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HYDROLOGICAL MODELING USING REMOTE SENSING AND GIS

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ABSTRACT

Accurate modeling will require estimation of the spatial and temporal distribution of the water resources parameters. During the last decades engineers and planners have shown the increasing interest of applying Geographic Information Systems (GIS) and satellite based Remote Sensing (RS) technologies to extract land surface parameters, which exist as a threshold in early days to approach reasonable results in hydrologic modeling. With the advancement of the computer technology, GIS and RS have become efficient tools to integrate the spatial and non-spatial databases for the hydrological modeling. In this study a hydrological model was developed for the Bata River basin, which is one of the tributaries of the Yamuna river basin in India. Infiltration losses, Unit hydrograph and river routing are the main model components. ILWIS, ERDAS and AutoCAD Map software were used. Satellite based RS and GIS techniques were used to estimate the spatial variation of the hydrological parameters, which are used as input to the model. Survey of India (SOI) topomaps, field data, IRS LISS 111multy temporal satellite data for rabi and kharief seasons and IRS pan data were used. SCS curve number and unit hydrograph methods were used for the infiltration losses and synthesis of unit hydrographs respectively. The complete watershed was divided into 10 sub areas, where hydrographs were synthesized by routing the hydrographs along the river reach. Muskingum hydrological routing method was used for river routing. The model is capable of forecasting the runoff for given event of rainfall and deriving the hydrographs for the required duration.

1 INTRODUCTION

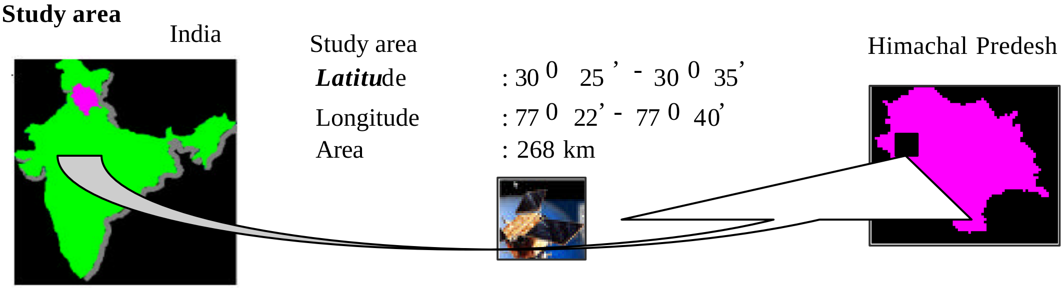
Water directly controls the diversity of the all living being on the earth. It is one of the most important natural resource of a country. Increase of the population growth demands fresh water for development process of the mankind has created enormous pressure on the water resources all around the globe. New scientific methods and technologies introduce new farming techniques in the field of agriculture resulting increase in irrigated land hence creating more demand for water.

Accuracy enhancement is a key point in hydrological modeling. RS has not yet reached to a level to use it directly for determining the key model components directly. Until today it use as an indirectly. Various parameters required for the modeling will be derive using RS data. For instance Land used/Land Cover map, Digital Elevation Model, drainage system, soil map etc. are derived using RS in most accurately based on the resolution researcher will select for the modeling.

1 Objectives of the study

1) Development a hydrological model for study area using SCS curve number and unit hydrograph methods.
2) Hydrological routing using Muskingum method.
3) Discharge forecasting at outlet.

1.2.2 Study area



2 MATERIALS AND METHODS

The methodology can be divided in to two parts. The first part is the modeling of the spatial variation of the terrain by remote sensing and GIS methods and creates the digital database. Second part involve in analysis of digital database of the hydrological model parameters.

Table 2.1 Data used – remote sensing data

Data	Path	Row	Acquisition Date
IRS 1-D LISS 111 (Kharief Season)	96	50	12th, October 1998
IRS 1-D LISS 111 (Rabi Season)	96	50	1st, March 1998
IRS 1-D PAN	96	50	08th, October 1998

