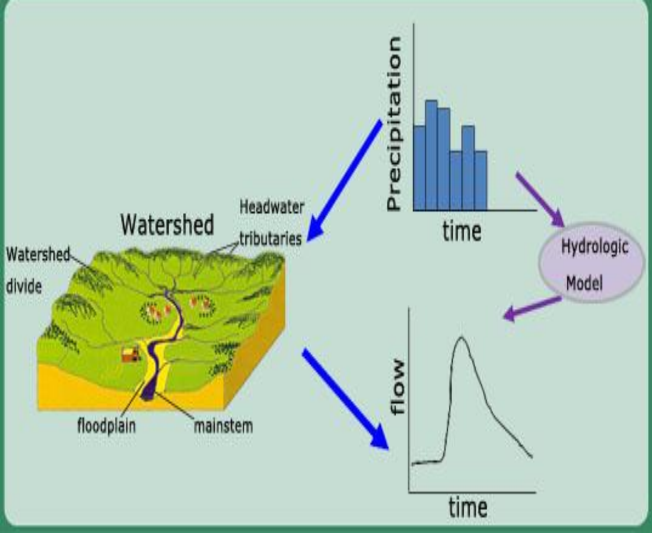
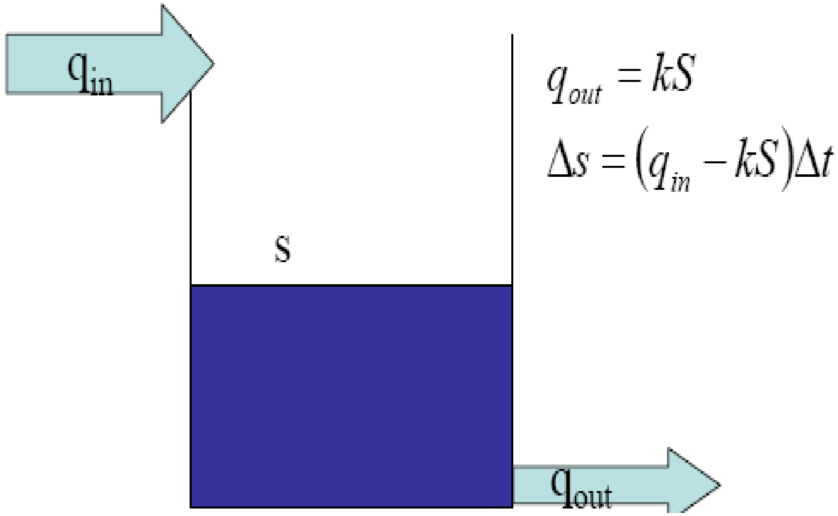




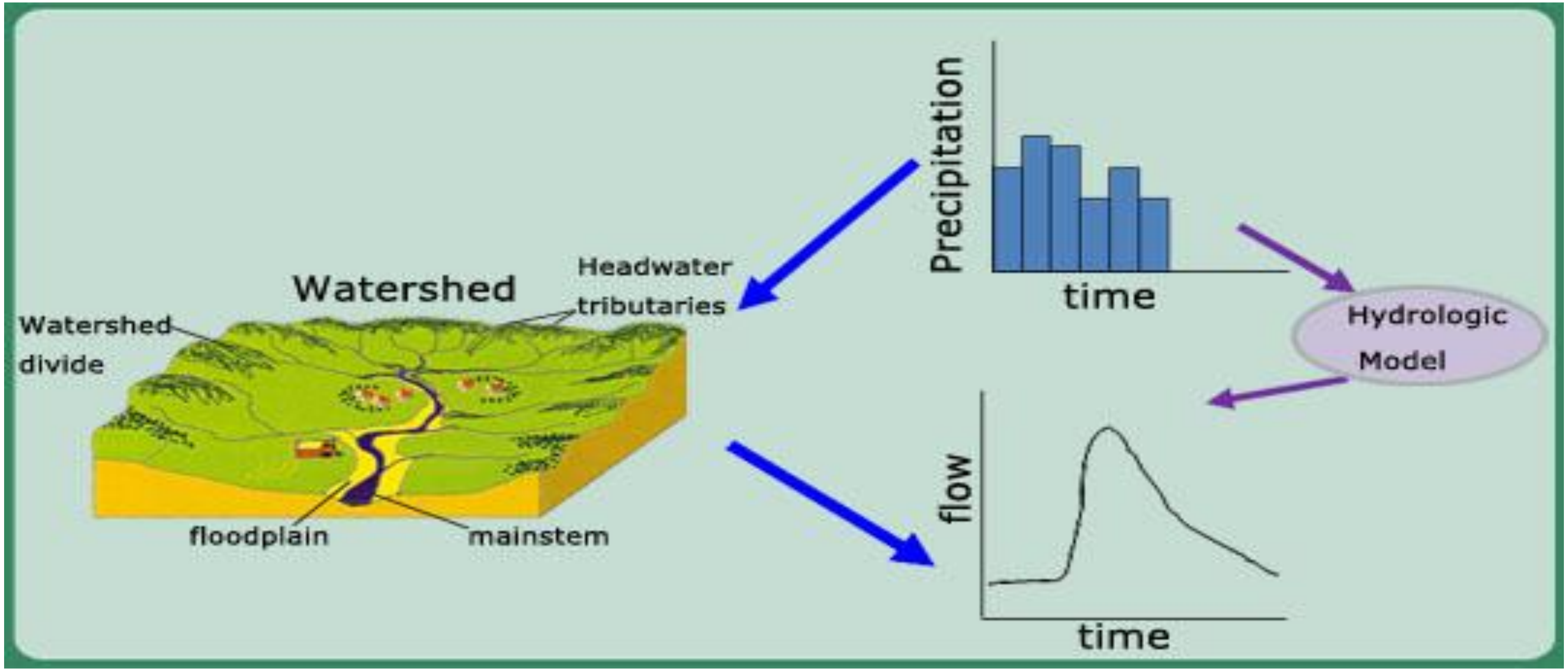
Rainfall Runoff Modelling

Prepared by: Birhanu W.

Hydrological modeling

What is a Model?

