DEVELOPMENT OF INFLOW FORECASTING MODEL FOR A RESERVOIR USING RTDAS

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ABSTRACT

The first requirement for management of water resources is to estimate the available water in respect of time and space. The occurrence of flood in a catchment is generally an effect of a severe combination of hydro-meteorological factors resulting in to a heavy precipitation. The mathematical models usually consider the rainfall data as an input and generate the flood hydrographs along with the time of its occurrence. Inflow forecasting is one of the applications of rainfall-runoff modeling in predicting stream flows at the outlet of the catchment or inflow into a reservoir from rainfall input. Availability of reliable and accurate data at desired time interval as an input to the forecast model is the major constraint in prediction of discharge value at the peak or the water level in the downstream reservoir.

Present study comprises of development of a distributed model for inflow forecasting for the Lower Goi Project site situated in the Goi river, a lower sub-basin of Narmada River. The catchment area upto the dam site is 1119.66 sq km. The Real Time Data Acquisition System (RTDAS) network developed by the Narmada Control Authority (NCA) is in operation at Pati village in the downstream catchment. The observed discharge in the Goi river is compared with the model discharge at the Pati site for validation purposes. The model can be applied for computation of inflows into the Lower Goi reservoir, after completion of dam.

Keywords: *GIS, RTDAS, Inflow Forecasting, Rainfall-Runoff Modeling*

1. INTRODUCTION:

One has to predict the exact quantity of flood discharge occurring at a particular time. The catchment where the actual measurement of the flood (discharge) is carried out is known as the gauged catchment and the others are known as un-gauged catchments. For most of the gauged catchments, the flood is considered to be known as soon as it is recorded. However, the prediction of long term behavior is not possible. In either of the cases the flood pattern prediction in the form of a flood hydrograph with a lead time ranging from a few hours to many hours is required. It has been established since long that the mathematical models have been the best tools for the prediction of flood in a catchment. The process is also called as rainfall runoff modeling or watershed modeling.

The uncertainty of the prediction of floods depends on both meteorological and hydrological models. Although there are several new methodologies used for precipitation to improve the forecasting accuracy, prediction of the possible precipitation with accurate timing and amount has not been accomplished yet. The existing errors and the sudden events on meteorology side also make it difficult for the hydrologists where they use hydrological models to define the possible runoff or floods. The development of data acquisition systems based on telemetry and satellite communication systems coupled with the increase in availability of computer resources enhances significantly the potential for providing real-time flood warning through flow forecasting methodologies, using current information on the river basin status.

The rainfall-runoff modeling approaches generally used for real-time flood predictions in small and medium size basins are either black-box (or system-theoretic) or conceptual. Black-box models do not describe the hydrological processes occurring within the catchment, even in a simplified manner; on the other hand they can be formulated easily in an adaptive framework which has made their application extremely appealing in hydrological practice. Conceptual models, such as SCS-CN Model, on the other hand, allow a description of large spatial and temporal scale conservation and response laws that are in accordance with the observed large-scale behavior of water in hydrological drainage basins.

1.1 SCS-CN approach for runoff calculations

The Soil Conservation Service (SCS) model developed by USDA (United States Department of Agriculture) computes direct surface runoff through an empirical equation that requires the rainfall and a watershed parameter popularly known as the Runoff Curve Number or simply the Curve Number (CN). The CN is a representation of complex land use/ land cover and soil conditions in a catchment and is determined either from the tables, charts etc. available in the literature or on the basis of experience of soils, land use and hydrological characteristics such as the soil moisture etc. The CN is used is estimating the potential retention or maximum potential losses to runoff.
The direct runoff depth (Q) is calculated using the following equation:

$$Q = \frac{(P-I_a)^2}{(P-I_a+S)} \quad \text{for } P > I_a \qquad (1)$$

Where, P= total precipitation (mm), I_a = initial abstraction (mm), and S= potential maximum retention (mm). This is valid for P > I_a, that means runoff begins after precipitation exceeds initial abstraction, Q = 0 otherwise. To simplify the Equation 1, a linear relationship between initial abstraction (I_a) and potential maximum retention (S) was suggested by USDA in 1986 in their publication (Technical Release 55)

$$I_a = \lambda S \qquad (2)$$

Where, λ is an initial abstraction ratio. The values of λ varies in the range of 0 and 0.3, which have been recorded in a number of studies carried out for various geologic and climatic regions in the United States and other countries (Ramasastri and Seth, 1985). The value of λ has been developed for black soil region for Indian conditions as 0.3 for AMC-I and 0.1 for AMC-II & III (Hand book of Hydrology, Mini. of Agriculture, 1972).

