Surface Runoff and Unit Hydrograph

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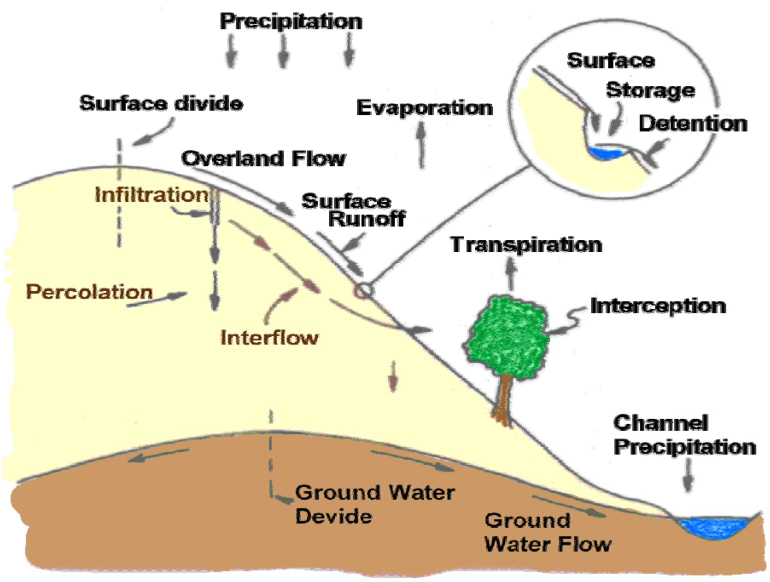
Why Construct & Analyse Hydrographs ?

- To find out discharge patterns of a particular drainage basin

- Help predict flooding events, therefore influence implementation of flood prevention measures

The Most Important Image



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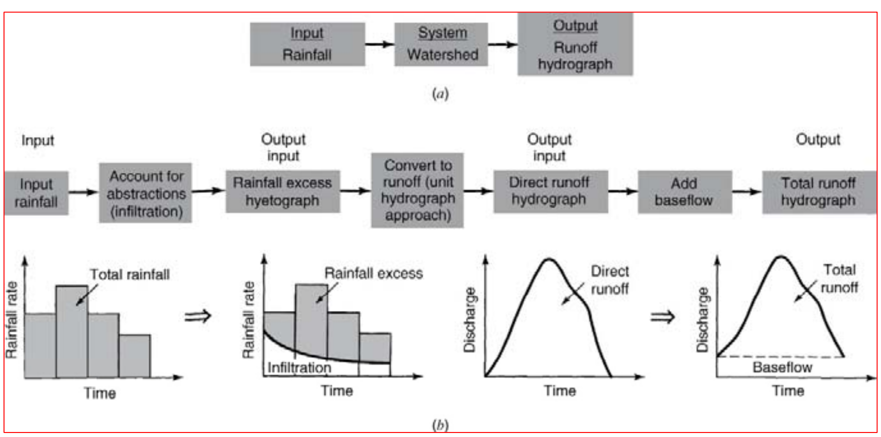
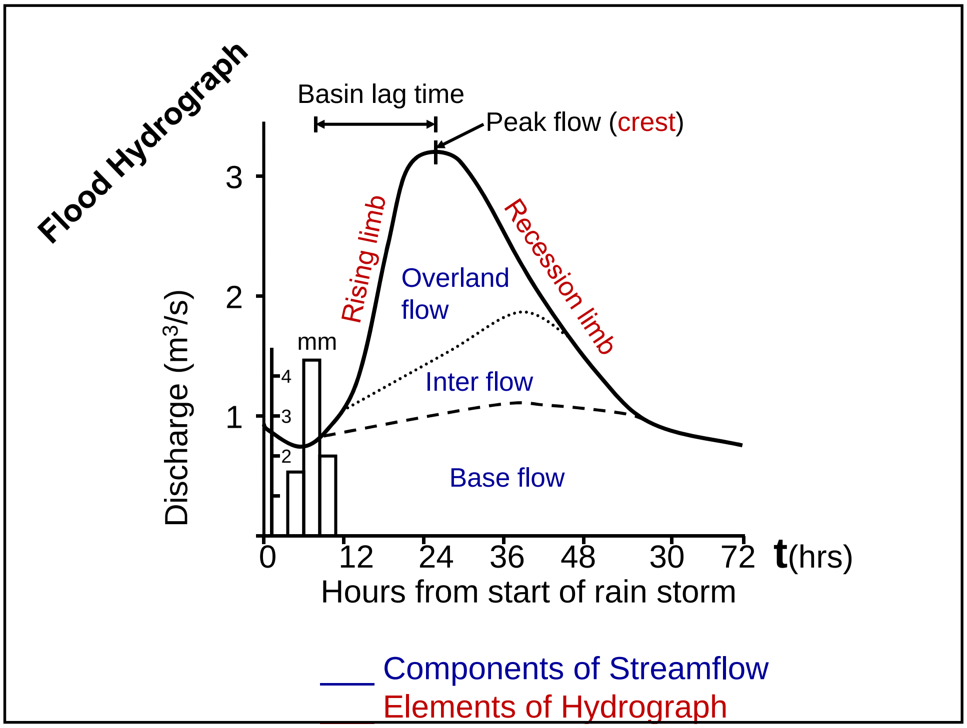
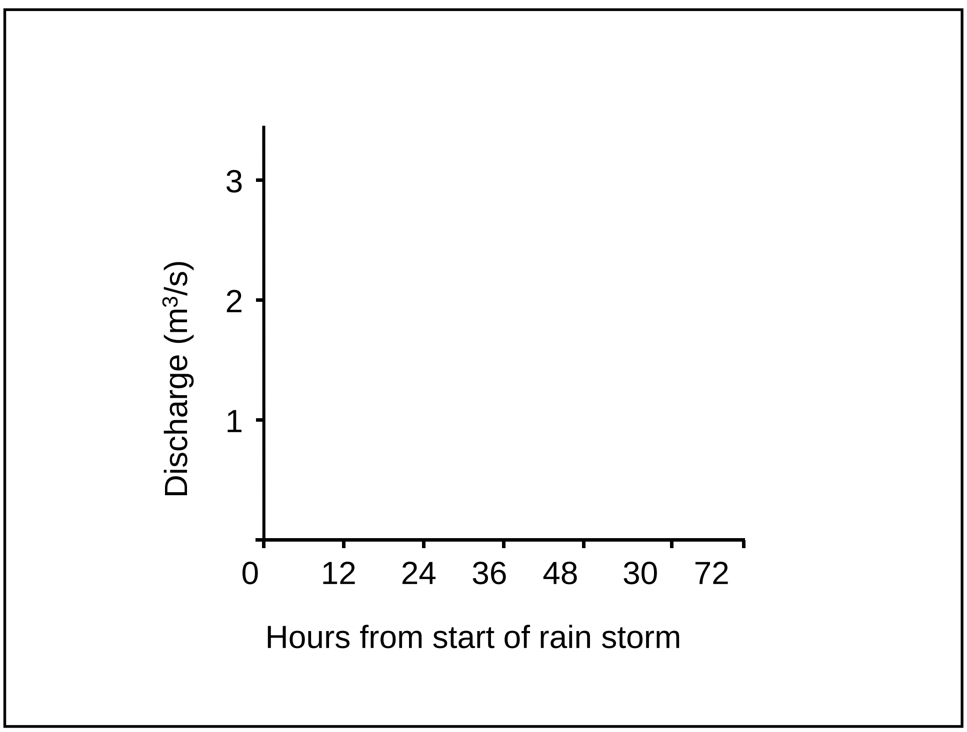
Rainfall – Runoff Analysis

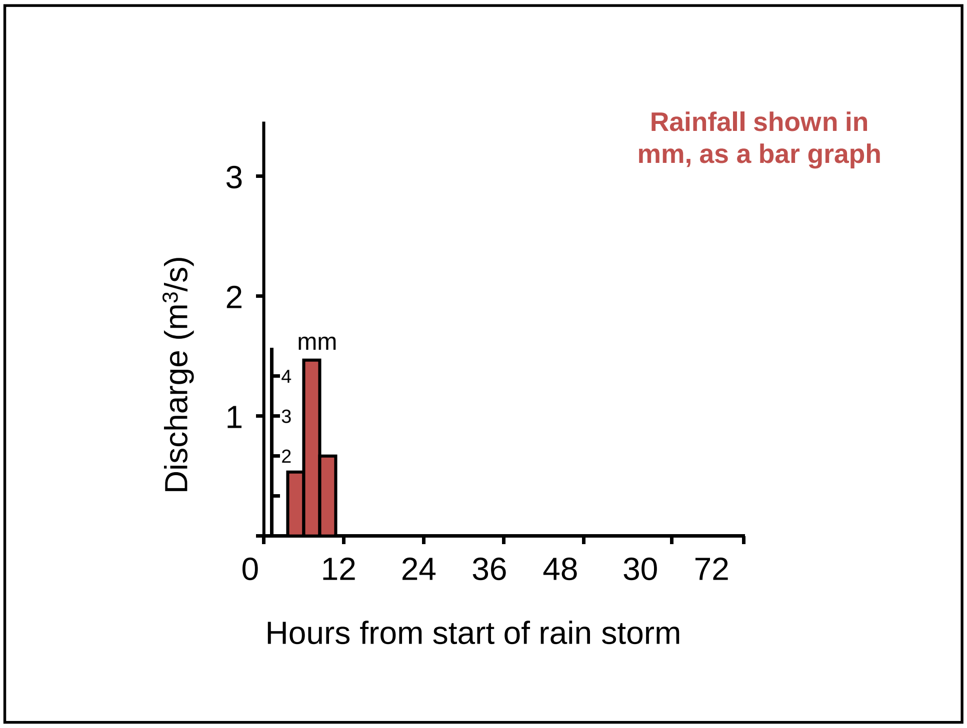


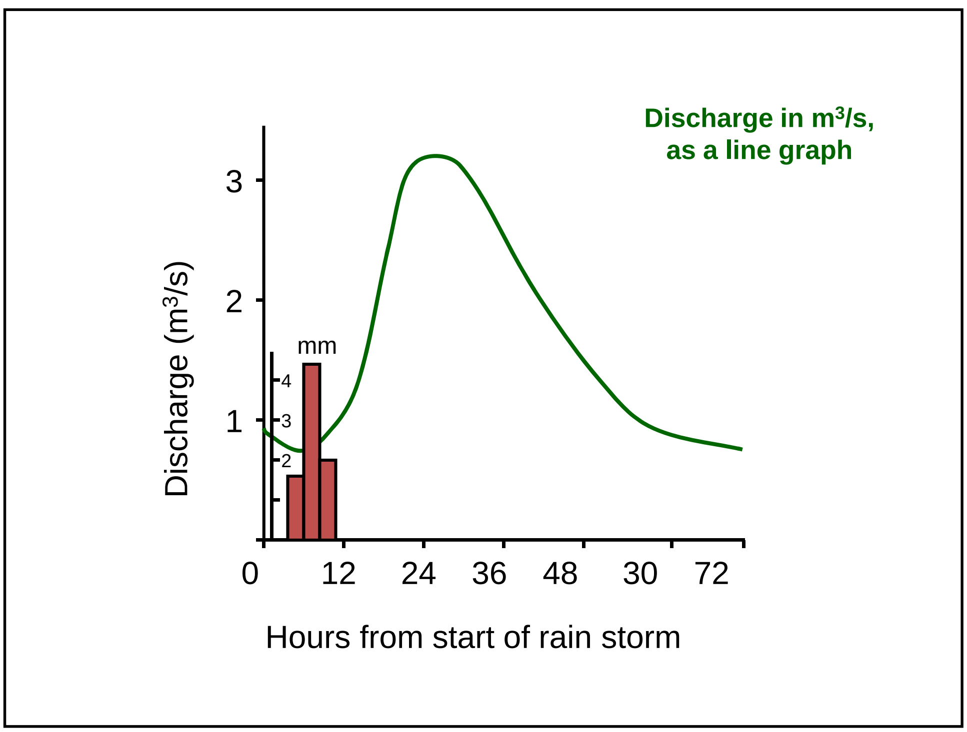
Storm Runoff Hydrograph **a) Rainfall-Runoff Modeling** **b) Steps to define storm runoff**

From Mays, 2011, Ground and Surface Water Hydrology


Flood Hydrograph
Basin lag time
Peak flow (crest)
Rising limb
Recession limb
Overland flow
Inter flow
Base flow
mm
4
3
2
Discharge (m3/s)
3
2
1
0
12
24
36
48
30
72
t(hrs)
Hours from start of rain storm
Components of Streamflow
Elements of Hydrograph