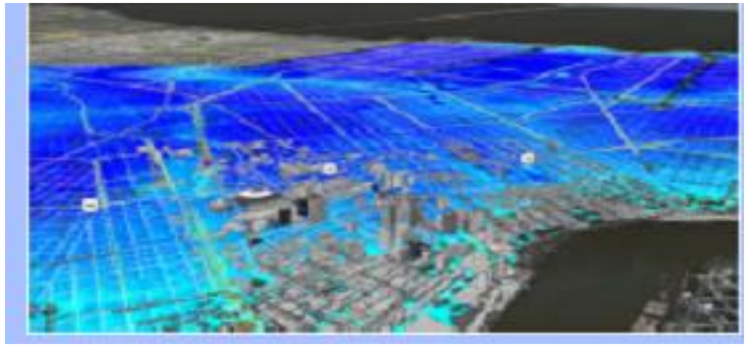
- simplified representation of a complex system
- The goal is to simulate/reproduce the shape of a hydrograph given a known input (Eg: rainfall) but not all characteristics of the system



Hydrological modelling

(physical, analog or mathematical)

- Mathematical model represents the system by a set of equations expressing relationship between a system variables & Parameters.
- Physical model: constructed in laboratory
- Analog models: uses electricity e.g. Ohm's law analogous to Darcy's law



Hydrological modeling

Constituents of a Model?

- **State variables:** are a characteristics of a system that may be measures and can assume different numerical values at different times, e.g rainfall, flow, etc
- **Parameters:** is a quantity/ characterizing a system. It may or may not remain constant in time – hydraulics conductivity (K), Manning's coefficient (n), Ordinates of UH, etc.
- **Boundary conditions:** These are the values of the system input the forces that act on the hydrologic system and cause it to change.
- **Initial Conditions:**

Hydrological modeling

A good Model?

- **Parsimony**: it should not be more complex than necessary and its Parameters should be derived from the data
- **Modesty**: it should not pretend too much
- **Accuracy**: it should not attempt predictions for situations that are more accurate than can be measured
- **Testability**: the results should be open to objective testing and the limits of its validity
- **Simplification**: answer specific questions, and nothing more
- **Verification** : test of the internal logic of a model. A logical evaluation of the model's assumptions. Good models reflect good science.
- **Validation**: test of the model behavior. Results should correspond to independent experimental data.

Hydrological modeling
Why Model?

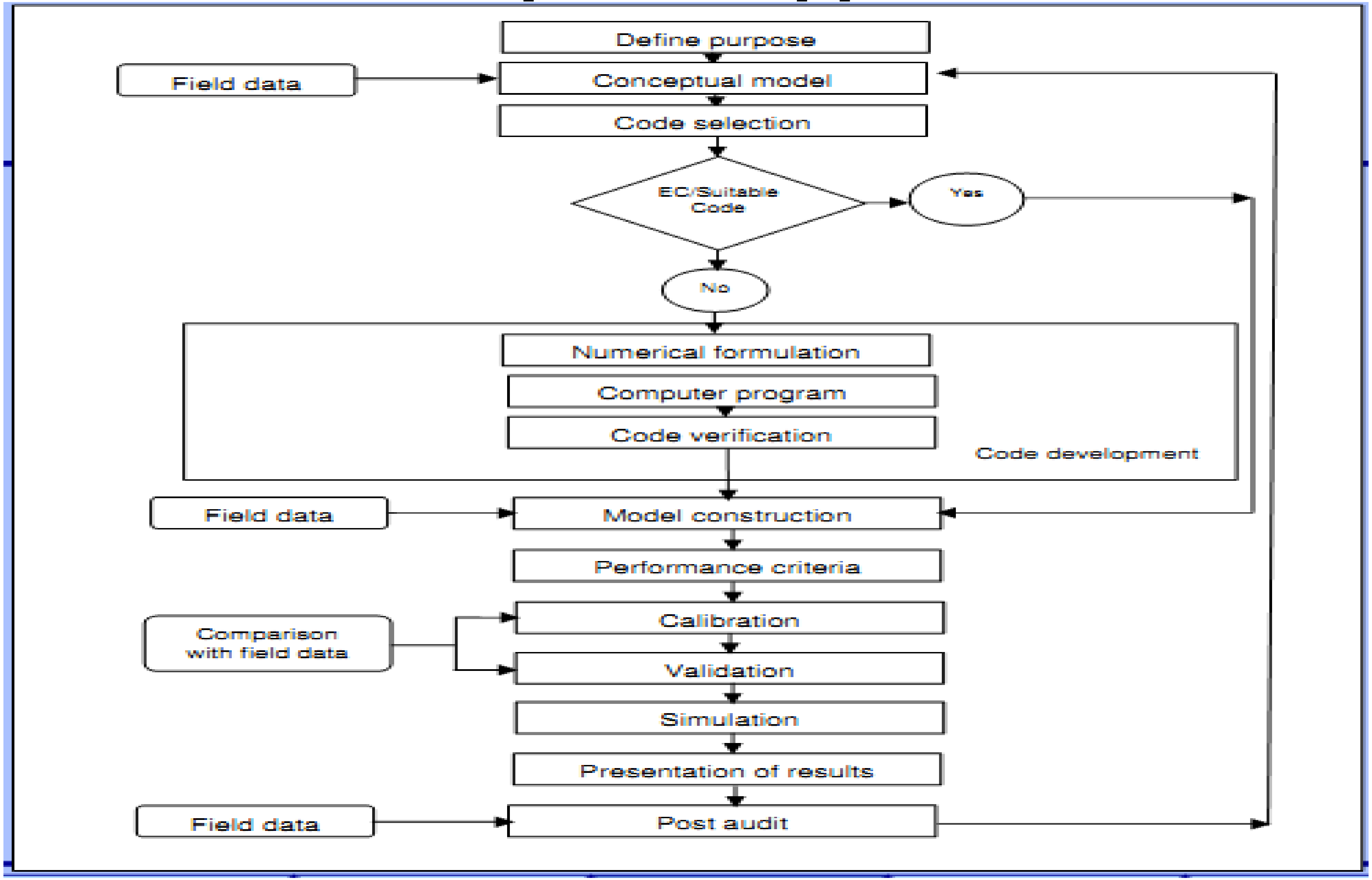
- to gain a better understanding of the hydrologic phenomena operating in a catchment
- how changes in the catchment may affect these phenomena.
- modelling is the generation of synthetic sequences of hydrologic data for facility design or for use in forecasting.
- They are also providing valuable for studying the potential impacts of changes in land use or climate.