In practice, the runoff Curve Number (CN) is used to compute S in mm as,

$$S = \frac{25400}{CN} - 254 \qquad (3)$$

CN values range from 0 to 100. The watersheds with higher CN value yield higher runoff volume for a given rainfall. The underlying difference between S and CN is that the former is a dimensional quantity (L) whereas the latter is a non-dimensional quantity (Mishra and Singh, 2003). Thus the method states that the value of the net runoff depth depends on the factors like precipitation depth and the curve number chosen for the specific catchment.

1.2 Antecedent moisture condition

The antecedent moisture condition (AMC) is the index of the soil condition with respect to runoff potential before the storm. The antecedent moisture conditions are based on the season and 5-days antecedent precipitation (SCS, 1984). For applications of the SCS-CN method to ungauged watersheds, NEH-4 related the above three antecedent moisture conditions with the amount of antecedent 5-day rainfall and the crop season and are defined as follows:

AMC I: Dormant season antecedent soil moisture less than 12 mm, Growing season antecedent soil moisture less than 36 mm.

AMC II: Dormant season antecedent soil moisture between 12 and 28 mm, growing season antecedent soil moisture between 36 and 53 mm.

AMC III: Dormant season antecedent soil moisture greater than 28 mm, growing season antecedent soil moisture greater than 53 mm.

1.3 Hydrologic soil group

The SCS has classified more than 4000 soils into four hydrologic soil groups (HSG) according to their minimum infiltration rate obtained for bare soil after prolonged wetting. The criteria for hydrologic soil group classification and CN values for selected landuse classes for different HSGs have been shown in Table 1 and Table 2 respectively.

Table 1. Hydrologic Soil Groups and the Infiltration Rates

Group	Minimum Infiltration Rate (in/hr)	Soil Texture
A	0.30 - 0.45	Sand, Loamy Sand or Sandy Loam
B	0.15 - 0.30	Silt Loam or Loam
C	0.05 - 0.15	Sandy Clay Loam
D	0 - 0.05	Clay Loam, Silty Clay Loam, Sandy Clay, Silty Clay or Clay

Table 2. CN values for standard land use classes and Hydrologic Soil Groups

Land use class	Hydrologic Condition	Hydrologic Soil Group			
		A	B	C	D
Woods And Forest	Poor	45	65	76	82
	Fair	36	60	73	79
	Good	30	55	70	77
Scrub with Cultivation		45	66	77	83
Pasture, grassland, or range-continuous forage for grazing	Poor	68	79	86	89
	Fair	49	69	79	84
	Good	39	61	74	80
Agricultural Land (row crops)	Poor	72	81	88	91
	Good	67	78	85	89
(Fallow)	Poor	76	85	90	93
	Good	74	83	88	90
Built Up (Rural) area		46	66	78	83
Water bodies - (River/Stream/ Lakes/ponds)		100	100	100	100

Source: Table 3.1 and Table 3.2 from NRCS (1986)

2. MATERIAL AND METHODS Main Headings [Times New Roman, 12-Bold]

2.1 Study area

Narmada is the largest west flowing river and is the fifth largest river of India water availability wise. It rises from Amarkantak in Madhya Pradesh at an elevation of 1057m. The Narmada forms the traditional boundary between North India and South India and flows westwards over a length of 1,312 km and drains an area of 98796 sq.km before falling into the Arabian Sea through the Gulf of Cambay (Khambat), 30 km west of Bharuch city of Gujarat. It flows through the States of Madhya Pradesh (1,079 km), Maharashtra (74 km): (35 km border between Madhya Pradesh and Maharashtra and 39 km border between Maharashtra and Gujarat) and in Gujarat (159 km). There are 41 major tributaries to the river of which 22 join into its southern bank and 19 into the northern bank. Goi is one of the important south side tributaries that originates from Jalalabad village in Satpura range at an elevation of 798m and meets Narmada near Village Pati in Barwani district (M.P). It lies between 21°32’30”N & 21°58’30”N latitudes and 74°32’30”E & 75°24’15”E longitudes having 1874.86 sq.km of the catchment area. The base map showing drainage network, roads, major settlements, grid lines indicating latitude and longitude of the area and the gauging site situated at Village Pati is given in Figure1.