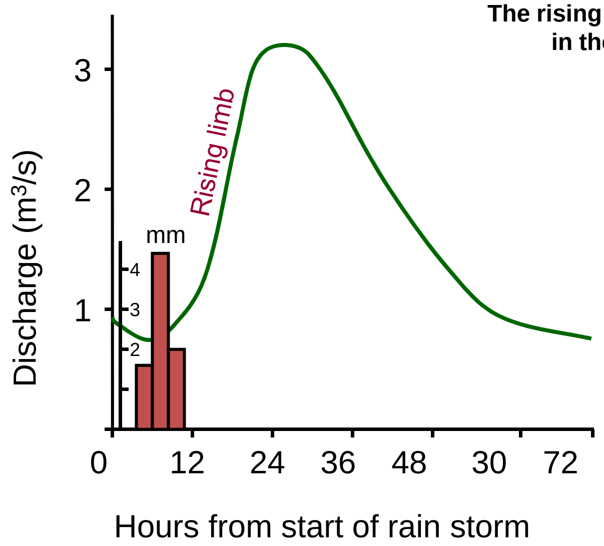

Discharge (m3/s)
3
2
1
0
12
24
36
48
30
72
Hours from start of rain storm


Rainfall shown in mm, as a bar graph
Discharge (m³/s)
3
2
1
mm
4
3
2
0
12
24
36
48
30
72
Hours from start of rain storm


Discharge in m³/s, as a line graph
Discharge (m³/s)
3
2
1
mm
4
3
2
0
12
24
36
48
30
72
Hours from start of rain storm

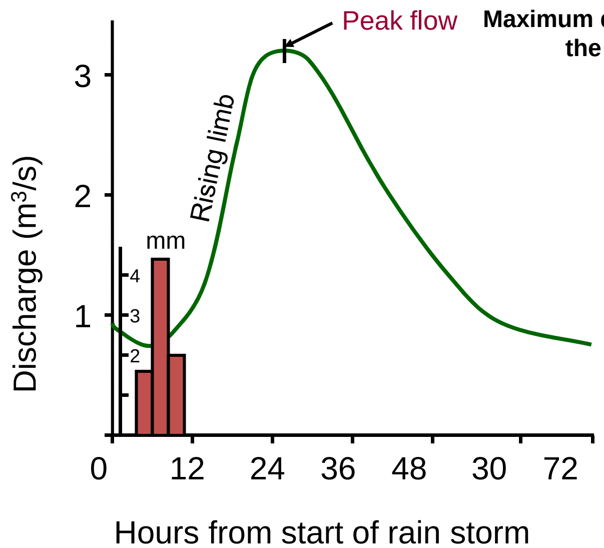
Rising limb

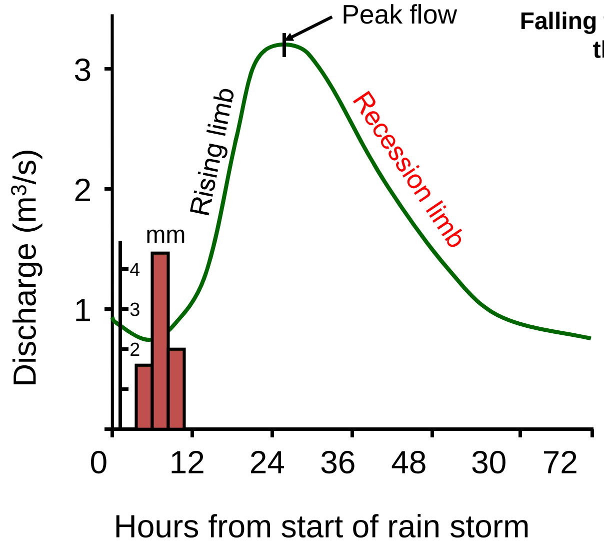
The rising flood water in the river



Peak flow

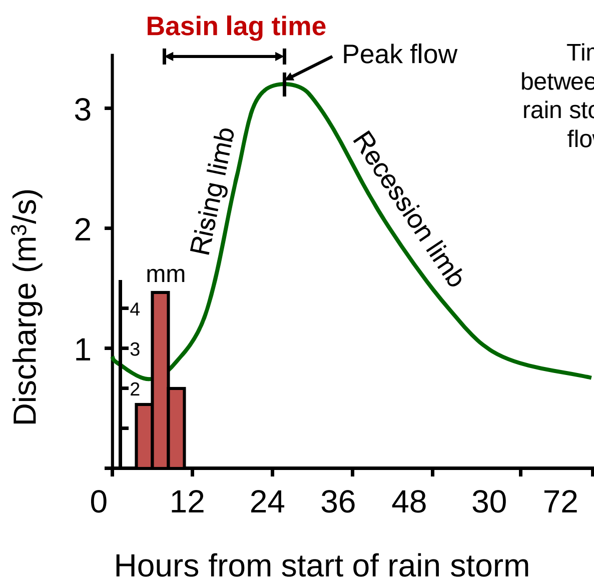
Maximum discharge in the river





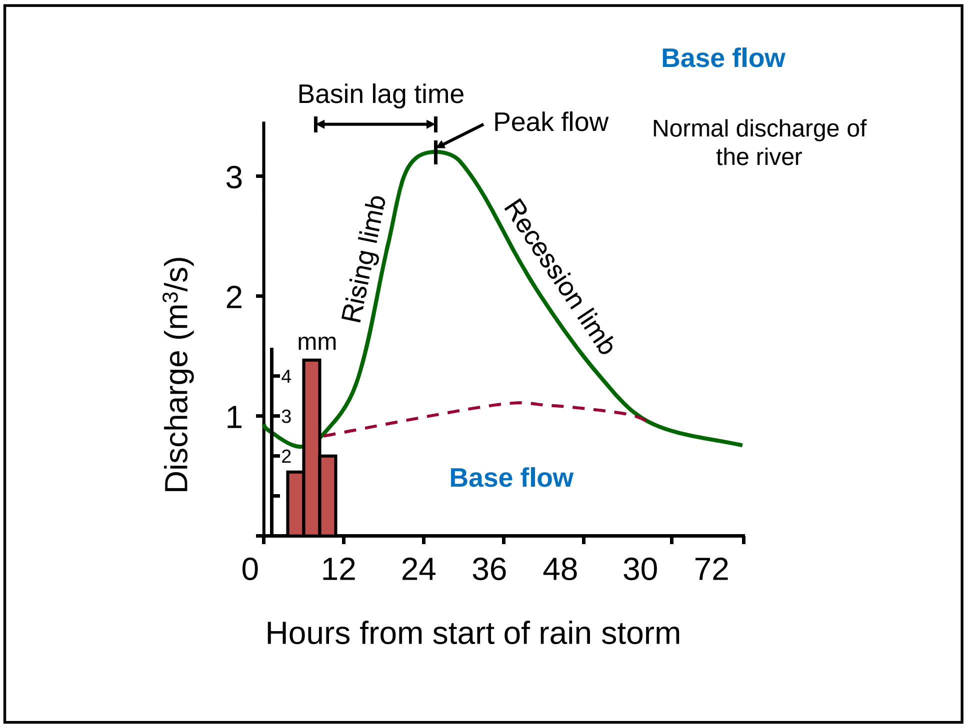
Recession limb

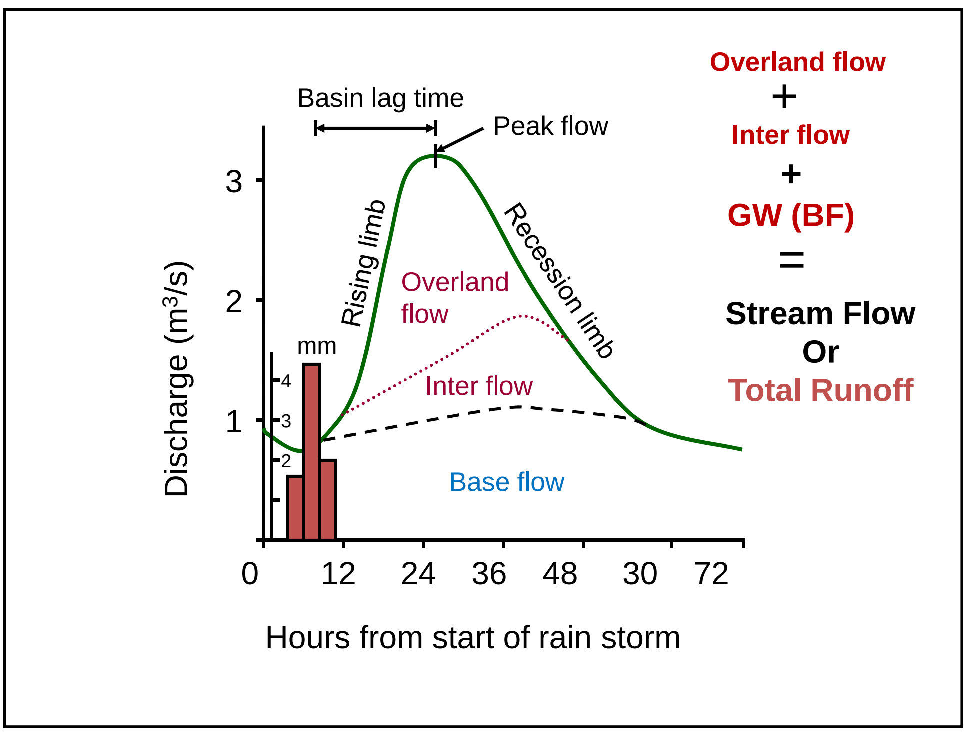
Falling flood water in the river



Basin lag time

Time difference between the peak of the rain storm and the peak flow of the river


Base flow
Normal discharge of the river
Basin lag time
Peak flow
Rising limb
Recession limb
Discharge (m3/s)
mm
Base flow
0 12 24 36 48 30 72
Hours from start of rain storm


Overland flow
+
Inter flow
+
GW (BF)
=
Stream Flow
Or
Total Runoff
Basin lag time
Peak flow
Rising limb
Recession limb
Overland flow
Inter flow
Base flow
Discharge (m3/s)
mm
0 12 24 36 48 30 72
Hours from start of rain storm

Overland flow

Volume of water reaching the river from surface run off

Inter flow

Volume of water reaching the river through the soil and underlying rock layers

GW

The Base flow

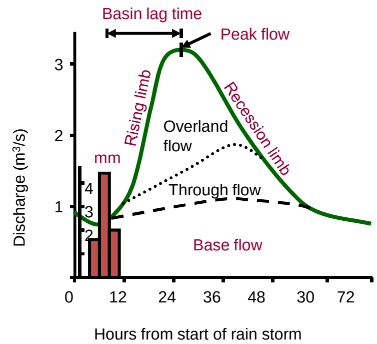
Factors influencing Storm Hydrographs

- Area
- Shape
- Slope
- Rock Type
- Soil
- Land Use
- Drainage Density
- Precipitation / Temp
- Tidal Conditions

©Microsoft Word clipart

Interpretation of Storm Hydrographs

You need to refer to:



- •Rising Limb
- •Recession Limb
- •Lag time
- •Rainfall Intensity
- •Peak flow compared to Base flow
- •Recovery rate, back to Base flow

Area

- Large basins receive more precipitation than small therefore have larger runoff

- Larger size means longer lag time as water has a longer distance to travel to reach the trunk river

Area	Rock Type	Drainage Density
Shape	Soil	Precipitation / Temp
Slope	Land Use	Tidal Conditions

Shape

- Elongated basin will produce a lower peak flow and longer lag time than a circular one of the same size

Area	Rock Type	Drainage Density
Shape	Soil	Precipitation / Temp
Slope	Land Use	Tidal Conditions

Slope

- Channel flow can be faster down a steep slope therefore steeper rising limb and shorter lag time

Area	Rock Type	Drainage Density
Shape	Soil	Precipitation / Temp
Slope	Land Use	Tidal Conditions

Rock Type

- Permeable rocks mean rapid infiltration and little overland flow therefore shallow rising limb

Area	**Rock Type**	Drainage Density
Shape	Soil	Precipitation / Temp
Slope	Land Use	Tidal Conditions

Soil

- Infiltration is generally greater on thick soil, although less porous soils eg. clay act as impermeable layers

- The more infiltration occurs the longer the lag time and shallower the rising limb

Area	Rock Type	Drainage Density
Shape	**Soil**	Precipitation / Temp
Slope	Land Use	Tidal Conditions

Land Use

- Urbanisation - concrete and tarmac form impermeable surfaces, creating a steep rising limb and shortening the time lag

- Afforestation - intercepts the precipitation, creating a shallow rising limb and lengthening the time lag

Area	Rock Type	Drainage Density
Shape	Soil	Precipitation / Temp
Slope	Land Use	Tidal Conditions

Drainage Density

- A higher density will allow rapid overland flow

Area	Rock Type	Drainage Density
Shape	Soil	Precipitation / Temp
Slope	Land Use	Tidal Conditions

Precipitation & Temperature

- Short intense rainstorms can produce rapid overland flow and steep rising limb
- If there have been extreme temperatures, the ground can be hard (either baked or frozen) causing rapid surface run off
- Snow on the ground can act as a store producing a long lag time and shallow rising limb. Once a thaw sets in the rising limb will become steep