Hydrological modeling

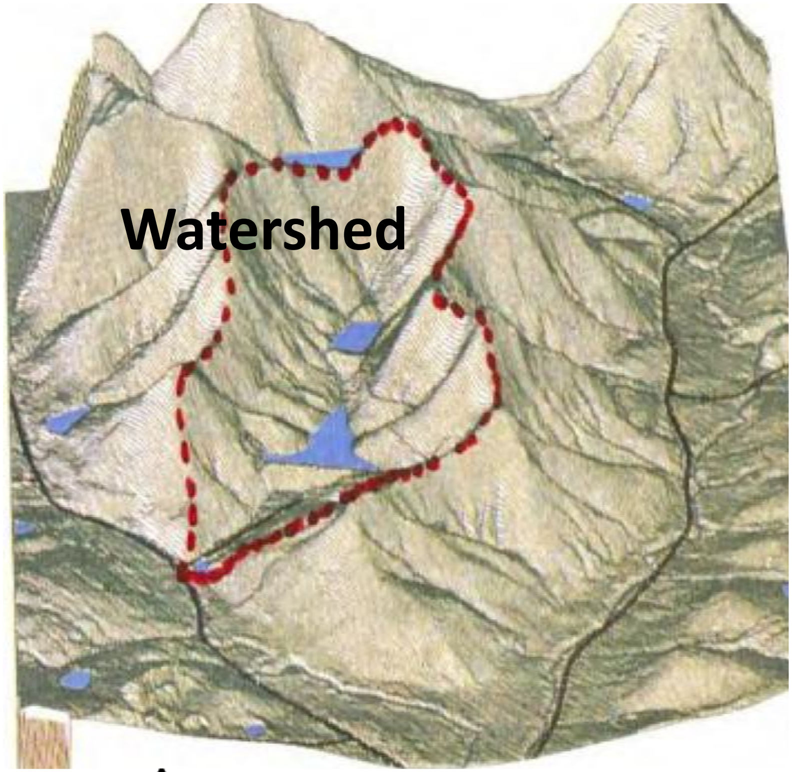
Why Model?

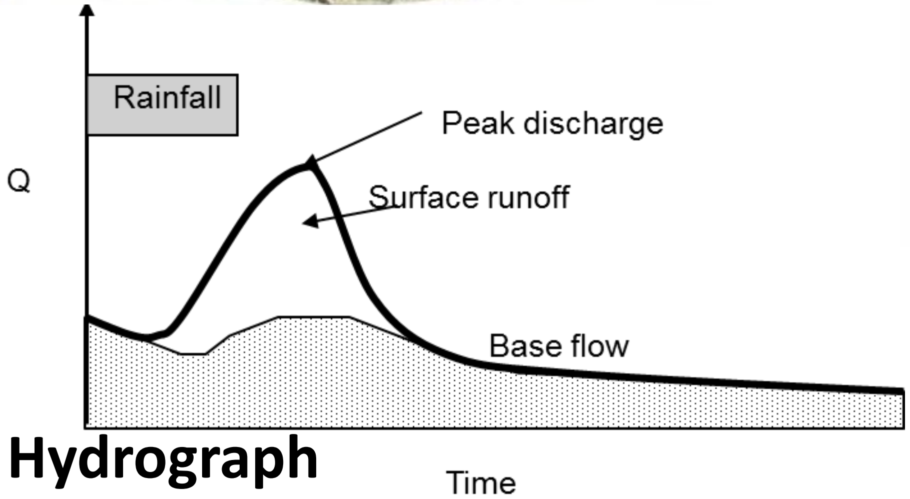
- Estimate and predict water quantities, and flow rates for a given scenario
- Used to make efficient and cost effective quantitative estimates of water related variables at ungauged catchments
- Help in making decisions related to planning, design, operation and management of water related structures
- Rates of surface flows, underground water movement
- Amount of water stored in water bodies
- Amount of sediment
- How these rates and amounts vary in time
- Determine increase in stream flow due to new development

Model development approaches

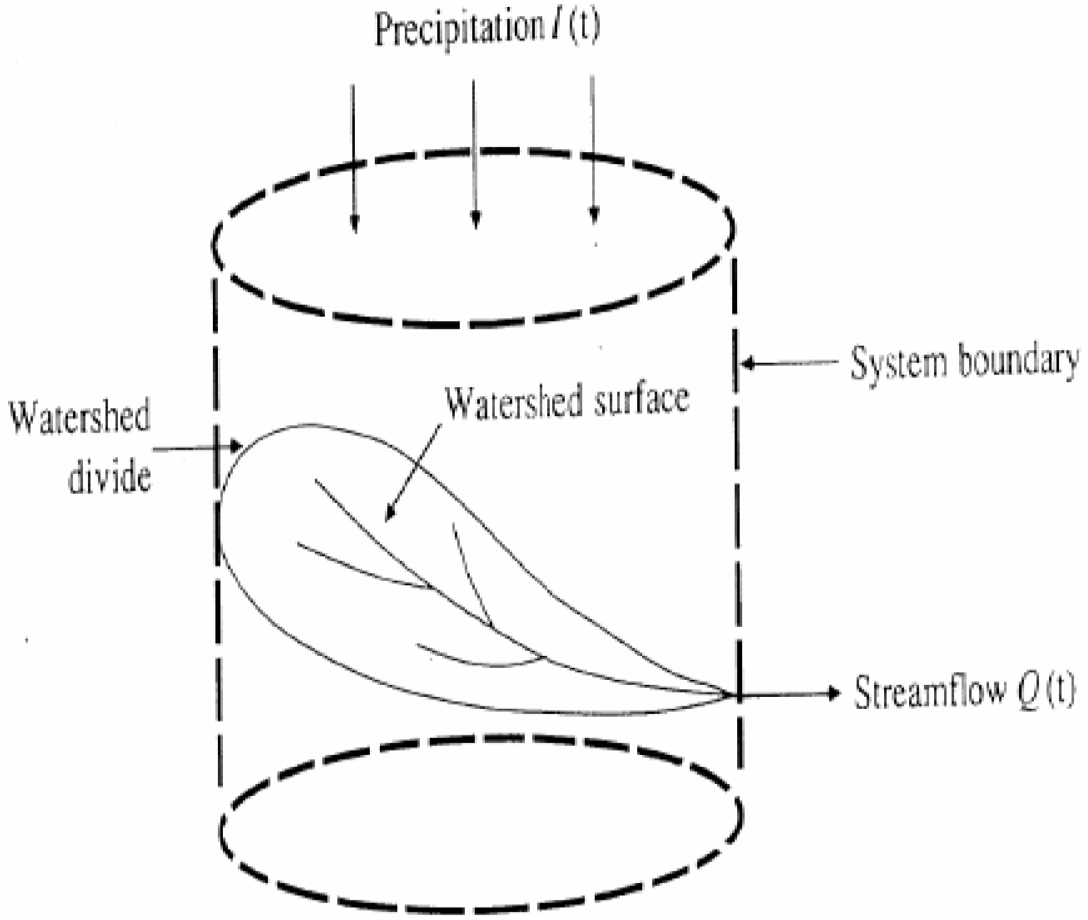


Rainfall-Runoff





Hydrograph



Classification of Hydrologic Models

Based on process representation (the nature of the algorithms)