2.1 Data used – ancillary data/collateral/topographic data

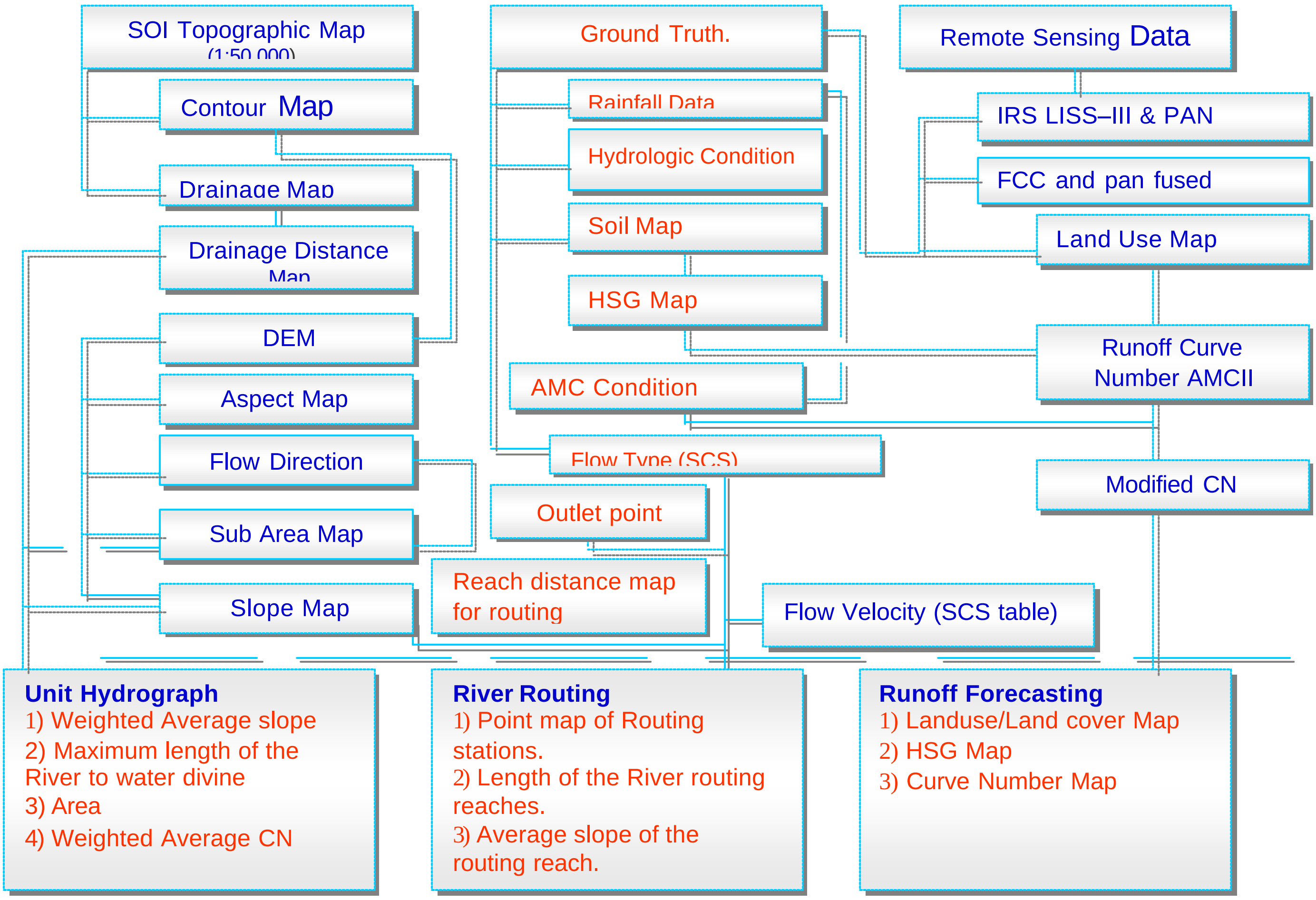
a) Survey of India (SOI) toposheets.
b) Soil map of watershed area.
c) General information of the watershed and its vegetation.
d) Soil related information.
e) Hydrological information.

2.2 Software used

a) GIS/Image processing software
   1) ELWIS 2) ERDAS 3) ARC/VIEW 4) AutoCAD Map
b) Analytical software and tools
   1) Visual Basic and Visual Basic for application. 2) AutoLisp

2.3 Methodology

Following flow chart will illustrate the complete methodology used to model the unit hydrograph, river routing and runoff forecasting. Input parameters for the each model components were given below.