Area	Rock Type	Drainage Density
Shape	Soil	**Precipitation / Temp**
Slope	Land Use	Tidal Conditions

Tidal Conditions

- High spring tides can block the normal exit for the water, therefore extending the length of time the river basin takes to return to base flow

Area	Rock Type	Drainage Density
Shape	Soil	Precipitation / Temp
Slope	Land Use	**Tidal Conditions**

Hydrograph Analysis :
Hydrograph : Q vs t

- **Duration , t**
- **Lag Time , t_L**
- **Time of Concentration , tc**
- **Rising Limb**
- **Recession Limb (falling limb)**
- **Peak Flow ,Q_p**
- **Time to Peak (rise time),t_p**
- **Recession Curve**
- **Base flow , BF**
- **Separation of BF from Runoff**

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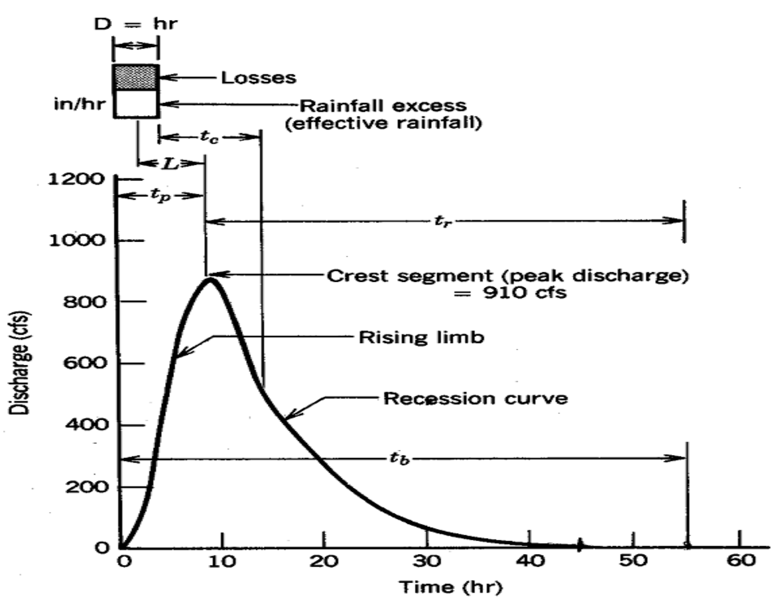
Hydrograph Components



Taken from Wanielista, M., R. Kersten, and R. Eaglin, *Hydrology: Water Quantity and Quality Control,* p. 184

UNIT HYDROGRAPH APPROACH

- A **unit hydrograph** is the direct runoff hydrograph resulting from **1 in (or 1 cm in SI units) of excess rainfall** generated **uniformly** over a drainage area **at a constant rate for an effective duration**.
- The unit hydrograph is a simple linear model that can be used to derive the hydrograph resulting from any amount of excess rainfall.

The following **basic assumptions** are inherent in the unit hydrograph approach:

1. *The excess rainfall has a constant intensity within the effective duration.*
2. *The excess rainfall is uniformly distributed throughout the entire drainage area.*
3. *The base time of the direct runoff hydrograph (i.e., the duration of direct runoff) resulting from an excess rainfall of given duration is constant.*
4. *The ordinates of all direct runoff hydrographs of a common base time are directly proportional to the total amount of direct runoff represented by each hydrograph.*
5. *For a given watershed, the hydrograph resulting from a given excess rainfall reflects the unchanging characteristics of the watershed.*

Assumptions in the Unit Hydrograph Theory

1. Time Invariance: The unit hydrograph theory assumes the principle of time invariance. This implies that the direct runoff hydrograph from a given drainage basin due to a given pattern of effective rainfall will be always same irrespective of the time, i.e. *even if the basin characteristics change with season etc., the unit hydrograph remains the same.*

2. Linear Response: Unit Hydrograph theory assumes the principle of linearity, superimposition or proportionality. It means that:

- If the ordinates of a unit hydrograph of say 1 hour duration are 0,1,6,4,3,2,1,0 units respectively, the effective rainfall of 2 units falling in 1 hour will produce a direct runoff hydrographs having ordinates of 0,2,12,8,6,4,2,0 units.
- Secondly, if the effective rainfall of two units occurs in 2 hours, i.e. 1 unit per hour, the direct runoff hydrograph ordinates will be obtained by summing up the corresponding ordinates of the two unit hydrographs as shown here.

Question Time !

Given below are the ordinates of a 6-h unit hydrograph for a catchment. Calculate the ordinates of the DRH due to a rainfall excess of 3.5 cm occurring in 6 hr.

Time (h)	0	3	6	9	12	15	18	24	30	36	42	48	54	60	69
UH ordinate (m^3/s)	0	25	50	85	125	160	185	160	110	60	36	25	16	8	0

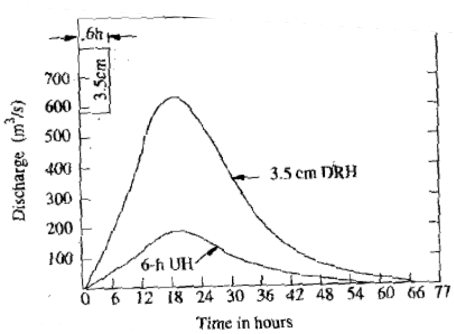
Answer !

EXAMPLE 6.4 *Given below are the ordinates of a 6-h unit hydrograph for a catchment. Calculate the ordinates of the DRH due to a rainfall excess of 3.5 cm occurring in 6 hr.*

Time (h)	0	3	6	9	12	15	18	24	30	36	42	48	54	60	69
UH ordinate (m^3/s)	0	25	50	85	125	160	185	160	110	60	36	25	16	8	0

The desired ordinates of the DRH are obtained by multiplying the ordinates of the unit hydrograph by a factor of 3.5 as in Table 6.3.

Note that the time base of DRH is not changed and remains the same as that of the unit hydrograph.



Unit Hydrograph of Different Durations

- Under condition where lack of adequate data in developement of unit hydrograph
- D-hour unit hydrograph is used to develop unit hydrographs of differing durations nD
- Two method available:
  1. Method of superposition

Method of Superpositions

If a D-h unit hydrograph is available, and its desired to develop unit hydrograph of nD, its is easily accomplished by superposing n unit hydrographs with each graph separated from the previous on by D-h.

D = 2-Hr Unit Hydrograph

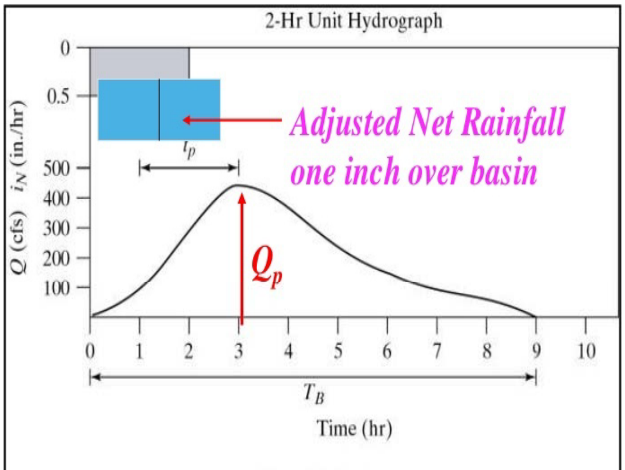


Figure E2.3(c)

Change UH Duration

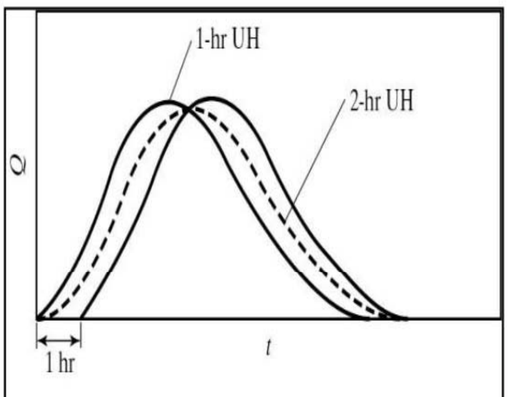


Figure 2.8

Unit hydrograph lagging.

Consider **1 hr** UH

Add and Lag two UH by one hour

Sum and divide by 2

Results in **2 hr** UH

Given the ordinates of a 4-hr unit hydrograph as below derive the ordinates of a 12-hr unit hydrograph for the same catchment

Time (hr)	0	4	8	12	16	20	24	28	32	36	40	44
Ordinates of 4-hr UH	0	20	80	130	150	130	90	52	27	15	5	0

Table 6.7 Calculation of a 12-h Unit Hydrograph from a 4-H Unit Hydrograph—Example 6.9

Time (h)	Ordinates of 4-h UH (m^3/s)			DRH of 3 cm in 12-h (m^3/s) (Col. 2+3+4)	Ordinate of 12-h UH (m^3/s) (Col. 5)/3
	A	*B* Lagged by 4-h	*C* Lagged by 8-h		
1	2	3	4	5	6
0	0	—	—	0	0
4	20	0	—	20	6.7
8	80	20	0	100	33.3
12	130	80	20	230	76.7
16	150	130	80	360	120.0
20	130	150	130	410	136.7
24	90	130	150	370	123.3
28	52	90	130	272	90.7
32	27	52	90	169	56.3
36	15	27	52	94	31.3
40	5	15	27	47	15.7
44	0	5	15	20	6.7
48		0	5	5	1.7
52			0	0	0

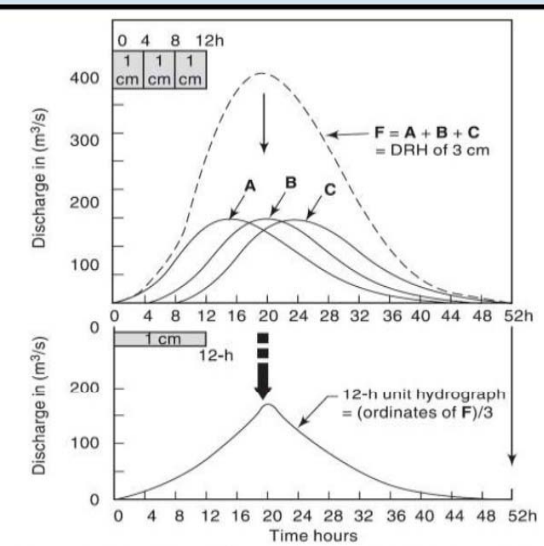


Fig. 6.15 Construction of a 12-h Unit Hydrograph from a 4-h Unit Hydrograph—Example 6.9

S-Curve

- Also known as S-hydrograph
- Hydrograph produced by continous effective rainfall at a constant rate for infinite period.
- Curve obtained by summation of an infinite series of D-h UH spaced D-h apart.

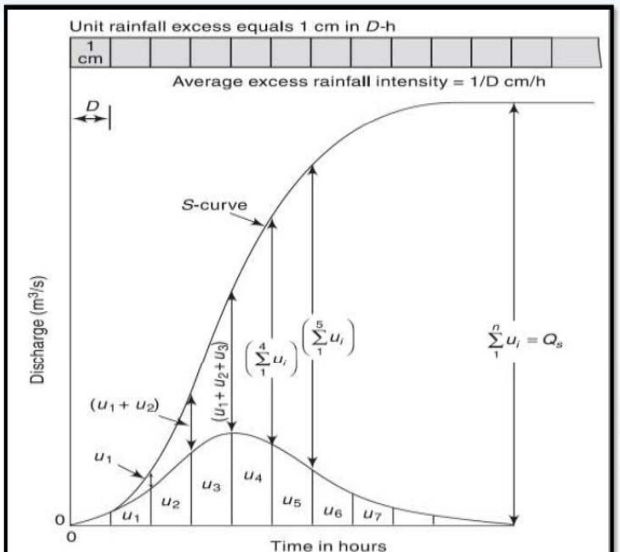


Fig. 6.16 S-curve

S-Curves for UH

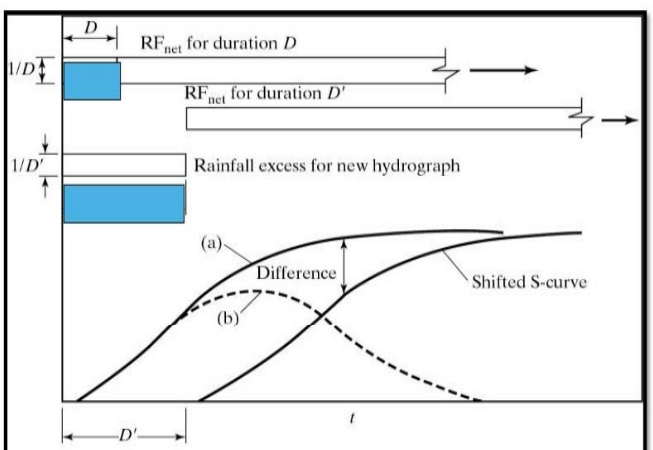


Figure 2.9

S-curve hydrograph method.