- ❑ When evaluating models, it is useful to consider which processes must be physically based and which can be modelled conceptually

- ❑ Because deep underground processes are linear, damped and generally unaffected by climate change (outside of permafrost regions), they can often be modelled conceptually in models of surface hydrology.

Classification of Hydrologic Models

Based on process representation (the nature of the algorithms)

- **Statistical/stochastic**
  - Unconcerned with the representation of physical processes
  - They are intended to represent the distribution of a quantity (such as rainfall or streamflow) in space, time or frequency
  - Typically used for design of systems, or construction of future scenarios
  - Used for estimating seasonal stream flows, and the operation of irrigation or hydraulic structures (dams)
- **Deterministic**
  - They attempt to represent the behavior of a system by reproducing its properties
  - A given set of inputs and state variables will result in a single set of outputs
  - Usually divided into conceptual and physical models

Classification of Hydrologic Models

Based on process representation (algorithms)

- **Empirical/Black box**
  - involving mathematical equations that have been assessed, not from the physical processes in the catchment
- **Conceptual/grey box**
  - Do not attempt to reproduce the physical basis of hydrological processes
  - They generally use empirical relationships to simulate processes e.g. the use of degree day method for snowmelt
  - The parameters of conceptual models are arrived at by calibration, which consists of running the model repeatedly, while adjusting its parameters

Classification of Hydrologic Models

Based on process representation (the nature of the algorithms)

Physically based/white box

- Use physical science to describe hydrological processes and generally have physically identifiable parameters
- To the degree that the underlying science is accurate, physical models can be used under changing climates
- Typically, physical models require more meteorological input data than conceptual models, which makes them more difficult to use operationally
- Physically based models will have mostly measured parameters, particularly for surface hydrological processes

Classification of Hydrologic Models

Based on nature of spatial representation (by model scale)

- **Lumped**
  - Lumped models use a single set of state variables and parameters to represent entire basins or sub basins
  - These models are the simplest to use, requiring the smallest numbers of state variables, parameters and inputs
  - do not include comprehensive or appropriate representations of physical processes, as it is very difficult to do so at such large scales
  - have difficulty in accurately representing the response of a basin to a hydrological event that only affects part of the basin, such as a small convective storm.
  - cannot easily take advantage of the many available distributed data sets, such as surface elevations, soil textures and vegetation types, to set the model parameters
  - Lumped models require lumped precipitation inputs