2.3.1 Discharge forecasting. - SCS method: Discharge forecasting was carried out for the complete watershed as well as sub areas. Discharge forecasting was modeled using SCS curve number method. SCS method involves the relationship of land cover description (Cover type, land treatment and hydrologic condition), hydrologic soil group and curve number. Curve number represents the runoff potential of the hydrological soil cover complexes.

SCS Runoff equation

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

Here Q – Direct runoff in Cumes I_a– Initial abstraction.
P – Precipitation S – Maximum potential retention

Table 2.2 Variation of initial abstraction & maximum potential retention against soil and cover conditions.

Soil and cover condition	Relation to S
Black soil region for AMC2 & AMC3	$I_a = 0.1S$
Black soil region for AMC1	$I_a = 0.2S$
All other region	$I_a = 0.3S$

Antecedent Moisture Conditions. (AMC) – AMC is the index, which yield different runoff conditions if the same rainfall condition. It considers five days earlier rainfall conditions according to following criteria.

Table 2.3 AMC conditions.

AMC Class	AMC (mm)	Condition
AMC1	<35	Dry soil but not the wilting point
AMC11	35- 52.5	Average condition.
AMC111	>52.5	Saturated soil; heavy rainfall of lighter rain

Plotting the data for P and Q for many watersheds has revealed an relationship which is known as runoff curve number (CN). CN varies form 100 to 0 where impervious surfaces and water body yield 100 and other surfaces as indicated in the Table 2.4. The major factors that determine CN are hydrological soil group (HSG), cover type, land treatment, hydrologic condition and antecedent moisture condition. Maximum potential storage is related to soil and soil cover condition of the watershed through CN as given in the equation 2.

$$S = \frac{254000}{CN} - 254 \qquad 2$$

2.3.2Unit hydrograph: Unit hydrographs were synthesized at the outlet using complete watershed as a whole as well as sub area basis. The method applied is SCS dimensionless unit hydrograph method. Followings are the parameters involve in this method.

1) Time of concentration. -T_c
2) Lag time- T_{lag}
3) Duration of the excess Rainfall-D
4) Time to peak flow-T_p
5) Peak Flow- Q_p

3 RESULTS AND DISCUSSION

3.1 Discharge forecasting

It was estimated that out of total rainfall of the area 20% contribute as runoff in 1998 and it is 14.5% in of 1997.The reason for this is that most of the times in 1997 rainfall is not enough to generate runoff. Further if rainfall occurs continuously for some period it will increase the AMC, which leads to high runoff. By observing rainfall distribution graph it is clear that rainfall in 1997 is scattered much more compared to that of 1998. This also substantiates the daily average initial abstraction values tabulated in table 3.1.

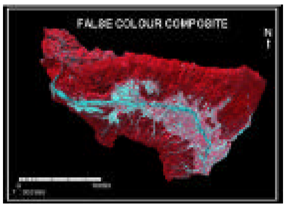
Table3.1 Daily Initial abstraction values in year 1997 and 1998

Year	Daily average Initial abstraction-Ia
1997	145.531
1998	138.13

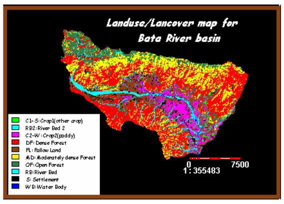
3.2 Rainfall runoff relation.

Present study shows that catchment yield 106.468 M Cu m per Year. Following figure 3.2 will forecast event based rainfall runoff relationship in year 1997,1998. Since SCS curve number is an event-based runoff forecasting method the figure 3.2 shows the validity of the relation once it compare with the previous year. Figure 3.3 will give the better result since it has analyzed the two -year rainfall events for the catchment

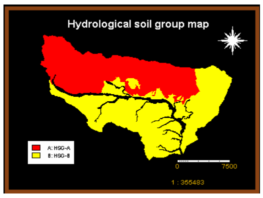
3.3 Digital Database for hydrological modeling.



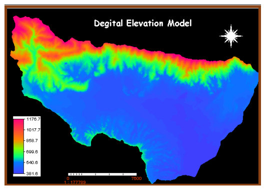
Map 1



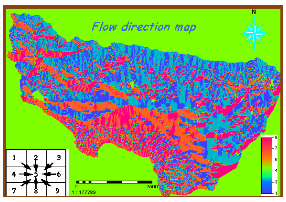
Map2.