Answer !

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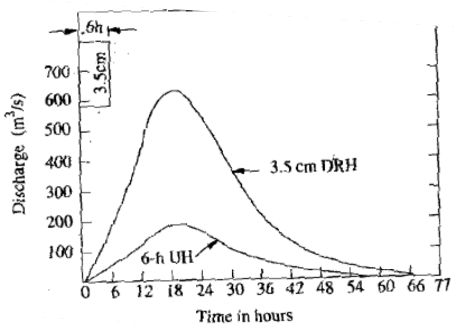


Gauged and ungauged watersheds

- Gauged watersheds
  - Watersheds where data on precipitation, streamflow, and other variables are available
- Ungauged watersheds
  - Watersheds with no data on precipitation, streamflow and other variables.

Need for synthetic UH

- UH is applicable only for gauged watershed and for the point on the stream where data are measured
- For other locations on the stream in the same watershed or for nearby (ungauged) watersheds, synthetic procedures are used.

Synthetic UH

- Synthetic hydrographs are derived by
  - Relating hydrograph characteristics such as peak flow, base time etc. with watershed characteristics such as area and time of concentration.
  - Using dimensionless unit hydrograph
  - Based on watershed storage

Snyder's Synthetic UH Methods

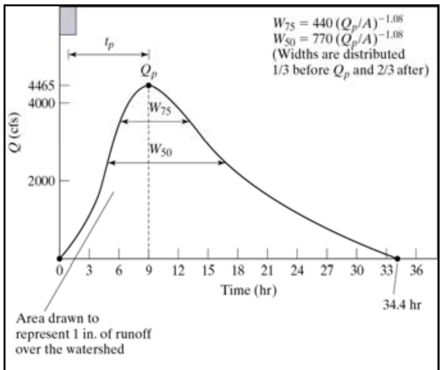


Figure E2.7

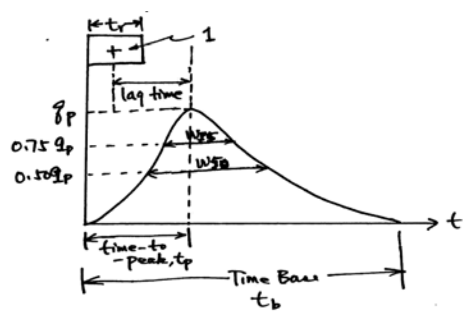
- A unit hydrograph is intended to quantify the unchanging characteristics of the watershed
- The synthetic unit hydrograph approach quantifies the unit hydrograph from watershed attributes
- Methods to characterize ungauged basins
- Use data and relationships developed from gauges
- Variety of approaches but most based on T_p and Q_p

Snyder's Synthetic Unit Hydrograph ***(Chow et al. p225)***

- L = main channel length (km or mi)
- L_c = length to point opposite centroid
- $t_p = C_1 C_t (L \cdot L_c)^{0.3}$ *hr*
- $q_p = Q_p / A = C_2 C_p / t_p$

Snyder's Synthetic UH

Snyder's method allows the computations of



(a) lag time (t_p);

(b) UH duration (t_r);

(c) UH peak discharge (q_p);

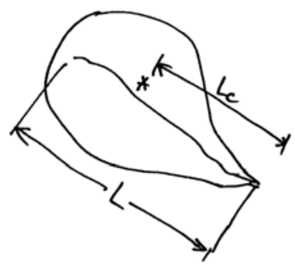
(d) Hydrograph time width at 50% and 75% (W_{50}, W_{75}) of peak flow

Snyder's Synthetic UH

Lag time (t_p): time from the center of rainfall – excess to the UH peak

$$t_p = C_1 C_t (LL_c)^{0.3}$$

where t_p = Basin Lag Time [hrs]; C_1 = 0.75 for SI unit; 1.0 for English unit; C_t = Coefficient which is a function of watershed slope and shape, 1.8-2.2 (for steeper slope, C_t is smaller); L = length of the main channel from the outlet to the watershed divide (Note here that the length is upto the watershed divide and not where the stream begins) [mi, km]; L_c = length along the main channel to the point nearest to the watershed centroid



Snyder's Synthetic UH

UH Duration (t_r):

$$t_r = t_p / 5.5$$

where t_r and t_p are in [hrs].

If the Unit Hydrograph is desired for duration other than t_r, use following relation for adjusting lag time:

$$t_{pR} = t_p + 0.25 (t_R - t_r)$$

where t_{pR} = corresponding basin lag; t_R = desired rainfall duration.

UH Peak Discharge (q_p):

$$q_p = \frac{C_2 C_p}{t_p} \quad \text{or} \quad q_p = \frac{C_2 C_p}{t_{pR}}$$

where C_2 = 2.75 for SI unit; 640 for English unit; C_p = coefficient accounting for flood wave and storage condition, 0.4 - 0.8; q_p = specific discharge, [$m^3/s/km^2$] or [$ft^3/s/mi^2$]

To compute actual discharge, $Q_p = A * q_p$

where A = drainage area

Snyder's Synthetic UH

Time Base (t_b) in days:

$t_b = 3 + t_p / 8$ *(for large watersheds)*

$t_b = 4\, t_p$ *(for small watersheds)*

Note: *After plotting unit hydrograph, you should always check if the area under the unit hydrograph is 1.0 and the time base should be adjusted, if necessary, until the area under the unit hydrograph is 1.0.*

UH Widths:

$$W_{75} = \frac{C_{w,75}}{q_p^{1.08}} \quad \text{or} \quad W_{50} = \frac{C_{w,50}}{q_p^{1.08}}$$

where

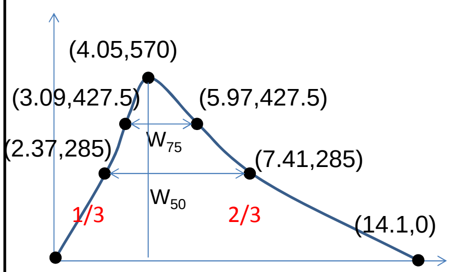
$C_{W,75}$ = 1.22 for SI unit; 440 for English unit;
$C_{W,50}$ = 2.14 for SI unit; 770 for English unit;.
W_{50}, W_{75} are in hours; Usually, 1/3 of the width is distributed before UH peak and 2/3 after the peak
Remember to check that the volume of UH is close to 1 cm or 1 inch

Steps for constructing Snyder UH:

1. **Compute the lag time t_p for given Ct and Cp.**
2. **Compute the peak flow rate Q_p.**
3. **Find time base t_b. For small watersheds, time base can be estimated by multiplying time to the peak by 3 to 5.**
4. **Find duration of rainfall D.**
5. **Use W50 and W75 ordinates for shaping the hydrograph at 50% and 75% of the peak flows. W50 and W75 are located at 1/3 before Qp and 2/3 after Qp.**
6. **Ensure that the area under the constructed unit hydrograph is 1.0.**

Example Snyder's Synthetic Unit Hydrograph

A watershed has a drainage area of 5.42 mi^2; the length of the main stream is 4.45 mi, and the main channel length from the watershed outlet to the point opposite the center of gravity of the watershed is 2.0 mi. Using Ct = 2.0 and Cp = 0.625, determine the standard synthetic unit hydrograph for this basin. What is the standard duration? Use Snyder's method to determine the 30- min unit hydrograph parameter.



Follow the procedure of table 8.4.1

- L = main channel length = 4.45 mi
- L_c = length to point opposite centroid = 2.0 mi
- A = watershed area = 5.42 mi^2
- $t_p = C_1 C_t (L \cdot L_c)^{0.3}\ hr = 1 \cdot 2 \cdot (4.45 \cdot 2)^{0.3} = 3.85\ hr$
- $t_r = t_p/5.5 = 0.7\ hr$
- $t_{pR} = t_p + 0.25(t_R - t_r) = 3.85 + 0.25(0.5 - 0.7) = \mathbf{3.8}\ hr$
- $Q_{pR} = \frac{C_2 C_p A}{t_{pR}} = 640 * 0.625 * 5.42/3.8 = \mathbf{570}\ cfs$
- Widths
- $W_{75} = \frac{C_{75}}{(Q_{pR}/A)^{1.08}} = \frac{440}{(570/5.42)^{1.08}} = 2.88\ hr$
- $W_{50} = \frac{C_{50}}{(Q_{pR}/A)^{1.08}} = \frac{770}{(570/5.42)^{1.08}} = 5.04\ hr$
- $T_b = 2581\frac{A}{Q_{pR}} - 1.5\ W_{50} - W_{75} = 2581\frac{5.42}{570} - 1.5 * 5.04 - 2.88 = 14.1\ hr$

NRCS (SCS) RAINFALL-RUNOFF RELATION

For the storm as a whole, the depth of excess precipitation or direct runoff P_e is always less than or equal to the depth of precipitation P; likewise, after runoff begins, the additional depth of water retained in the watershed Fa is less than or equal to some potential maximum retention S (see Figure 8.6.1).

There is some amount of rainfall I_a (initial abstraction before ponding) for which no runoff will occur, so the potential runoff is P - I_a.

The SCS method assumes that the ratios of the two actual to the two potential quantities are equal, that is,

$$\frac{F_a}{S} = \frac{P_e}{P - I_a} \quad \frac{\text{Actual}}{\text{Potential}}$$

From continuity,

$$P = P_e + I_a + F_a$$

$$P_e = \frac{(P - I_a)^2}{P - I_a + S}$$

$$I_a = 0.2S$$

$$P_e = \frac{(P - 0.2S)^2}{P + 0.8S} \qquad S = \frac{1000}{CN} - 10$$

where S = potential maximum retention

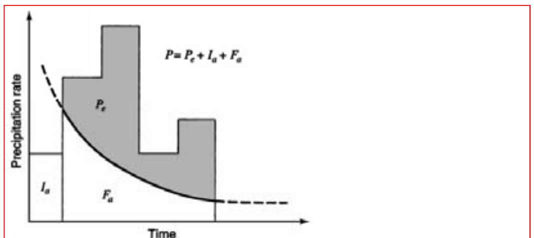


Figure 8.6.1 Variables in the SCS method of rainfall abstractions: I_a = initial abstraction, P_e = rainfall excess, F_a = continuing abstraction, and P = total rainfall.

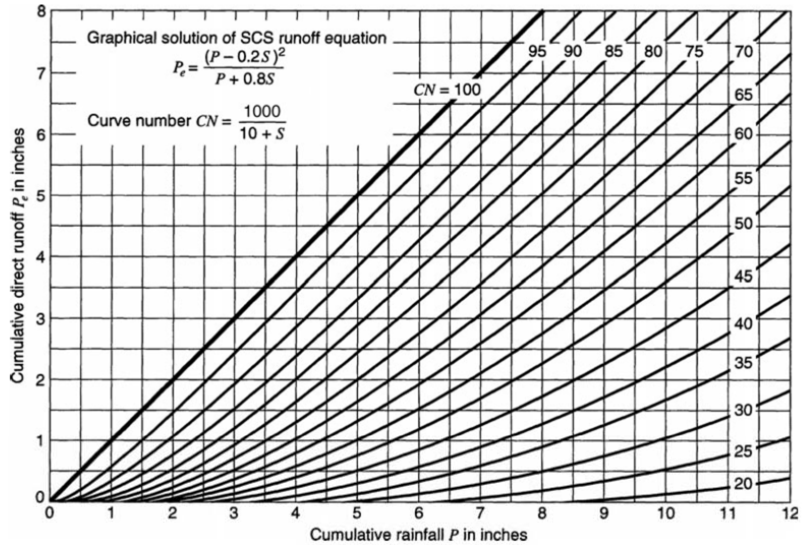


Figure 8.6.2 Solution of the SCS runoff equations (from U.S. Department of Agriculture Soil Conservation Service (1972)).

CURVE NUMBER ESTIMATION AND ABSTRACTIONS

Antecedent Moisture Conditions

The curve numbers shown in Figure 8.6.2 apply for normal antecedent moisture conditions (AMC II). Antecedent moisture conditions are grouped into three categories:

AMC I—Low moisture
AMC II—Average moisture condition, normally used for annual flood estimates
AMC III—High moisture, heavy rainfall over the preceding few days

For dry conditions (AMC I) or wet conditions (AMC III), equivalent curve numbers can be computed using

$$CN(\text{I}) = \frac{4.2CN(\text{II})}{10 - 0.058CN(\text{II})}$$

$$CN(\text{III}) = \frac{23CN(\text{II})}{10 + 0.13CN(\text{II})}$$

Table 8.7.1 Classification of Antecedent Moisture Classes (AMC) for the SCS Method of Rainfall Abstractions

	Total 5-day antecedent rainfall (in)	
AMC group	Dormant season	Growing season
I	Less than 0.5	Less than 1.4
II	0.5 to 1.1	1.4 to 2.1
III	Over 1.1	over 2.1

Source: U.S. Department of Agriculture Soil Conservation Service (1972).