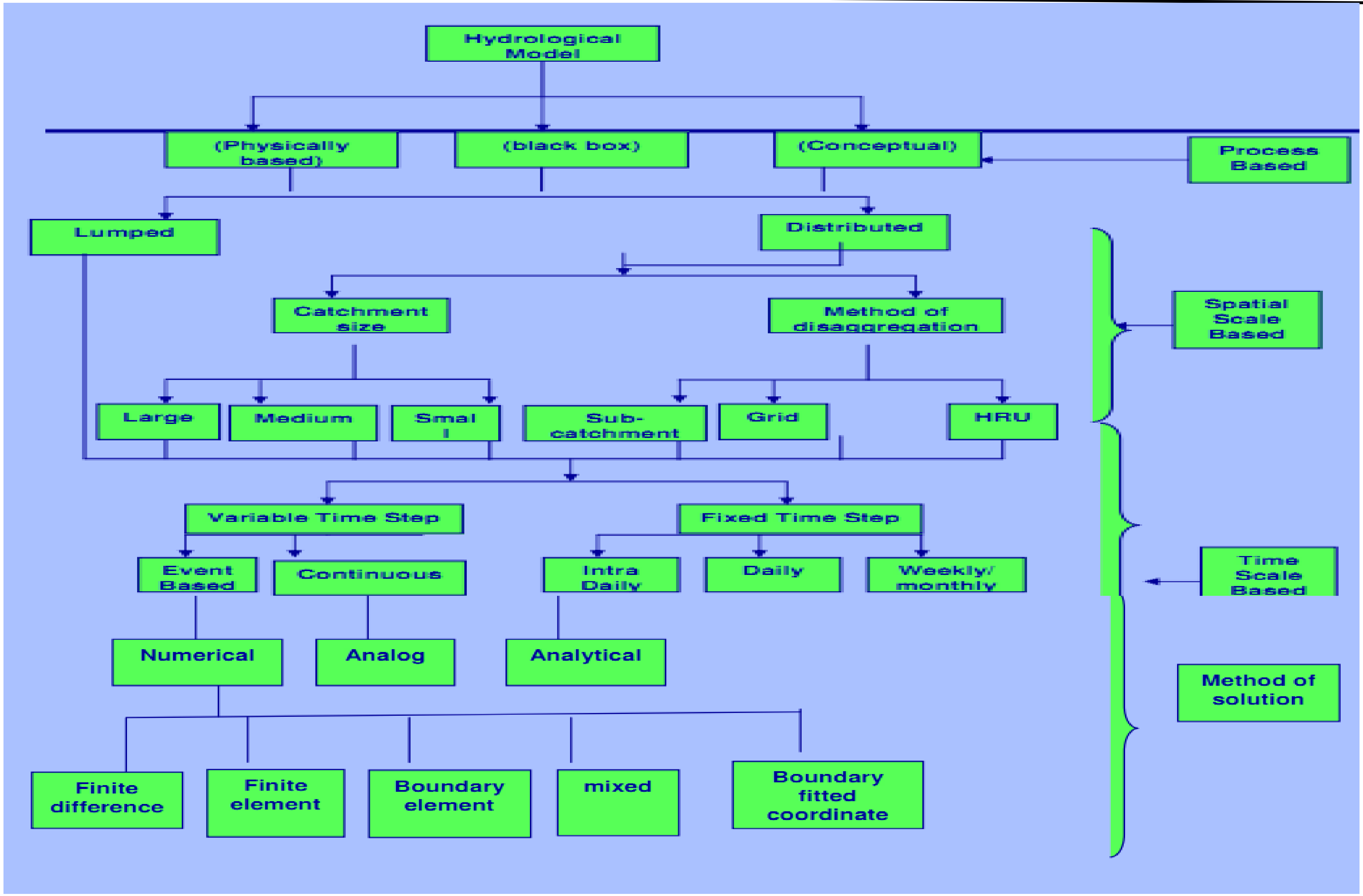
Classification of Hydrologic Models

- **Based on nature of spatial representation (model scale)**
  - **Semi-Distributed**
    - Semi-distributed models lie between lumped and distributed models in their level of complexity
    - They allow the representation of basins in a more realistic way than lumped models, with smaller requirements for parameters and forcing data than distributed models.
    - Typically, semi-distributed models aggregate landscape units of similar type (vegetation, soil, topography) within a basin to form hydrological response units (HRUs) or grouped response units (GRUs).
    - Each HRU or GRU has its own set of parameters
    - Because HRUs/GRUs are essentially fractions of a basin, they do not have a specific location
    - determination of the HRU parameters usually requires considerable GIS work

Classification of Hydrologic Models

- **Based on nature of spatial representation (by model scale)**
  - **Distributed**
    - Distributed models sub-divide basins into very small units, often based on a grid
    - they respond well to events which only occur in a very small part of the basin
    - Distributed models have the greatest number of state variables, and therefore the greatest number of parameter values
    - Distributed models should be forced with distributed meteorological data
    - Distributed hydrological models are very large and complex and can use very physically based algorithms
    - These models may require supercomputers, particularly as the models are being run at increasingly-fine scales

Diagram of Model Classification



Summary of Hydrological Models

Based on *process*, Hydrological Models can be classified:

1. Deterministic
2. Stochastic

Deterministic: permit only one outcome from a simulation with one set of inputs and parameter values.

Stochastic: allow for some randomness or uncertainty in the possible outcomes due to uncertainty in input variables, boundary conditions or model parameters.

Deterministic Models (forecast)

Classified according to the description given to the considered area:

Lumped:

considers the area as a whole/lumped.(*Semi-empirical)*

(Hydrological processes are considered similar in the watershed &

Most Lumped models are conceptual)

Distributed/semi: considers spacial variability of the hydrological process within the watershed.

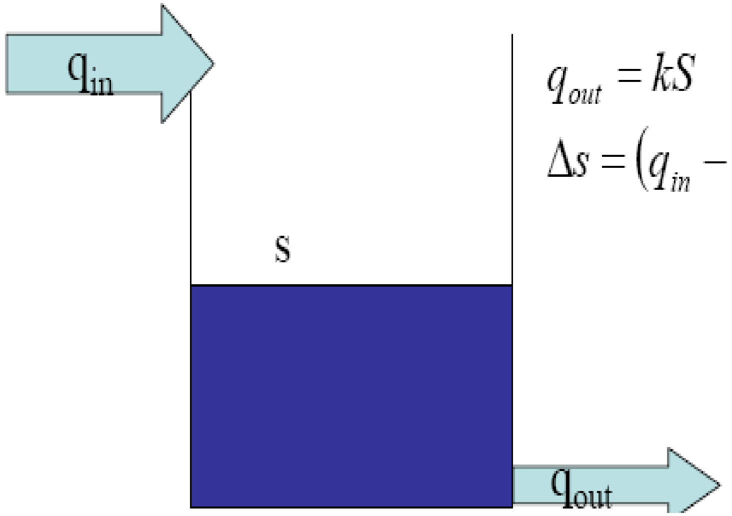
(Most distributed models are physically based)

Further, <u>Empirical models</u> exist by which analysis of concurrent input and output time series are the basis to derive not physical process.

Lumped Conceptual Models

Some characteristics:

- Considers the watershed as a single unit
- Parameters are averaged over the catchment
- Calibration required/ direct measurement of parameter value is less
- Mostly has less no. of parameters compared to distributed
- Relatively give good result in big areas
- Difficult to account changes/variability in the catchment