The temperature of Goi catchment is maximum in the month of May and minimum in the month of December. The Annual Average Rainfall of the Districts of Khargone and Barwani is around 830 mm. 50 years rainfall data at Khargone (M.P.) reveal that 90.5% of the precipitation takes place during southwest monsoon, 7.5% during post monsoon, 1.5% during pre monsoon and only 0.5% of the total precipitation occurs in the winter period.

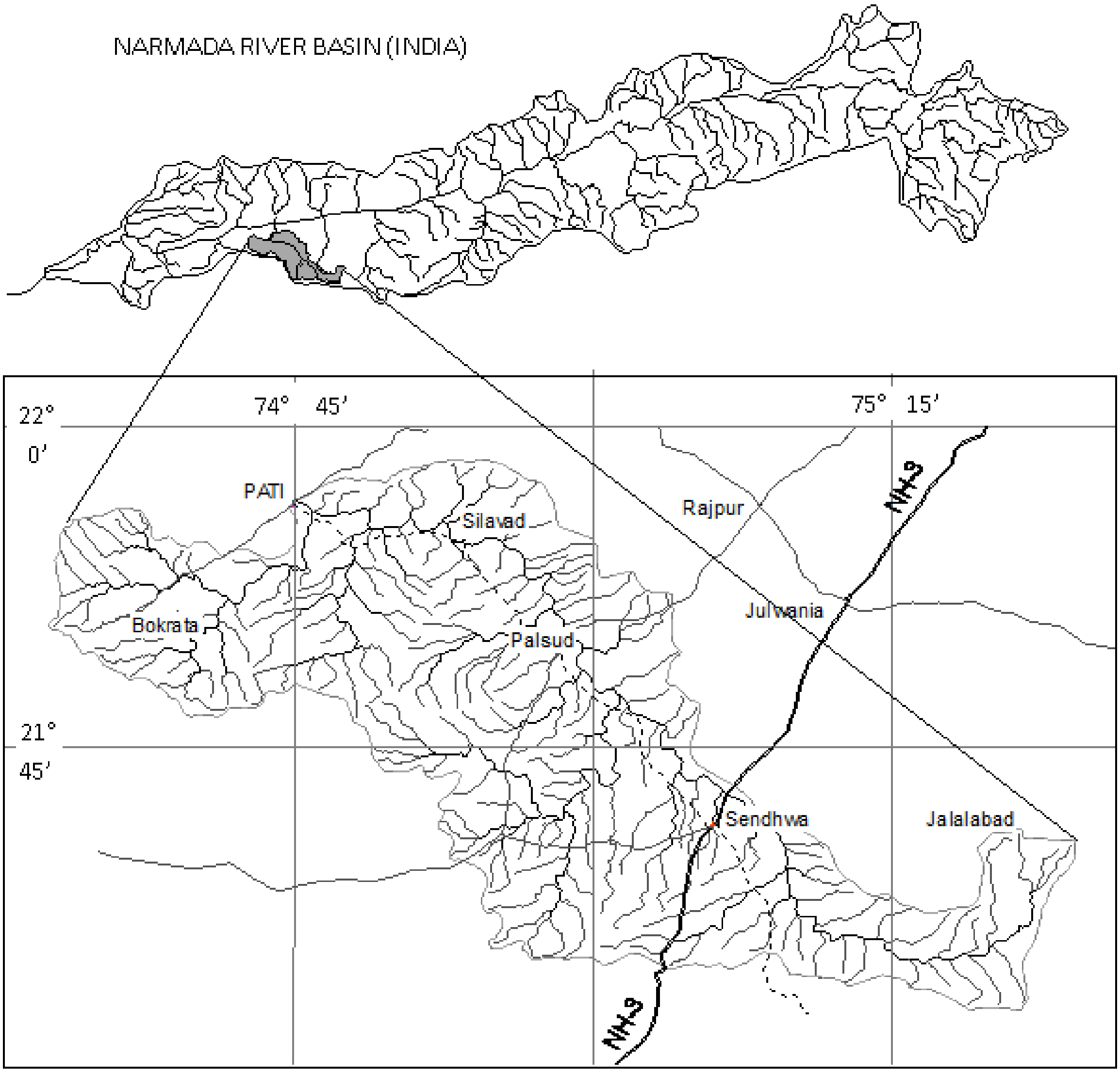

Figure 1. Index map showing Goi river catchment in Narmada basin

2.2 Soils

The map showing soils of Goi sub-basin was digitized from the soil map of Lower Narmada Basin procured from CE & AD, SGSITS, Indore, which were prepared using IRS LISS-II satellite imageries and the NBSS & LUP Soil Map under a sponsored project of the Government of M.P. (Figure 2). The soil map has been further assigned the hydrologic soil group for each of the classes. The soils of 58% of the catchment area are categorized as hydrologic group 'D', 28% as group 'B' and soils of the rest 14% of the area as hydrologic group 'C'.

2.3 Hydrological data

The daily rainfall at Khargone district HQ is being recorded by the India Meteorological Department (IMD). The Water Resources Department, GoMP had established rain-gauge station and Gauge & Discharge site at Pati on river Goi in the year 1989 to take daily observations, which was transferred to the Central Water Commission in the year 1999. The Narmada Control Authority has also established automatic rain-gauge station (Tipping bucket type) and automatic water level recorder (Stilling well and float type) at Pati under Real Time Data Acquisition System (RTDAS) project implemented in 2005. At this station the hourly data is recorded and transmitted to the Master Control Centre at Indore on a real time basis.