Map3

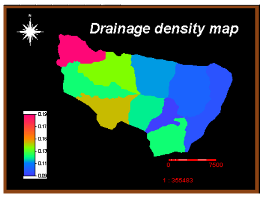


Map4

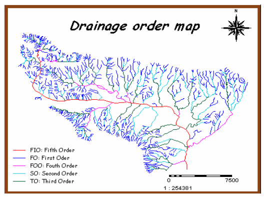


Map5

Map6



Map7



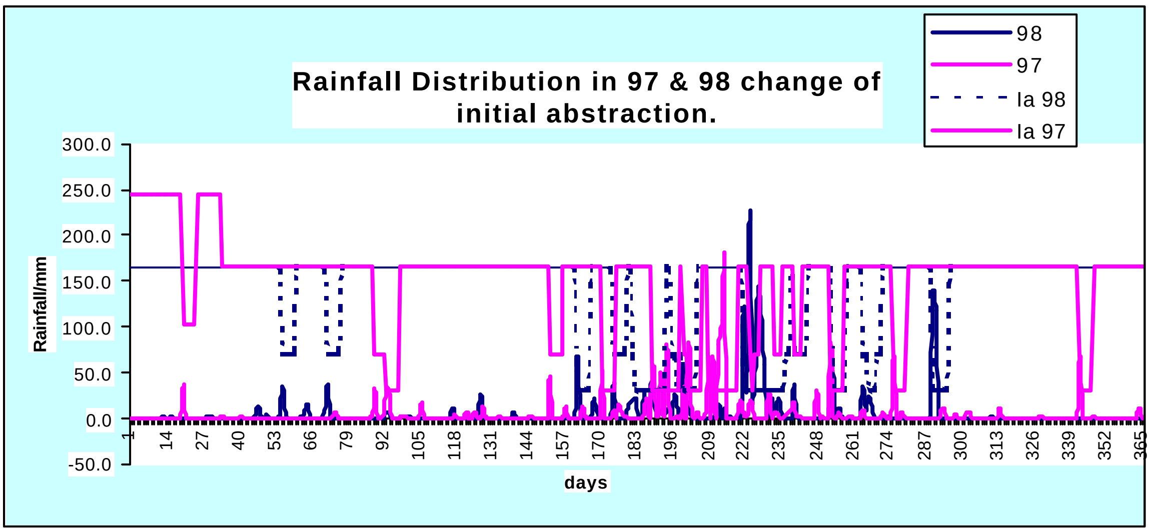
Map8

Map 1: False colour comp osite of the Bata river basin
Map2: Land use land cover map of the watershed
Map3: Hydrological soil group map (HSG)
Map 4: Digital elevation model

Map 5: Flow Direction map
Map 6: Sub area map of the watershed
Map7: Drainage density map
Map 8: Dra inage order map

Note: All the maps were derived at 20m resolutions. All the calculations were based on the above cell size.

Figure 3.1 Variation of runoff with initial abstraction and rainfall runoff relationship for 1997/1998



Note: The figure 3.1 shows the relationship between rainfall and initial abstraction. It can be clearly observed that once rainfall occurred initial abstraction value would come down and increase the runoff potential.

Table 3.2 Variation of runoff potential

Group	Area percentage	Percentage of HSG	Major Land Cover
High runoff potential	21.36	6.4-%-A, 93.6% -B	40% paddy, 43%-Fallow 6% other crop, 11% settlement
Moderate runoff potential	61.54	44.3%-A, 55.7-B	38%-Dense Forest, 36% Mode dense forest, 25% - open forest 1%-Cuitivativation+ Settlement
Low runoff potential	17.10	100% -A	100% Dense forest