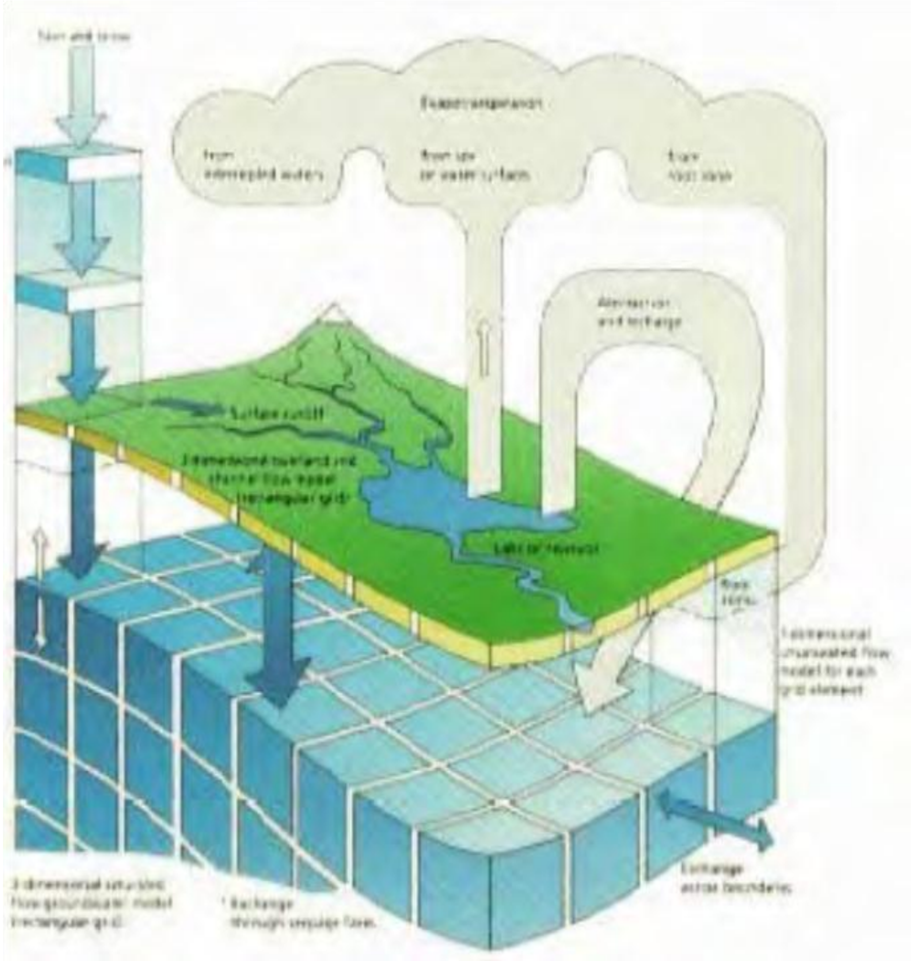
$$q_{out} = kS$$

$$\Delta s = (q_{in} - kS)\Delta t$$

Distributed Models

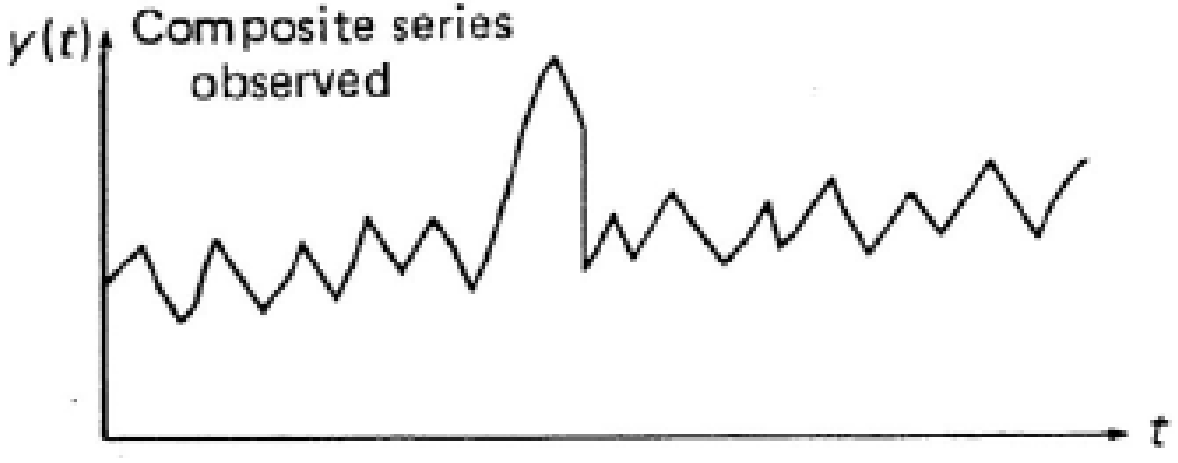
Some characteristics:

- Based on the governing equations of surface & sub-surface processes
- Define parameter value in each cell/mesh
- Can be easy in small catchments
- Can account changes in the catchment easily
- Made calibration difficult with observation
- Require many parameter



Stochastic Time Series Models (unpredicted)

- Considers uncertainties/randomness in input, boundary cond., parameters and output data.
- Derived from historic time series data analysis
- Statistically similar data series is synthesized



Topic: Discharge Computation/Black box

Objectives: At the end of this lesson, students will be able to:

- Mention and explain various methods of discharge computation/black box model
- Learn the steps to develop and draw the IDF curves
- Identify the various assumptions in rational methods
- Determine the design discharge

Empirical Models/*Black box*

Can be derived from observations, regression analysis,…

To design peak discharge

1. Rational method
2. SCS curve number method
3. Time-Area method

Other empirical formulas developed

Inglish Formula (1940)

$$Q_p = \frac{124A}{\sqrt{(A + 10.4)}}$$

Meyer formula(1926) in USA

$$Q_p = 175A^{0.5}$$

Coutagne formula

$$Q_p = 150A^{0.5}$$

and many other

Empirical model/Black box

- Black box models are empirical, involving mathematical equations that have been assessed, not from the physical processes in the catchment, but from analysis of concurrent input and output time series.
- The first of this kind of model was the ***Rational Method*** published by the Irish engineer Thomas James

Empirical model…..

- The model was a single simple equation often used for drainage design for small suburban and urban watersheds.
- The equation assumes the proportionality between peak discharge, q_{pk}, and the maximum average rainfall intensity, i_{eff}:
- $q_{pk} = C_R * i_{eff} * A_D$

  Where A_D is drainage area and C_R is the runoff coefficient, which depends on watershed land use.
- *The duration of the rainfall to be used in the equation is the mean intensity of precipitation for duration equal to the time of concentration and an exceedence probability of P.*

Rational Method

- The most common method, given by:

$$Q_p = \frac{1}{3.6} C . i_{tc,p} . A$$

Where:

Q_p = Peak flow(m^3/s)

C = Dimensionless runoff coefficient

$i_{tc,p}$ = Mean intensity of precipitation (mm/h) for a duration equal to t_c and an exceedence probability of P

A= Drainage area in km^2

Assumptions in Rational Method

- The peak flow occurs when the entire watershed is contributing to the flow
- The rainfall intensity is the same over the entire drainage area
- The rainfall intensity is uniform over a time duration equal to the time of concentration, tc
- The frequency of the computed peak flow is the same as that of the rainfall intensity, i.e., the 10-yr rainfall intensity is assumed to produce the 10-yr peak flow
- The coefficient of runoff is the same for all storms of all recurrence probabilities

Because of these inherent assumptions, the Rational Formula should only be applied to drainage areas smaller than 50km^2.

Runoff Coefficient

- Accounts for different land cover, slope, storm type,…
- The value ranges from 0.05(flat sandy area) to 0.95(impervious surface)
- Areal weighted average is taken for mixed drainage covers

$$C = \frac{\sum(C_x\, A_x)}{A_{total}}$$

- C_x indicates runoff coefficient for the part of the watershed(A_x) with the same land cover

Factors affecting C

- Initial losses
- Nature of the soil
- Surface slope
- Degree of saturation
- Rain fall intensity
- Geology of the catchment

Time of Concentration

- The time required by the flow to traverse from the most remote area to the measurement/outlet point of the watershed.
  - ✓ *Can be calculated by using equations for the respective consecutive flow types:*
    - ✓ equation given by Kirpich (1940).

$$t_c = 0.02\,L^{0.77}\ S^{-0.385}$$

where t_c is time of concentration in min, L is the maximum length of travel of water along the water course in meter and S is the slope expressed as the ratio of difference in elevation between the remotest point and the catchment outlet to the length L.