Table 8.7.2 Adjustment of Curve Numbers for Dry (Condition I) and Wet (Condition III) Antecedent Moisture Conditions

	Corresponding *CN* for condition	
CN for condition II	I	III
100	100	100
95	87	99
90	78	98
85	70	97
80	63	94
75	57	91
70	51	87
65	45	83
60	40	79
55	35	75
50	31	70
45	27	65
40	23	60
35	19	55
30	15	50
25	12	45
20	9	39
15	7	33
10	4	26
5	2	17
0	0	0

Source: U.S. Department of Agriculture Soil Conservation Service (1972).

Soil Group Classification

Curve numbers have been tabulated by the Soil Conservation Service on the basis of soil type and land use. The four soil groups are described as:

Group A: Deep sand, deep loess, aggregated silts
Group B: Shallow loess, sandy loam
Group C: Clay loams, shallow sandy loam, soils low in organic content, and soils usually high in clay
Group D: Soils that swell significantly when wet, heavy plastic clays, and certain saline soils

Minimum infiltration rates for the various soil groups are:

Group	Minimum infiltration rate (in/hr)
A	0.30 – 0.45
B	0.15 – 0.30
C	0 – 0.05

Runoff Curve Numbers for Urban Areas

Table 2-2a Runoff curve numbers for urban areas [1]

Cover description: Cover type and hydrologic condition	Average percent impervious area [2]	Curve numbers for hydrologic soil group: A	B	C	D
Fully developed urban areas (vegetation established)					
Open space (lawns, parks, golf courses, cemeteries, etc.) [3]:					
Poor condition (grass cover < 50%)		68	79	86	89
Fair condition (grass cover 50% to 75%)		49	69	79	84
Good condition (grass cover > 75%)		39	61	74	80
Impervious areas:					
Paved parking lots, roofs, driveways, etc. (excluding right-of-way)		98	98	98	98
Streets and roads:					
Paved; curbs and storm sewers (excluding right-of-way)		98	98	98	98
Paved; open ditches (including right-of-way)		83	89	92	93
Gravel (including right-of-way)		76	85	89	91
Dirt (including right-of-way)		72	82	87	89
Western desert urban areas:					
Natural desert landscaping (pervious areas only) [4]		63	77	85	88
Artificial desert landscaping (impervious weed barrier, desert shrub with 1- to 2-inch sand or gravel mulch and basin borders)		96	96	96	96
Urban districts:					
Commercial and business	85	89	92	94	95
Industrial	72	81	88	91	93
Residential districts by average lot size:					
1/8 acre or less (town houses)	65	77	85	90	92
1/4 acre	38	61	75	83	87
1/3 acre	30	57	72	81	86
1/2 acre	25	54	70	80	85
1 acre	20	51	68	79	84
2 acres	12	46	65	77	82
Developing urban areas					
Newly graded areas (pervious areas only, no vegetation) [5]		77	86	91	94
Idle lands (CN's are determined using cover types similar to those in table 2-2c).					

1 Average runoff condition, and $I_a = 0.2S$.
2 The average percent impervious area shown was used to develop the composite CN's. Other assumptions are as follows: impervious areas are directly connected to the drainage system, impervious areas have a CN of 98, and pervious areas are considered equivalent to open space in good hydrologic condition. CN's for other combinations of conditions may be computed using figure 2-3 or 2-4.
3 CN's shown are equivalent to those of pasture. Composite CN's may be computed for other combinations of open space cover type.
4 Composite CN's for natural desert landscaping should be computed using figures 2-3 or 2-4 based on the impervious area percentage (CN = 98) and the pervious area CN. The pervious area CN's are assumed equivalent to desert shrub in poor hydrologic condition.
5 Composite CN's to use for the design of temporary measures during grading and construction should be computed using figure 2-3 or 2-4 based on the degree of development (impervious area percentage) and the CN's for the newly graded pervious areas.

United States Department of Agriculture (USDA), 1986. Urban Hydrology for Small Watersheds. Soil Conservation Service, Engineering Division. Technical Release 55 (TR-55).

Runoff Curve Numbers for Cultivated Agricultural Lands

Table 2-2b Runoff curve numbers for cultivated agricultural lands [1]

Cover type	Treatment [2]	Hydrologic condition [3]	A	B	C	D
Fallow	Bare soil	—	77	86	91	94
	Crop residue cover (CR)	Poor	76	85	90	93
		Good	74	83	88	90
Row crops	Straight row (SR)	Poor	72	81	88	91
		Good	67	78	85	89
	SR + CR	Poor	71	80	87	90
		Good	64	75	82	85
	Contoured (C)	Poor	70	79	84	88
		Good	65	75	82	86
	C + CR	Poor	69	78	83	87
		Good	64	74	81	85
	Contoured & terraced (C&T)	Poor	66	74	80	82
		Good	62	71	78	81
	C&T+ CR	Poor	65	73	79	81
		Good	61	70	77	80
Small grain	SR	Poor	65	76	84	88
		Good	63	75	83	87
	SR + CR	Poor	64	75	83	86
		Good	60	72	80	84
	C	Poor	63	74	82	85
		Good	61	73	81	84
	C + CR	Poor	62	73	81	84
		Good	60	72	80	83
	C&T	Poor	61	72	79	82
		Good	59	70	78	81
	C&T+ CR	Poor	60	71	78	81
		Good	58	69	77	80
Close-seeded or broadcast legumes or rotation meadow	SR	Poor	66	77	85	89
		Good	58	72	81	85
	C	Poor	64	75	83	85
		Good	55	69	78	83
	C&T	Poor	63	73	80	83
		Good	51	67	76	80

1 Average runoff condition, and I_a=0.2S
2 Crop residue cover applies only if residue is on at least 5% of the surface throughout the year.
3 Hydraulic condition is based on combination factors that affect infiltration and runoff, including (a) density and canopy of vegetative areas, (b) amount of year-round cover, (c) amount of grass or close-seeded legumes, (d) percent of residue cover on the land surface (good ≥ 20%), and (e) degree of surface roughness.

Poor: Factors impair infiltration and tend to increase runoff.

Good: Factors encourage average and better than average infiltration and tend to decrease runoff.

United States Department of Agriculture (USDA), 1986. Urban Hydrology for Small Watersheds. Soil Conservation Service, Engineering Division. Technical Release 55 (TR-55).

Runoff Curve Numbers for Other Agricultural Lands

Table 2-2c Runoff curve numbers for other agricultural lands [1]

Cover description — Cover type	Hydrologic condition	Curve numbers for hydrologic soil group — A	B	C	D
Pasture, grassland, or range—continuous forage for grazing. [2]	Poor	68	79	86	89
	Fair	49	69	79	84
	Good	39	61	74	80
Meadow—continuous grass, protected from grazing and generally mowed for hay.	—	30	58	71	78
Brush—brush-weed-grass mixture with brush the major element. [3]	Poor	48	67	77	83
	Fair	35	56	70	77
	Good	30 [4]	48	65	73
Woods—grass combination (orchard or tree farm). [5]	Poor	57	73	82	86
	Fair	43	65	76	82
	Good	32	58	72	79
Woods. [6]	Poor	45	66	77	83
	Fair	36	60	73	79
	Good	30 [4]	55	70	77
Farmsteads—buildings, lanes, driveways, and surrounding lots.	—	59	74	82	86

1 Average runoff condition, and $I_a = 0.2S$.
2 *Poor:* <50%) ground cover or heavily grazed with no mulch.
Fair: 50 to 75% ground cover and not heavily grazed.
Good: > 75% ground cover and lightly or only occasionally grazed.
3 *Poor:* <50% ground cover.
Fair: 50 to 75% ground cover.
Good: >75% ground cover.
4 Actual curve number is less than 30; use CN = 30 for runoff computations.
5 CN's shown were computed for areas with 50% woods and 50% grass (pasture) cover. Other combinations of conditions may be computed from the CN's for woods and pasture.
6 *Poor:* Forest litter, small trees, and brush are destroyed by heavy grazing or regular burning.
Fair: Woods are grazed but not burned, and some forest litter covers the soil.
Good: Woods are protected from grazing, and litter and brush adequately cover the soil.

United States Department of Agriculture (USDA), 1986. Urban Hydrology for Small Watersheds. Soil Conservation Service, Engineering Division. Technical Release 55 (TR-55).

Runoff Curve Numbers for Arid and Semiarid Rangelands

Table 2-2d Runoff curve numbers for arid and semiarid rangelands [1]

Cover description — Cover type	Hydrologic condition [2]	Curve numbers for hydrologic soil group — A [3]	B	C	D
Herbaceous—mixture of grass, weeds, and low-growing brush, with brush the minor element.	Poor		80	87	93
	Fair		71	81	89
	Good		62	74	85
Oak-aspen—mountain brush mixture of oak brush, aspen, mountain mahogany, bitter brush, maple, and other brush.	Poor		66	74	79
	Fair		48	57	63
	Good		30	41	48
Pinyon-juniper—pinyon, juniper, or both; grass understory.	Poor		75	85	89
	Fair		58	73	80
	Good		41	61	71
Sagebrush with grass understory.	Poor		67	80	85
	Fair		51	63	70
	Good		35	47	55
Desert shrub—major plants include saltbush, greasewood, creosotebush, blackbrush, bursage, palo verde, mesquite, and cactus.	Poor	63	77	85	88
	Fair	55	72	81	86
	Good	49	68	79	84

1 Average runoff condition, and $I_a = 0.2S$. For range in humid regions, use table 2-2c.
2 Poor: <30% ground cover (litter, grass, and brush overstory).
Fair: 30 to 70% ground cover.
Good: > 70% ground cover.
3 Curve numbers for group A have been developed only for desert shrub.

United States Department of Agriculture (USDA), 1986. Urban Hydrology for Small Watersheds. Soil Conservation Service, Engineering Division. Technical Release 55 (TR-55).

EXAMPLE 5.5 *In a 350 ha watershed the CN value was assessed as 70 for AMC-III. (a) Estimate the value of direct runoff volume for the following 4 days of rainfall. The AMC on July 1st was of category III. Use standard SCS-CN equations.*

Date	July 1	July 2	July 3	July 4
Rainfall (mm)	50	20	30	18

(b) *What would be the runoff volume if the CN_{III} value were 80?*

SOLUTION:

(a) Given $CN_{III} = 70$ $S = (25400/70) - 254 = 108.6$

$$Q = \frac{(P - 0.2S)^2}{P + 0.8S} \quad \text{for } P > 0.2S$$

$$= \frac{[P - (0.2 \times 108.86)]^2}{P + (0.8 \times 108.86)} = \frac{[P - 21.78]^2}{P + 87.09} \quad \text{for } P > 21.78 \text{ mm}$$

Date	*P* (mm)	*Q* (mm)
July 1	50	5.81
July 2	20	0
July 3	30	0.58
July 4	18	0
Total	**118**	**6.39**

Total runoff volume over the catchment $V_r = 350 \times 10^4 \times 6.39/(1000)$
$= \mathbf{22{,}365}$ m³

(b) Given $CN_{III} = 80$ $S = (25400/80) - 254 = 63.5$

$$Q = \frac{(P - 0.2S)^2}{P + 0.8S} \quad \text{for } P > 0.2S$$

$$= \frac{[P - (0.2 \times 63.5)]^2}{P + (0.8 \times 63.5)} = \frac{[P - 12.7]^2}{P + 50.8} \quad \text{for } P > 12.7 \text{ mm}$$

Date	*P* (mm)	*Q* (mm)
July 1	50	13.80
July 2	20	0.75
July 3	30	3.70
July 4	18	0.41
Total	**118**	**18.66**

Total runoff volume over the catchment $V_r = 350 \times 10^4 \times 18.66/(1000)$
$= \mathbf{65{,}310}$ m³