Table 3.3 Comparisons of the Time to peak, time bass and peak discharge

	Tp	**Qp**	**Tb**	**S**	**D**	**CN**	**Area**
SUBAREA	TIME TO PEAK (Hr)	PEAK DIS Cumecs	TIME BASE (Hr)	Average slope (%)	Drainage Density	CN (AMC2)	Km^2
Complete	8	76.864	40	21.4	0.12	52.4	268.
Subarea1	3	24.321	11	44.0	0.19	41.6	21.80
Subarea2	5	13.689	20	20.7	0.13	49.4	27.10
Subarea3	7	13.169	28	28.1	0.13	42.4	34.15
Subarea4	4	17.388	14	15.3	0.14	62.0	23.94
Subarea5	4	23.179	16	27.8	0.15	43.9	33.15
Subarea6	3	18.553	12	12.9	0.12	68.4	20.65
Subarea7	4	25.087	18	22.6	0.12	51.9	40.88
Subarea8	4	11.465	12	8.9	0.11	77.3	13.60
Subarea9	6	14.984	22	9.8	0.09	64.7	31.61
Subarea10	4	18.619	12	17.5	0.10	65.1	21.95

Highest average slope exist in the area1, which yield comparatively very less time to create its peak discharge at outlet. In sub area 4,6,and 8 create peak discharge within less time even though it's slope is comparatively less. Reason for this is high CN value

3.4) River routing.

Four routing stations were selected along the rivers. To keep the different k value arbitrary points in between above stations also selected.

Figure 3.2 Routing stations along the River

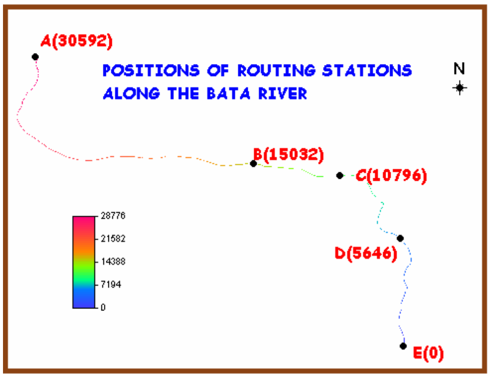
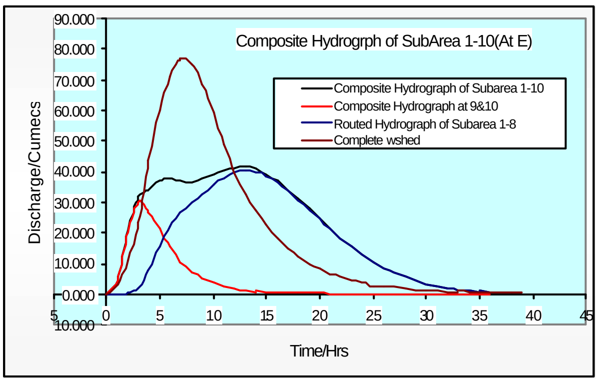


Figure 3.3 Composite hydrograph at outlet



3.4) Discussion

Hydrologic routing procedure interacts with river waves in two ways according to the routing constant K and X. Due to the effect of the X The Peak discharge always attenuate and it will release from the river storage. The area between two graphs indicates the river reach storage and area outside the inflow graph and inside the outflow graph indicates the volume release from the storage. Complete watersheds give a peak at 7 hrs of 76.864 cumecs. But routed hydrograph gives its peak at 13 hrs of 41.487 cumecs. But this peak is not prominent as the peak shown by the complete watershed analysis. Instead of giving a sharp peak routed hydrograph start to reach to peak at 3 hrs of 31.175 cumecs and reach to peak at 13 hrs of 41.487 cumecs and start the move away from peak at 18 Hrs of 31.175 cumecs. When we analyze the complete watershed as a whole it will average the slope, CN values etc. It can be clearly seen that the average slope percentage of the watershed is 21.4. But sub watershed basis it varies from 8.9 to 44.0. Same way CN average value is 52.4 but in sub watershed basis it vary 41 to 78.

4 CONCLUTION.

Water scarcity is one of the emerging problems faced by the mankind in future. Surface water flow resulting from the runoff is the major source for the increasing fresh water demand. Correct quantification of the stream from land system will require simulation of the contributing component in to hydrologic model. Modeling required determining its parameters, which will ultimately act as a key determination fact of the accuracy of the model result. All these hydrological parameters are spatially and temporally variables. Remote Sensing and GIS are the only technology available to estimate the model parameters, which yield the model to simulate more or less close to real nature. Our analysis on distributed subarea basis compared to the analysis as a whole gives better results, which is more similar to actual values. In reality it is very difficult to expect a sudden peak as indicated by the complete watershed hydrograph. So it can be concluded that distributed routed hydrograph is more accurate than that of complete watershed

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