- ✓ *Haan et al (1982) proposed for small watershed smaller than 5 sq.km*

$$T_c = 0.02\,L^{0.77}\cdot S^{-0.385} + \left[\frac{2\,L_0\sqrt{n}}{S_0}\right]^{0.467}$$

Where, L_0 = length of overland flow, m

n = Manning's roughness coefficient

S_0 = Slope along the flow path, m/m

Time of Concentration

Sheet flow travel time: Sheet flow is the shallow mass of runoff on a planar surface with a uniform depth across the sloping surface. This usually occurs at the head water of streams over relatively short distances, rarely more than about 90m and possibly less than 25m.Sheet flow is commonly estimated with a version of the kinematic wave equation, a derivative of manning's equation as follows.

$$T_{ti} = \frac{K_c}{I^{0.4}}\left(\frac{nL}{\sqrt{S}}\right)^{0.6}$$

Shallow concentrated flow velocity: After short distance of at most 90m, sheet flow tends to concentrates in rills and then gullies of increasing proportions. Such flow is usually referred to as shallow concentrated flow. The velocity of such flow can be estimated using a relationship between velocity and slope as follows.

$$V = kS_p^{0.5}$$

Where: V=velocity (m/s), k=intercept coefficients'=slope

Open Channel and pipe flow velocity: Flow in gullies empties in to channels or pipes. Open channel flow is assumed to begin where the stream follows and defined path and becomes visible /significant. Manning's equation can be used to estimate average flow velocities in pipe and open channels.

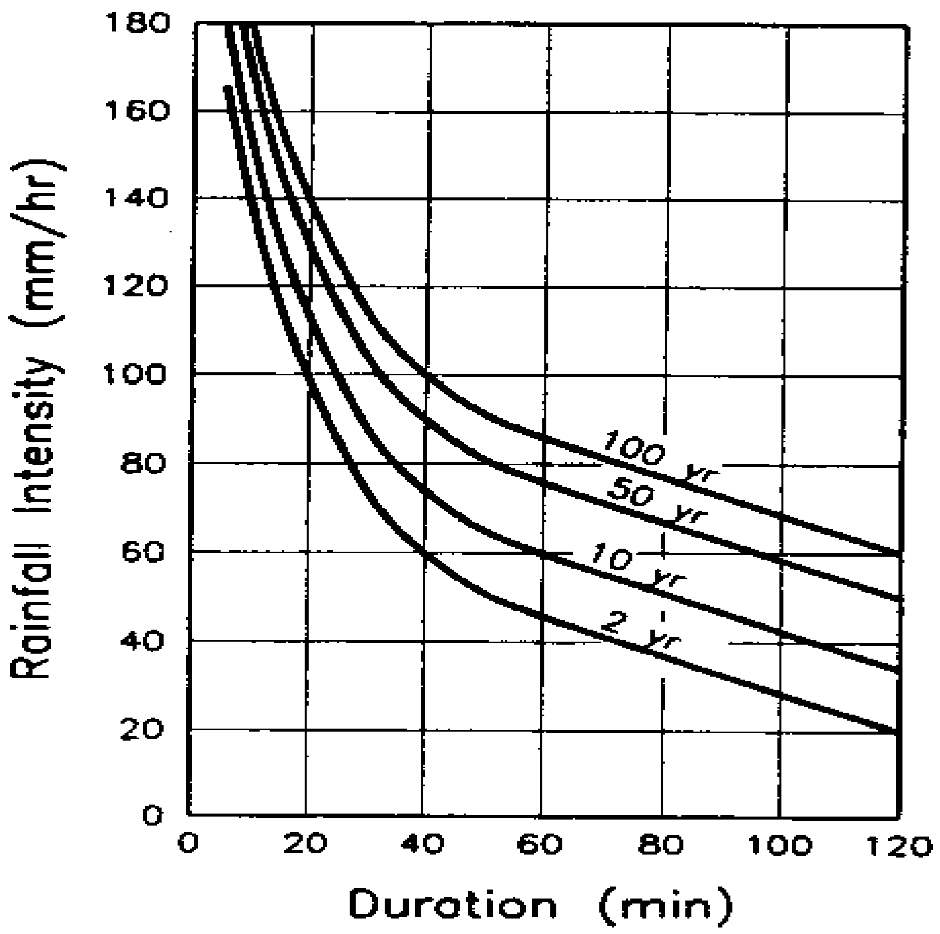
$$V = \frac{K_c}{n} * R^{2/3} S^{1/2}$$

Rainfall Intensity

- To estimate the peak flow with exceedence *p* (Q_p), the corresponding rainfall intensity with exceedence *p* and duration *t* is required ($i_{tc,p}$)

- $i_{tc,p}$ is assumed to be constant in the whole watershed for a period of t_c

- So that to use rational method, Intensity duration curves(IDF) need to be developed.



A sample IDF curve

Intensity

- Once the concentration time has been determined, the rainfall intensity can be determined using the *intensity-duration-frequency* relation applicable to the catchment area in question using eq.
- $$I = CT_r^{\,a}(t+b)^{-d} \qquad I = \frac{C\,T_r^{\,a}}{(t+b)^d}$$
- Where T_r is the return period in years t, duration of rain fall and C, b and d are regression constants for a given location