Thank you

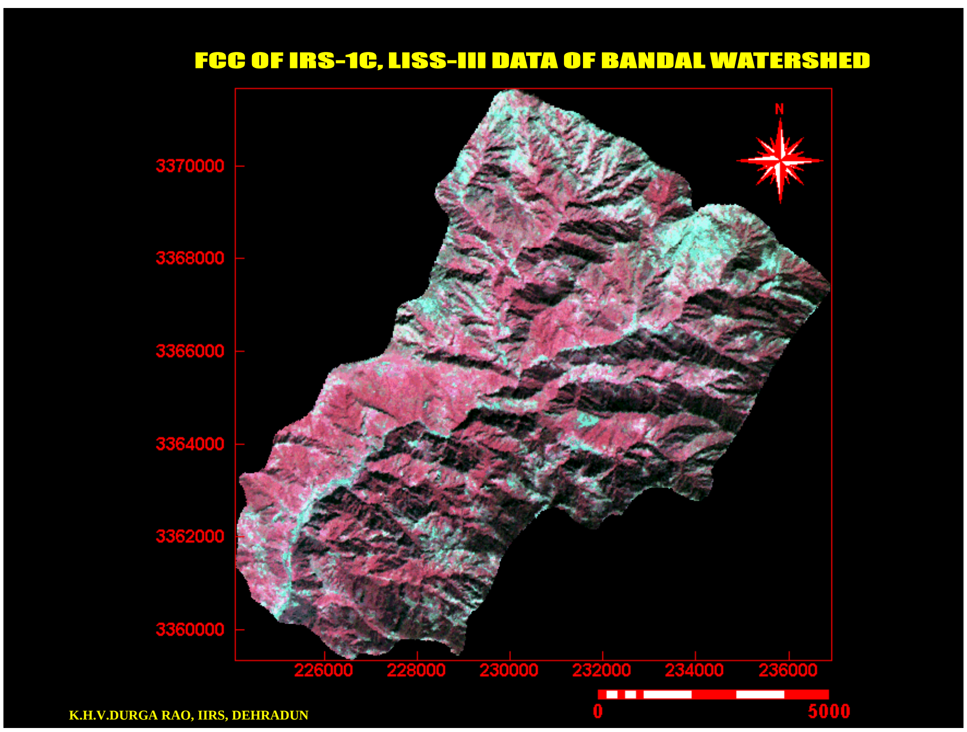
A CASE STUDY

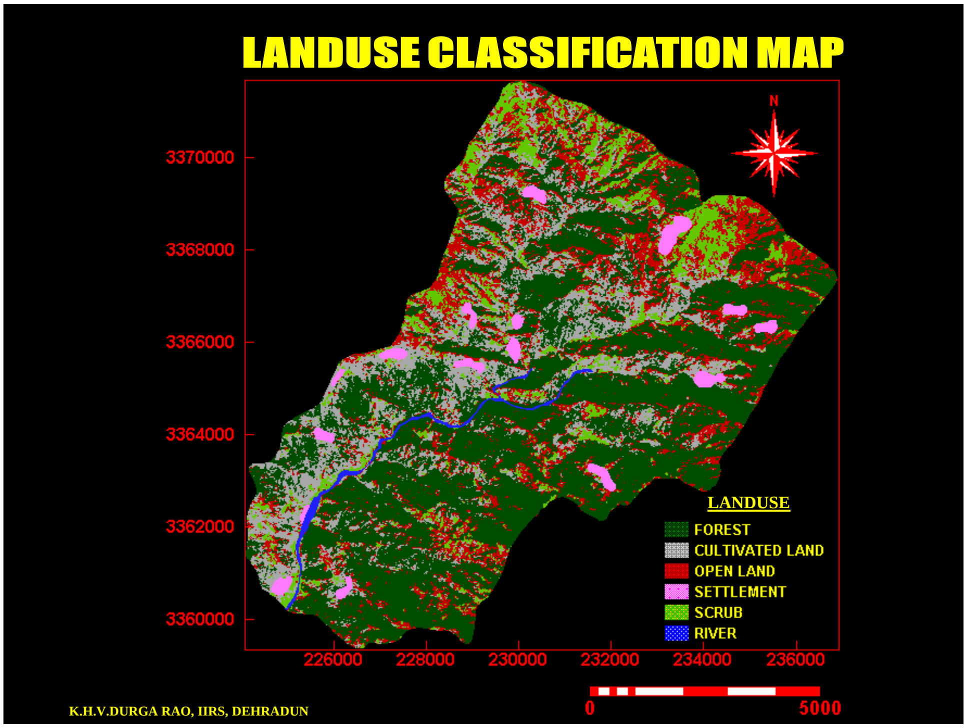
THE STUDY AREA

- The study area is Bandal watershed that is a sub watershed of Song river in Doon valley. Song River is a tributary of the river Ganga.
- The study area lies between 30^0 20^1N to 30^0 30^1 N latitude, 78^0 5^1E to 78^0 20^1 E longitude in Dehradun of India. The Areal extent of the watershed is 82.02 Sq.Km.
- Geology of the study area comprises of phyllites, shales and alluvium.
- The average slope of the watershed is approximately 52.7%.
- Average annual rainfall is 2500mm

DATA USED

- IRS-1C, LISS III digital data of dated 9th Oct' 97
- Survey of India topographic maps(53J/3 & 53J/7)
- Daily Rainfall & temperature data for the year 1997
- Ground truth data for landuse/landcover and soil classification




LANDUSE CLASSIFICATION MAP
N
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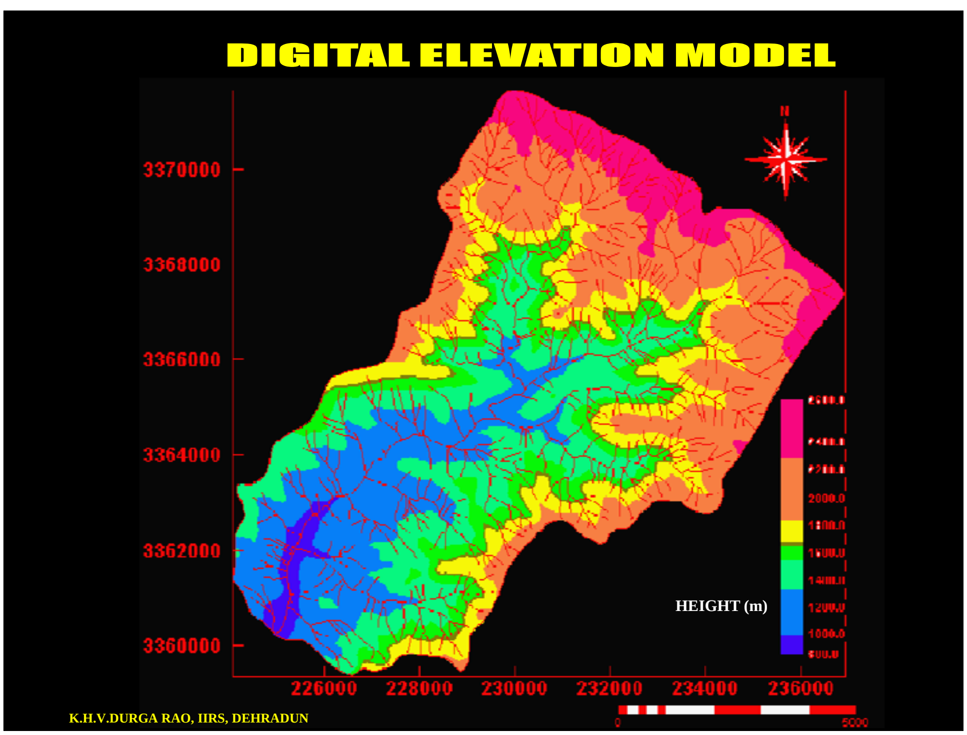
3366000
3364000
3362000
3360000
226000
228000
230000
232000
234000
236000
LANDUSE
FOREST
CULTIVATED LAND
OPEN LAND
SETTLEMENT
SCRUB
RIVER
K.H.V.DURGA RAO, IIRS, DEHRADUN
0
5000


DIGITAL ELEVATION MODEL
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3370000
3368000
3366000
3364000
3362000
3360000
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228000
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236000
HEIGHT (m)
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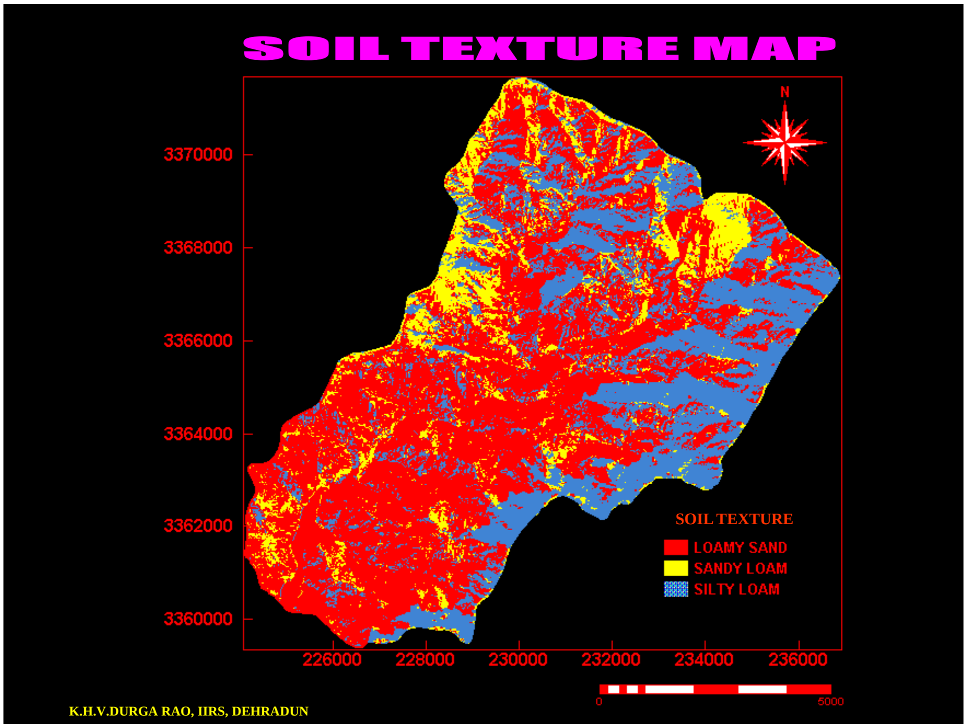
1200.0
1000.0
K.H.V.DURGA RAO, IIRS, DEHRADUN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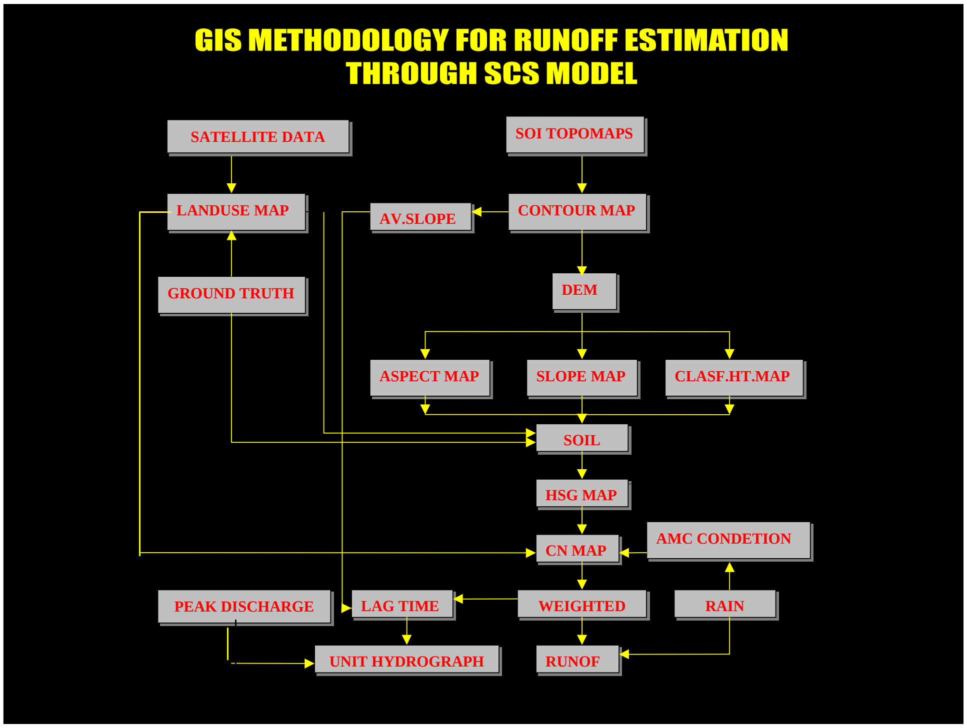
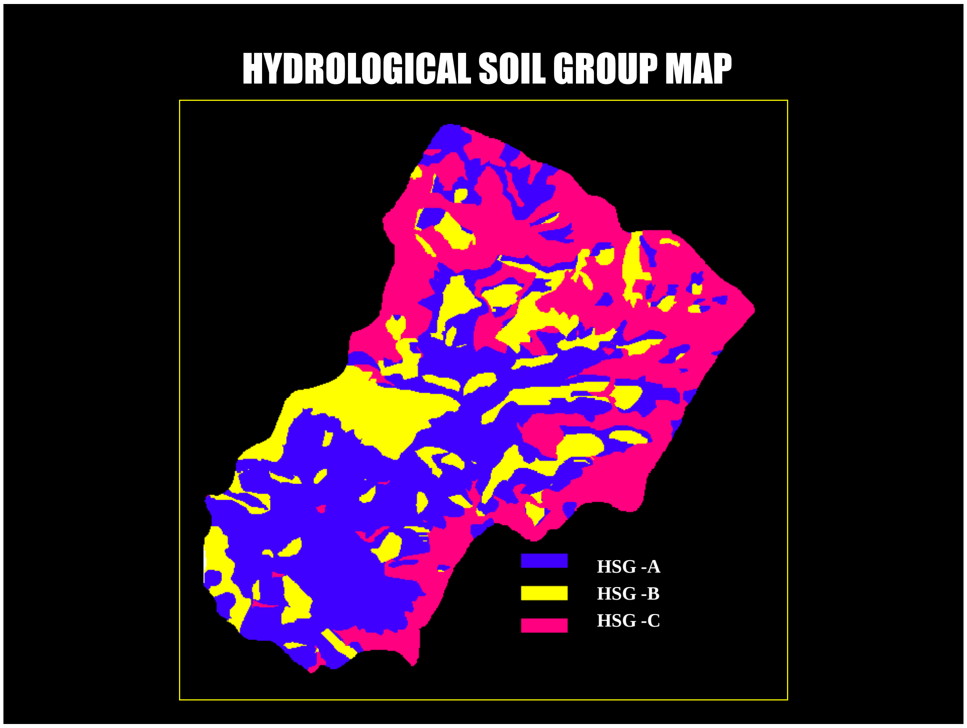
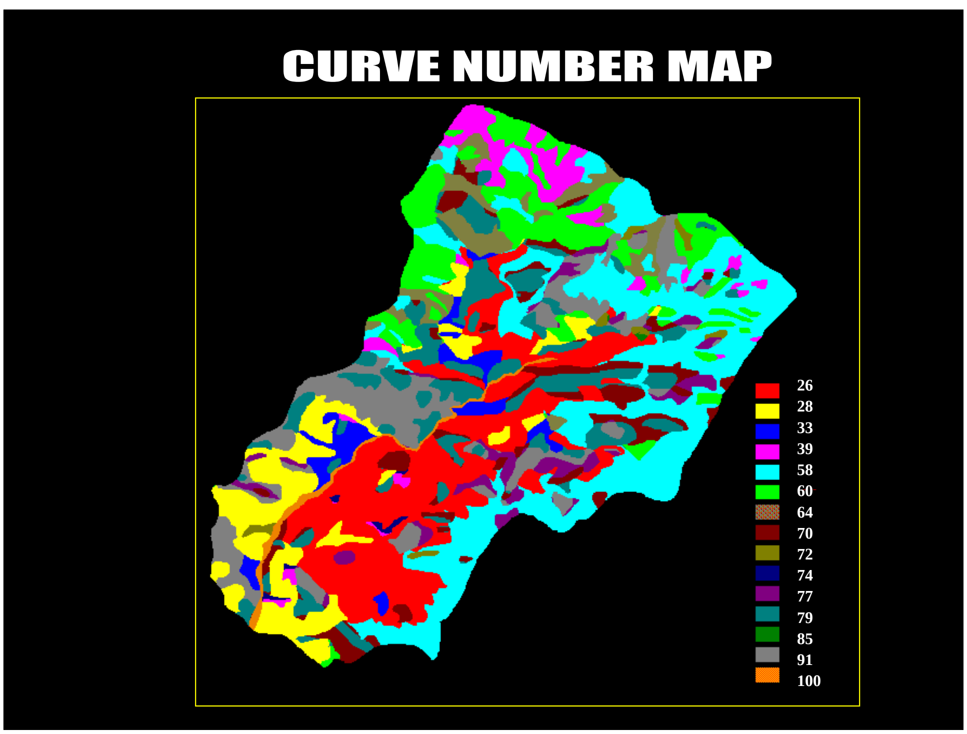
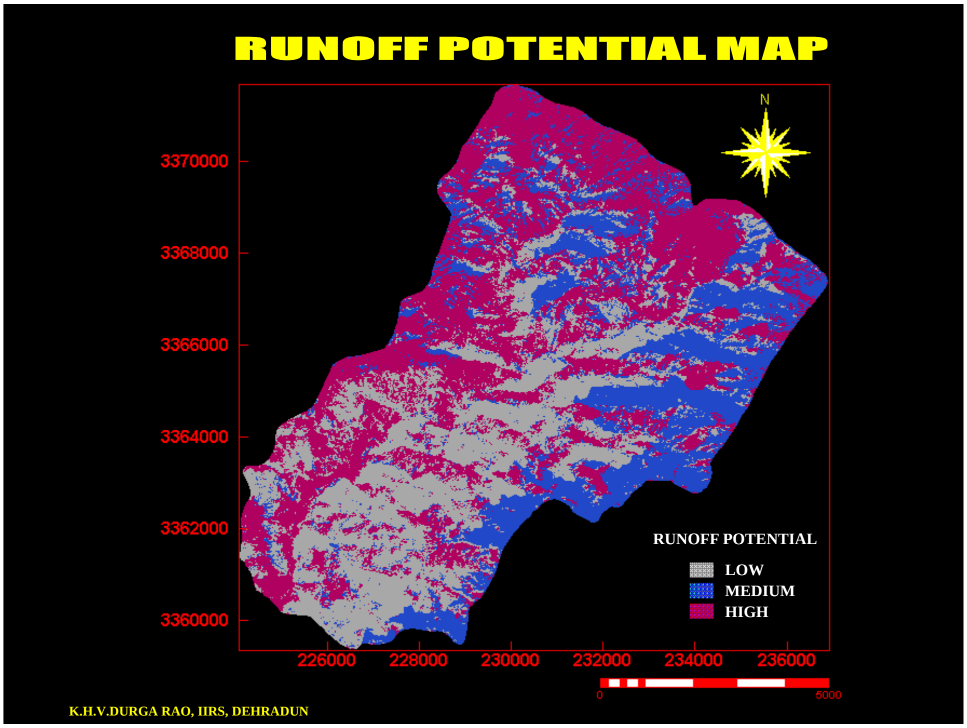
SOIL TEXTURE
LOAMY SAND
SANDY LOAM
SILTY LOAM
0
5000
K.H.V.DURGA RAO, IIRS, DEHRADUN