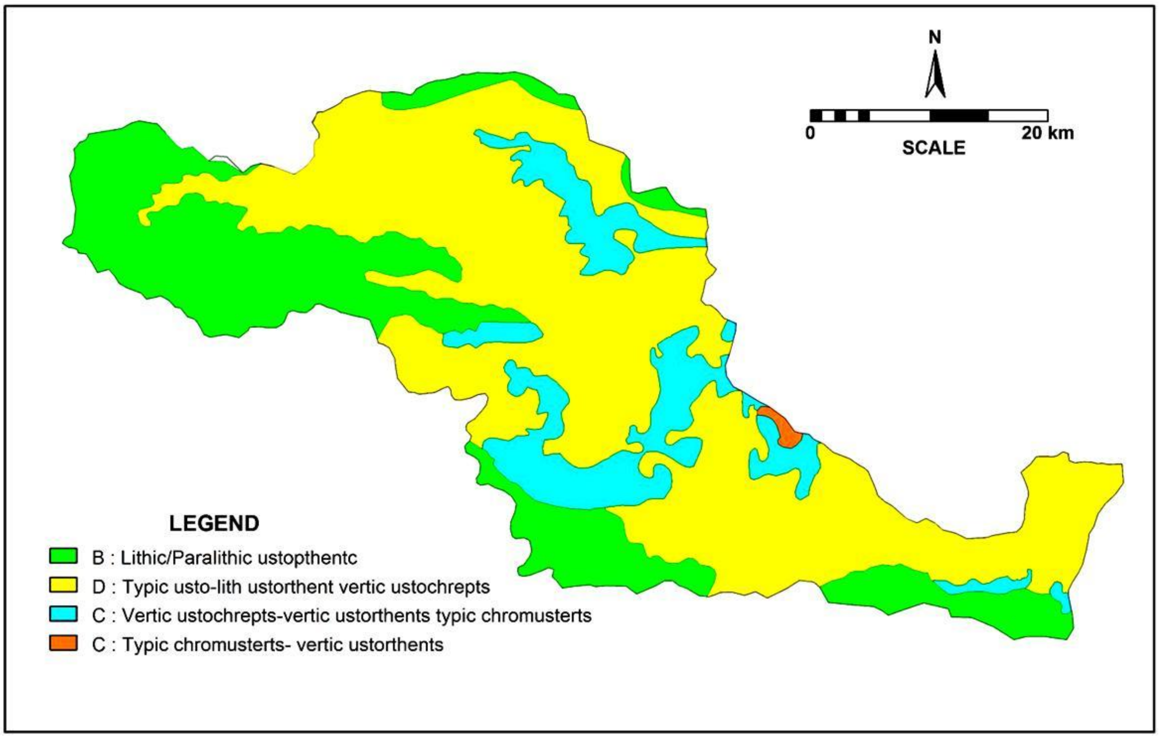

Figure 2. Soil map of Goi river sub-basin upto Pati G&D site

2.4 Land use map

The land use/land cover map for the year 2007 was collected from MPCS&T, Bhopal, which was interpreted from the satellite based imagery. Digital FCC imageries of the year 2007 (IRS 1D/P6 LISS-III) were delineated on screen through visual interpretation technique for level-1 classification for the major land use classes at MPCOST, Bhopal. The land use map for the year 2007 is shown in Figure 3. ILWIS GIS was used for computation of area under different land use categories as shown in Table 3.

2.5 Curve Number estimation

Area weighted average curve numbers for Goi watershed have been calculated for two land use conditions for both the years of analysis. The land use map was superimposed on the soil map in ILWIS GIS platform to get polygons with unique land use class and hydrologic soil group. Appropriate CN value is assigned to each polygon and the same is multiplied with the area of that polygon. Finally, sum of these products has been divided by the catchment area to get weighted average CN value for the Goi watershed. The value of average Curve Number computed for AMC-I, AMC-II and AMC-III were found to be 65.69, 80.38 and 91.34 respectively.

Having daily rainfall and runoff data for the catchment, the estimated runoff using weighted average CN values have been compared for storms of various intensities for different AMC conditions.

Table 3. Landuse/Land cover distribution of Goi river sub-basin for the year 2007

Landuse Class	No. of Pixels	Area (Sq.km.)
Built Up-Built Up (Rural)-Built Up area (Rural)	3036	7.59
Agricultural Land-Crop Land & Current Fellow	351806	879.52
Scrub with Cultivetion/Agriculture inside Forest	74483	186.21
Dense Canopy / Forest-Deciduous)-Closed	21637	54.09
Medium Canopy / Forest-Deciduous)-Open	33779	84.45
Low Canopy / Forest-Scrub Forest	92987	232.47
Scrub-Pasture / Scrub Land + Forest Blank	74857	187.14
Waterbodies-River/Stream	10361	25.90
Wastelands-Barren Rocky/Stony waste	1184	2.96
Grand Total	**664130**	**1660.33**

