forecasting at Hayaghat is based on WL/GD observation at Dhengbridge (in addition to other site WL/GD data and rainfall values). Based on observation of WL at these two GD sites, the lead time is varying from 30-40 hours. With IFAS model the lead time of FF is estimated as 3-4 days

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