GIS METHODOLOGY FOR RUNOFF ESTIMATION THROUGH SCS MODEL
SATELLITE DATA
SOI TOPOMAPS
LANDUSE MAP
AV.SLOPE
CONTOUR MAP
GROUND TRUTH
DEM
ASPECT MAP
SLOPE MAP
CLASF.HT.MAP
SOIL
HSG MAP
CN MAP
AMC CONDETION
PEAK DISCHARGE
LAG TIME
WEIGHTED
RAIN
UNIT HYDROGRAPH
RUNOF


HYDROLOGICAL SOIL GROUP MAP
HSG -A
HSG -B
HSG -C


CURVE NUMBER MAP
26
28
33
39
58
60
64
70
72
74
77
79
85
91
100


RUNOFF POTENTIAL MAP
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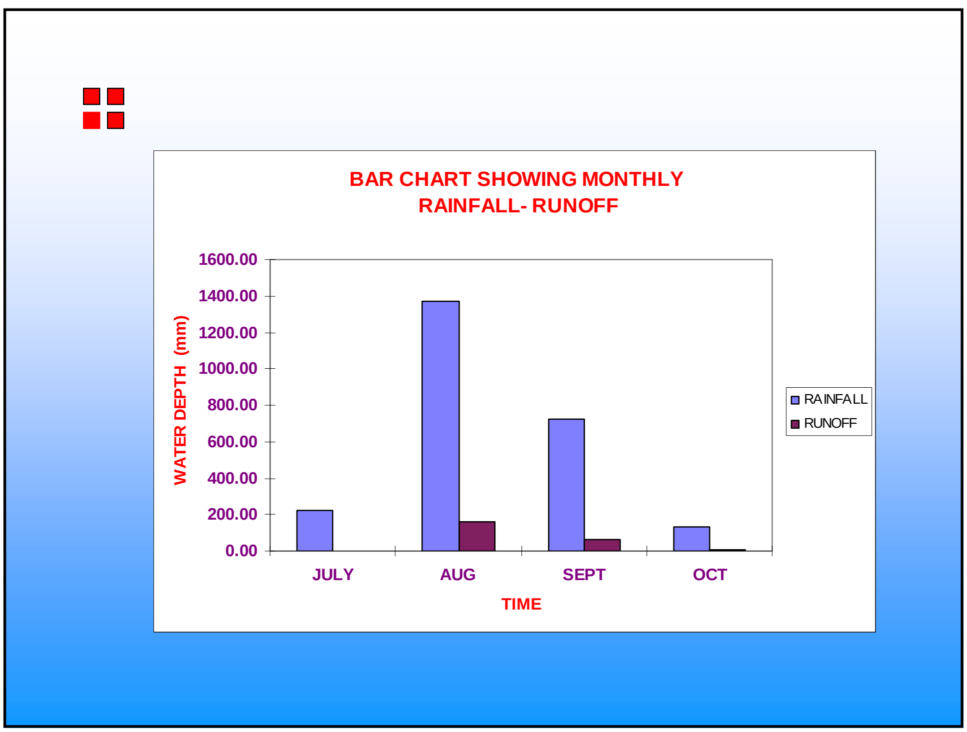
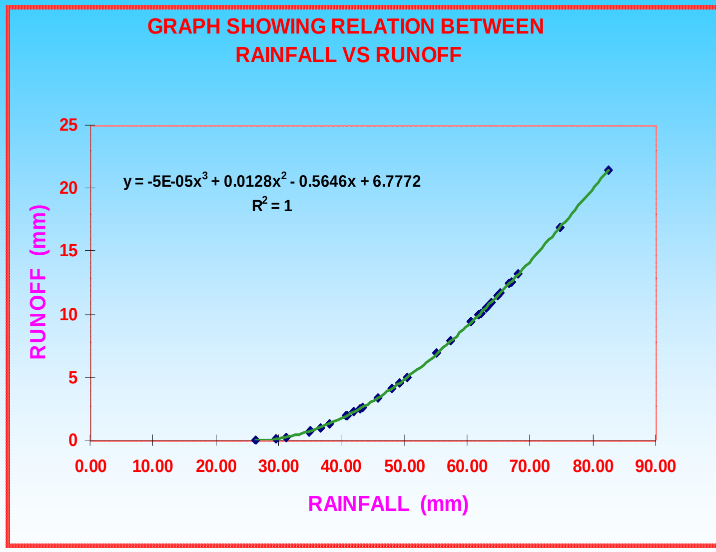
3362000
3360000
226000
228000
230000
232000
234000
236000
N
RUNOFF POTENTIAL
LOW
MEDIUM
HIGH
0
5000
K.H.V.DURGA RAO, IIRS, DEHRADUN


BAR CHART SHOWING MONTHLY RAINFALL- RUNOFF
WATER DEPTH (mm)
1600.00
1400.00
1200.00
1000.00
800.00
600.00
400.00
200.00
0.00
JULY
AUG
SEPT
OCT
TIME
RAINFALL
RUNOFF



UNIT HYDROGRAPH

An unit hydrograph of 0.5hours rainfall duration and one centimeter rainfall excess has been created using the SCS dimensionless hydrograph.

$$\text{Lag time(Tl; in hours)} = \frac{L^{0.8}((1000/CN) - 9)^{0.7}}{734.45Y^{0.5}} \quad \text{---4}$$

$$\text{Peak discharge(Qp; cumecs) for 1Cm.rainfall excess} = \frac{2.612\ A}{Tp} \quad \text{---5}$$

A = Area of the catchment in Sq.Km.; CN = Weighted Curve Number

L=Hydraulic length (m) = 890 $(A)^{0.65}$; Y = Average slope of the watershed in percent

RESULTS :

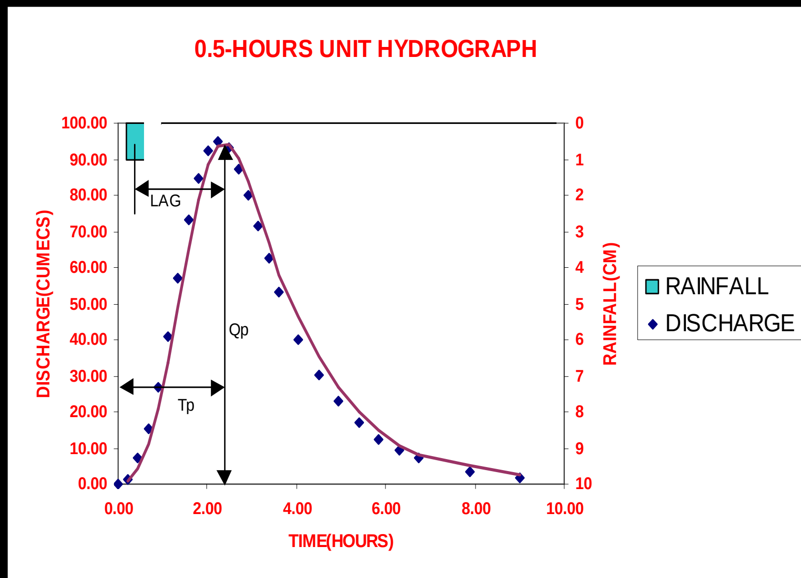
Hydraulic length = 15593.93 meters;