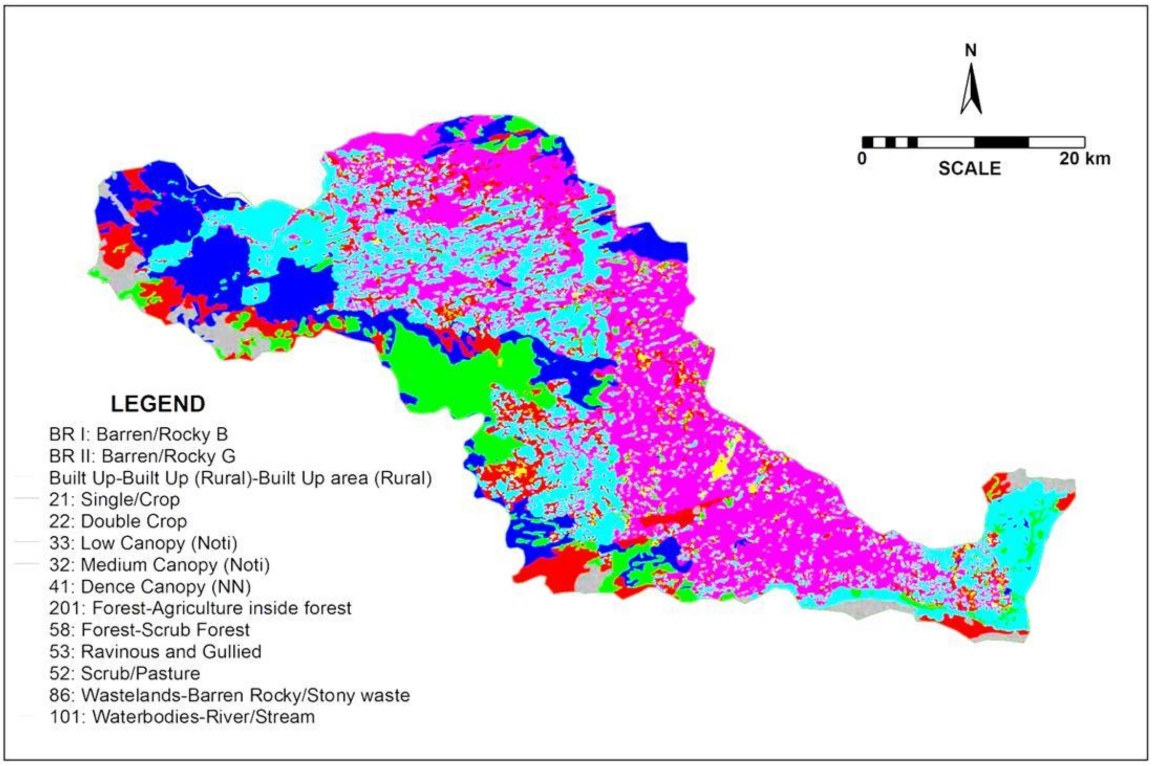

Figure 3. Land use map of Goi river sub-basin upto Pati G&D site

2.6 Development of Synthetic Unit Hydrograph

In order to disintegrate the rainfall excess over the time, the unit hydrograph is generally developed for the watershed under consideration. In this study, the synthetic unit hydrographs based on forest cover and SCS method have been combined together to develop the synthetic unit hydrographs. The Synthetic Unit Hydrograph has basically two components, time to peak and peak discharge and has a triangular shape which produces a unit depth of direct runoff or rainfall excess. However, the SCS method of development of a Unit Hydrograph provides more realistic curvilinear shape. The Peak discharge and time to peak for Goi river at Pati G&D site was computed to be 488 cumec and 8 hours respectively. The ordinates of synthetic unit hydrograph developed for Goi river sub-basin is shown at Figure 4.