Average slope of the watershed = 52.72%

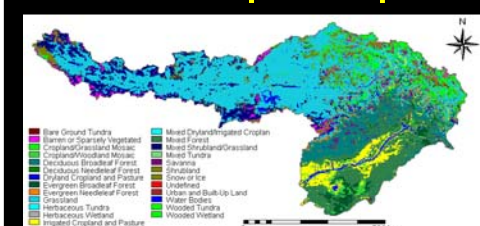
Lag time (T1) = 2.0 hours

Time to peak from the beginning of the rainfall(Tp) = 2.25 hours

Peak discharge = 95.05 cumecs

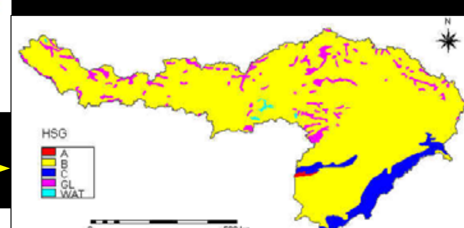


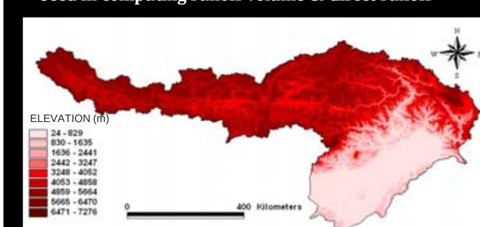
Input Spatial Database



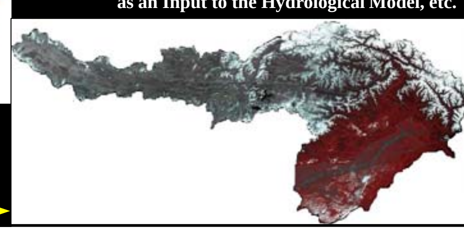
Landuse / landcover
Derived Output: Hydrological Landuse
Used in computing runoff volume and direct runoff

Hydrological Soil Groups
Used in computing runoff volume & direct runoff

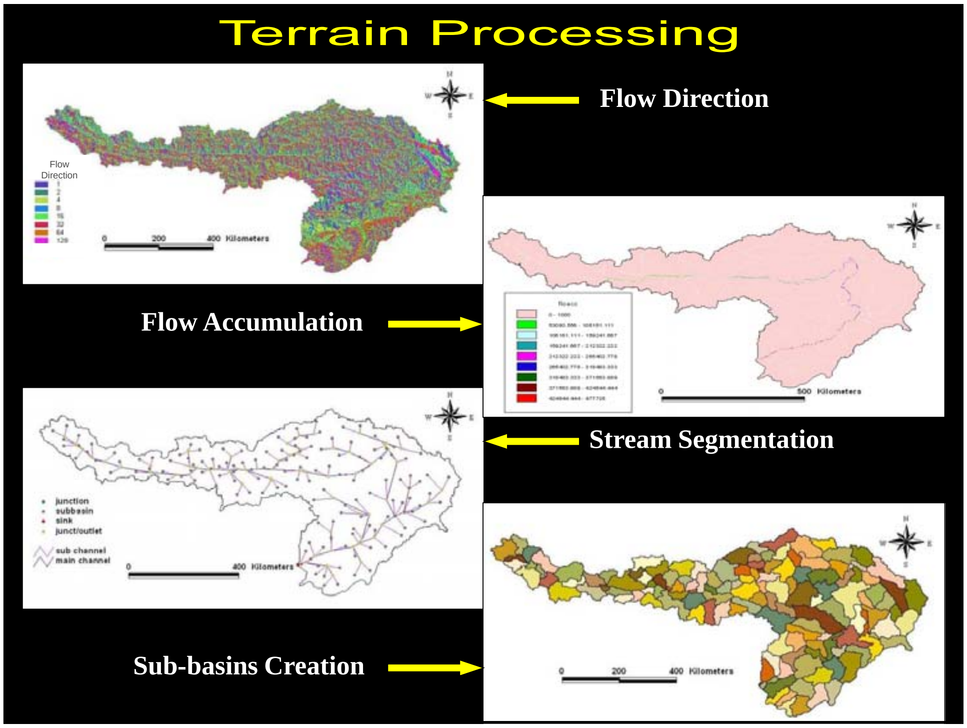




Digital Elevation Model
Derived Outputs: Slopes, Flow Direction, Flow Accumulation, Drainage, Sub-basins, as an Input to the Hydrological Model, etc.



IRS 1D WiFS Image of 2002 Nov
Used in updating drainage, basin boundaries, etc.


Terrain Processing
Flow Direction
Flow Accumulation
Stream Segmentation
Sub-basins Creation
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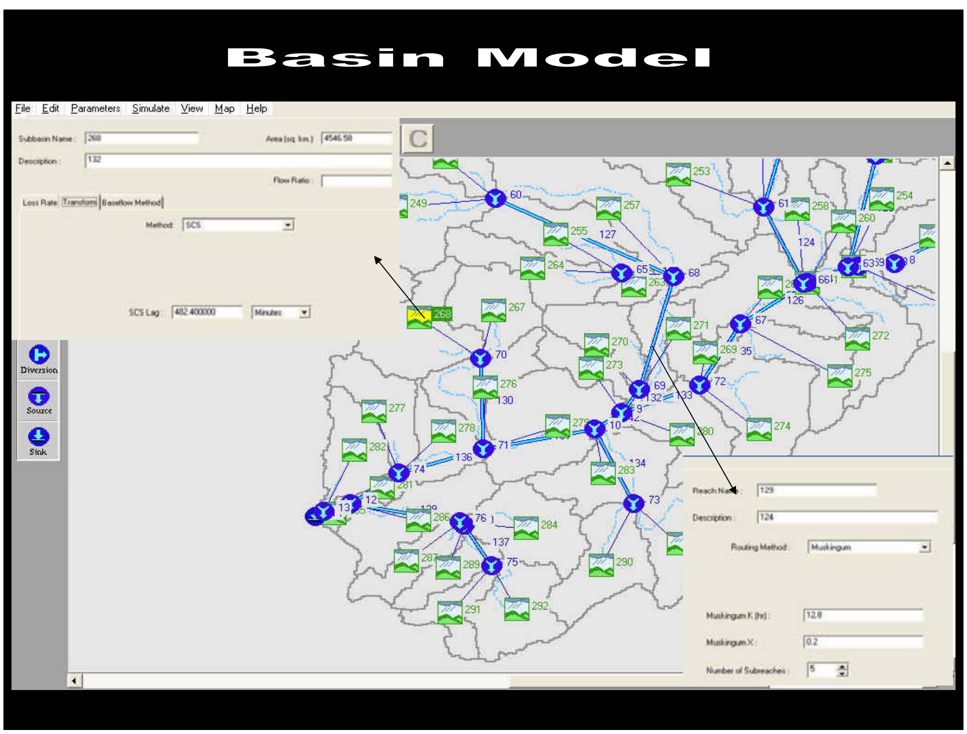
junction
subbasin
sink
junct/outlet
sub channel
main channel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File Edit Parameters Simulate View Map Help
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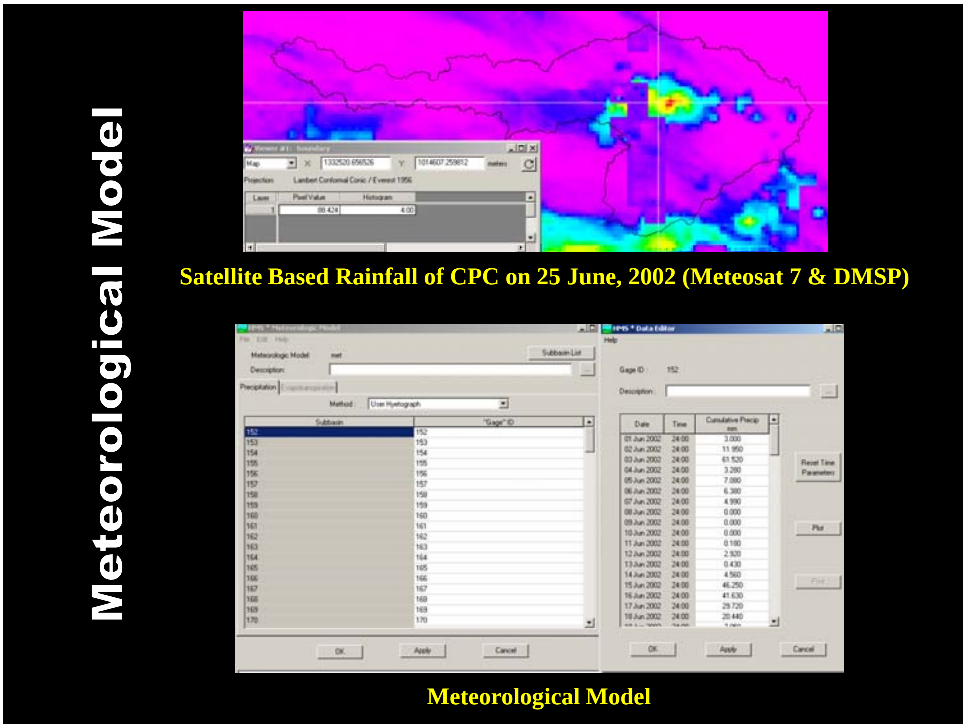
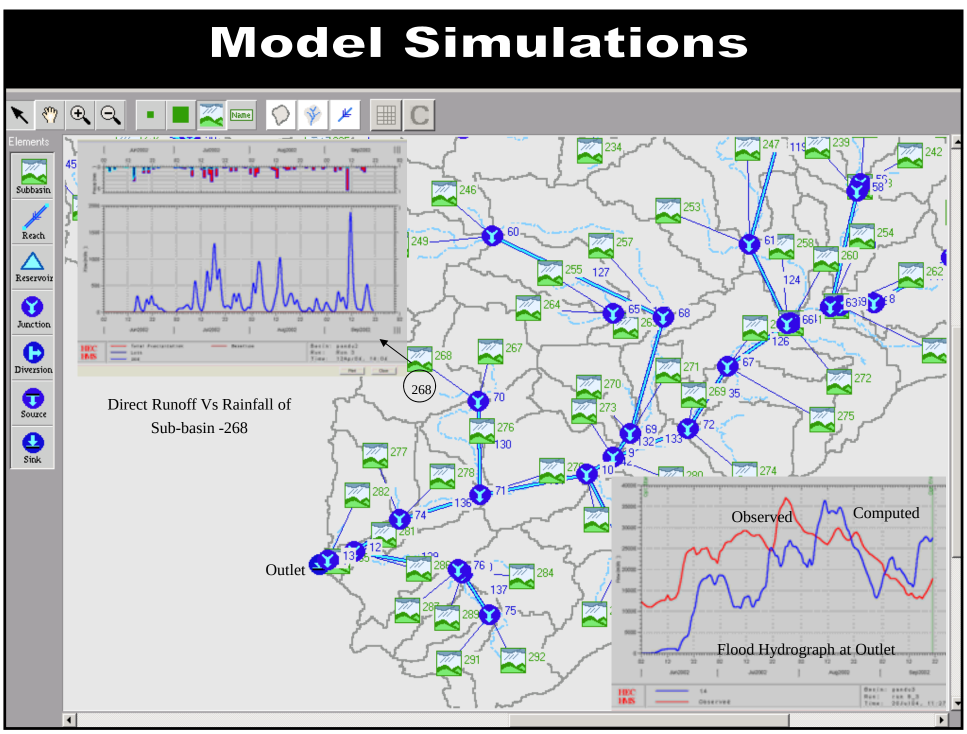
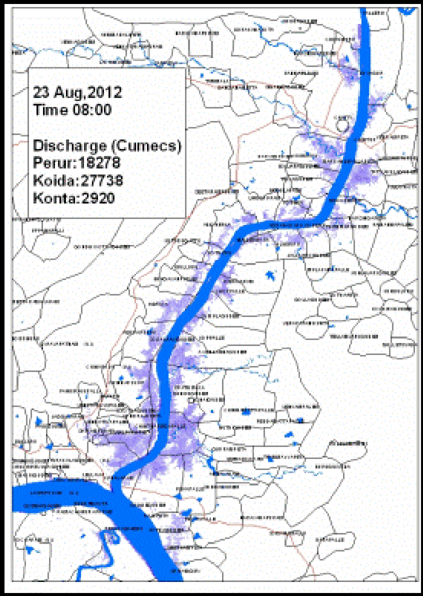
Area (sq. km.) 4546.58
Description: 132
Flow Ratio:
Loss Rate Transform Baseflow Method
Method: SCS
SCS Lag: 482.400000 Minutes
Diversion
Source
Sink
Reach Name: 129
Description: 124
Routing Method: Muskingum
Muskingum K (hr): 12.8
Muskingum X: 0.2
Number of Subreaches: 5


Meteorological Model
Satellite Based Rainfall of CPC on 25 June, 2002 (Meteosat 7 & DMSP)
Meteorological Model


Model Simulations
Direct Runoff Vs Rainfall of
Sub-basin -268
268
Outlet
Observed
Computed
Flood Hydrograph at Outlet

Inundation simulation using runoff estimation



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THANK YOU