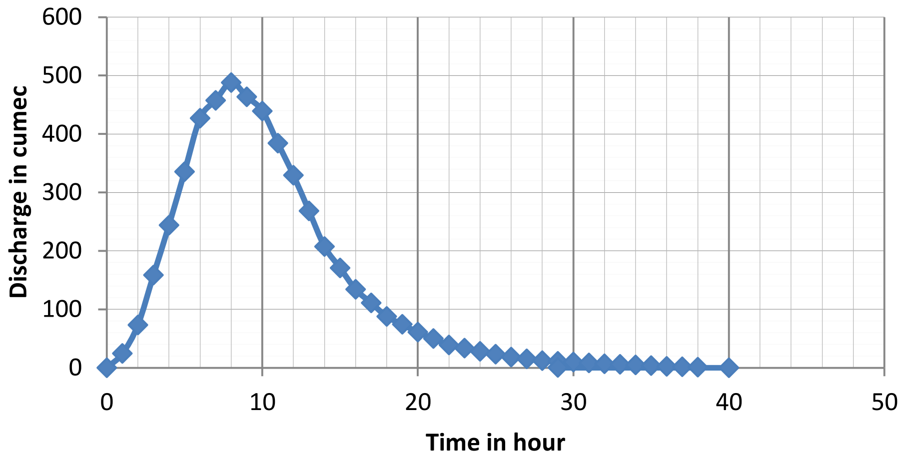

Figure 4. Ordinates of 1-hr SCS Unit Hydrograph in Cumecs

3. RESULTS AND ANALYSIS

Considering historical rainfall events and corresponding hydrographs available from the records the analysis was performed. The Base flow component form the observed hydrograph was separated out and direct runoff volumes have been computed for significant isolated rainfall events. The direct surface runoff volumes for these rainfall events were also computed using the SCS-CN method as described above. The unit of runoff computed by using Eq. 1 is in mm, which indicates the depth of runoff. The value thus obtained is multiplied with the catchment area to get the total daily discharge volume. and the results have been compared with the observed values. The detailed comparison of direct surface runoff volumes computed form the recorded hydrographs and the SCS-CN method for the year 2000-01 and 2006-2009 chosen for the analysis have been presented in Table 5.

Table 5. Comparison of computed and observed direct surface runoff

Date	Antecedent Moisture condition	Season	Rainfall (mm)	Estimated Direct runoff from CN Method Q (mm)	Estimated direct runoff Volume Q(MCM)	Observed direct runoff (MCM)	Percent difference
03 Jul, 2006 04 Jul, 2006 05 Jul, 2006 06 Jul, 2006	AMC-I AMC-I AMC-I AMC-III	Dormant	19.7 5.81 65.00 48.76	0.30 0.00 14.51 30.51	75.25	70.80	6.3%
07 Jul, 2007 08 Jul, 2007 09 Jul, 2007	AMC-I AMC-I AMC-III	Dormant	5.13 35.14 9.44	0.00 3.10 1.59	7.78	7.07	10.1%
19 Sep, 2007 20 Sep, 2007	AMC-I AMC-II	Full Growth	8.60 31.51	0.00 3.29	5.46	5.58	-2.2%
05 Aug, 2008 06 Aug, 2008	AMC-I AMC-II	Full Growth	14.61 31.01	0.00 3.10	5.16	5.13	0.5%
26 Aug, 2008 27 Aug, 2008 28 Aug, 2008	AMC-II AMC-II, AMC-III	Full Growth	22.65 33.84 6.5	0.74 4.19 0.01	8.20	9.60	-14.6%
03 Sep, 2009 04 Sep, 2009 05 Sep, 2009 06 Sep, 2009	AMC-I AMC-II AMC-II AMC-III	Full Growth	23.14 32.96 50.41 14.30	0.84 3.84 28.79 2.12	59.08	64.72	-8.7%

3.1 Computation of Hourly Discharge

The direct runoff depth (in mm) computed by SCS-CN model have been convoluted with the synthetic unit hydrograph of 1 hour duration to get the hourly discharge. The graph shown at Figure 5 represents the rainfall depth in mm and discharge computed at Pati site in cumecs. The entire process of forecast model has been coded in the FORTRAN language to obtain the end results, i.e. discharge at Pati G&D site.

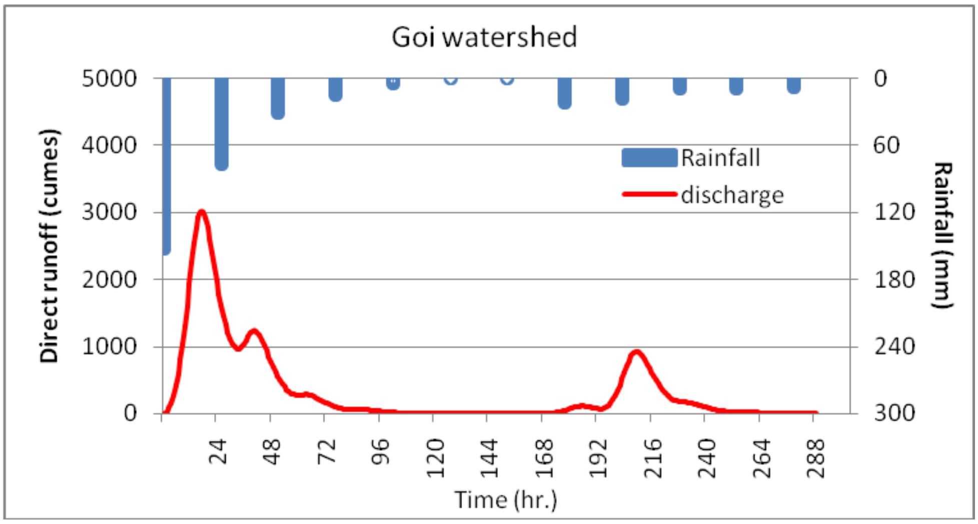

Figure 5. Rainfall and computed direct surface runoff during July 2007

4. CONCLUSIONS

- The SCS-CN method in GIS platform coupled with remote sensing data is found to be effective, since the spatial variation of soils and land use of the watershed are addressed.
- The study may be extended for estimation of peak discharge and time of concentration at the Lower Goi Project site to compute the hourly inflow into the reservoir.
- The modified distributed SCS-CN model may be developed and the study may be extended for few more sub-watersheds in Narmada basin for calibration of the model developed for assessment of floods during monsoon.
- Change in land use in the catchment in the form of deforestation or developmental activities may alter the runoff volume in the Goi catchment.

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