47

IDF development procedure

To develop the IDF curves

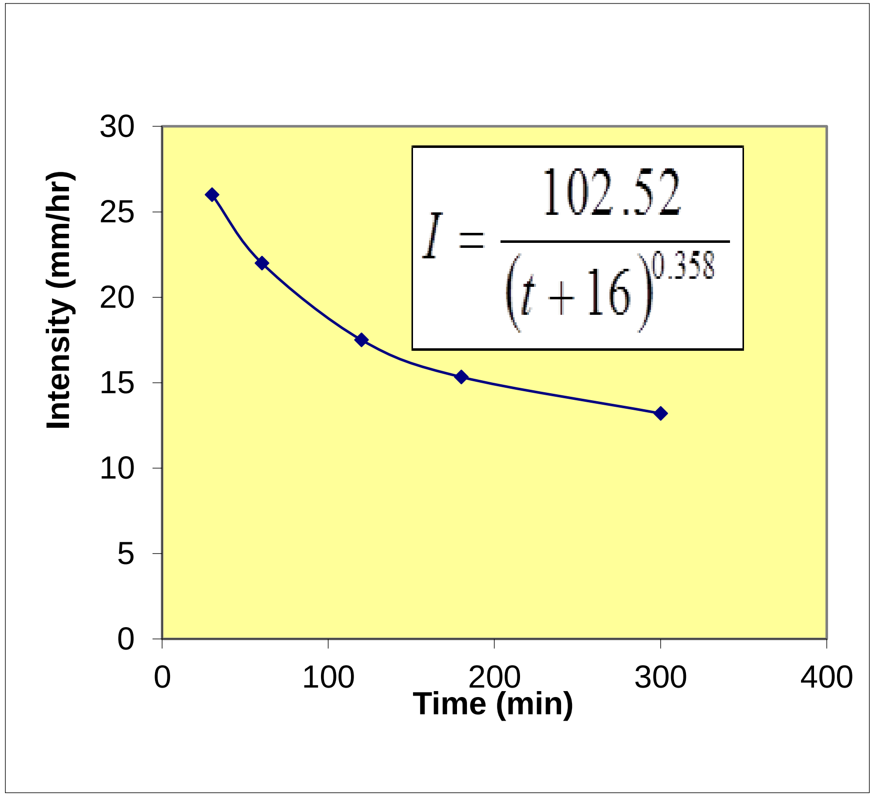
- Select a specific rainfall duration for a certain year
- For each year and the selected duration find the maximum rainfall and put it in descending order
- Calculate return period T = N/M
- Repeat the above step but different rainfall duration
- Compute intensity that correspond the different then select for specific frequency

Example: IDF

$$I = \frac{a}{(t+b)^c}$$

Intensity duration Frequency curve

Time (hr)	Rainfall (mm)	30 min	1 hr	2 hr	3 hr	5 hr
10:00:00	0					
10:30:00	6	6				
11:00:00	11	5	11			
11:30:00	16	5	10			
12:00:00	24	8	13	24		
12:30:00	29	5	13	23		
13:00:00	38	9	14	27	38	
13:30:00	51	**13**	**22**	**35**	45	
14:00:00	57	6	19	33	**46**	
14:30:00	61	4	10	32	45	
15:00:00	66	5	9	28	42	**66**
15:30:00	67	1	6	16	38	61
16:00:00	67	0	1	10	29	56
Max. Intensity (mm/hr)		26	22	17.5	15.33333333	13.2



Example

- The various data were obtained for rains of various durations at a station for 31 years.
- The records were analyzed and eleven worst storms of various duration have been stipulated in their decreasing order as shown below
- Plot the intensity-Duration curves for storms of frequencies

5min		10min		15 min		30 min		60min		90 min		120 min	
Year	ppt	Year	ppt	Year	ppt	Year	ppt	Year	ppt	Year	ppt	Year	ppt
1908	0.85	1908	1.20	1908	1.40	1908	1.74	1908	2.15	1908	2.46	1915	2.97
1921	0.76	1915	1.04	1915	1.18	1915	1.55	1915	1.92	1915	2.38	1908	2.63
1915	0.73	1921	0.93	1904	1.11	1915	1.36	1915	1.70	1904	2.14	1904	2.34
1934	0.72	1904	0.88	1921	1.03	1921	1.22	1926	1.45	1921	1.81	1921	2.12
1929	0.66	1926	0.84	1926	0.97	1926	1.18	1921	1.40	1926	1.65	1926	1.83
1926	0.62	1934	0.80	1934	0.92	1931	1.10	1914	1.33	1914	1.50	1917	1.64
1931	0.51	1929	0.78	1929	0.90	1934	1.05	1931	1.25	1931	1.40	1914	1.55
1904	0.45	1931	0.68	1931	0.82	1929	1.01	1934	1.20	1917	1.36	1931	1.51
1917	0.36	1911	0.52	1911	0.67	1911	0.95	1929	1.14	1934	1.34	1934	1.46
1914	0.28	1917	0.51	1917	0.62	1917	0.83	1911	1.11	1929	1.27	1929	1.41
1911	0.21	1914	0.39	1914	0.50	1914	0.79	1917	1.09	1911	1.23	1911	1.34

Solution

First of all calculate the frequency of varies storms using

$$T = \frac{m}{N}$$

S.No	5 minute ppt(cm)	10 min ppt(cm)	15 min ppt(cm)	30 min ppt(cm)	60 min ppt(cm)	90 min ppt(cm)	120min ppt(cm)	M= ranking of storm	T=Frequency =N/m
1	0.85	1.20	1.40	1.74	2.15	2.46	2.97	1	11
2	0.76	1.04	1.18	1.55	1.92	2.38	2.63	2	5.5
3	0.73	0.93	1.11	1.36	1.70	2.14	2.34	3	3.7
4	0.72	0.88	1.03	1.22	1.45	1.81	2.12	4	2.8
5	0.66	0.84	0.97	1.18	1.40	1.65	1.83	5	2.2
6	0.62	0.80	0.92	1.10	1.33	1.50	1.64	6	1.8
7	0.51	0.78	0.90	1.05	1.25	1.40	1.55	7	1.6
8	0.45	0.68	0.82	1.01	1.20	1.36	1.51	8	1.4
9	0.36	0.52	0.67	0.95	1.14	1.34	1.46	9	1.2
10	0.28	0.51	0.62	0.83	1.11	1.27	1.41	10	1.1
11	0.21	0.39	0.50	0.79	1.09	1.23	1.34	11	1.0

- Average Intensity for different durations such as 5,10,15,30,60,90and 120 minutes are then worked out for different frequencies.
- For example take 11,1.4 and 1.0 years frequencies

For frequency=11 years

Duration in minutes (1)	Ppt in cm (2)	Av.intensityin cm/hr col(2)*60/col (1) (3)
5	0.85	0.85*60/5=12.20
10	1.2	1.2*60/10=7.20
15	1.4	1.4*60/15=5.6
30	1.74	1.74*60/30=3.88
60	2.15	2.15*60/60=2.15
90	2.46	2.46*60/90=1.64
120	2.97	2.97*60/120=1.42

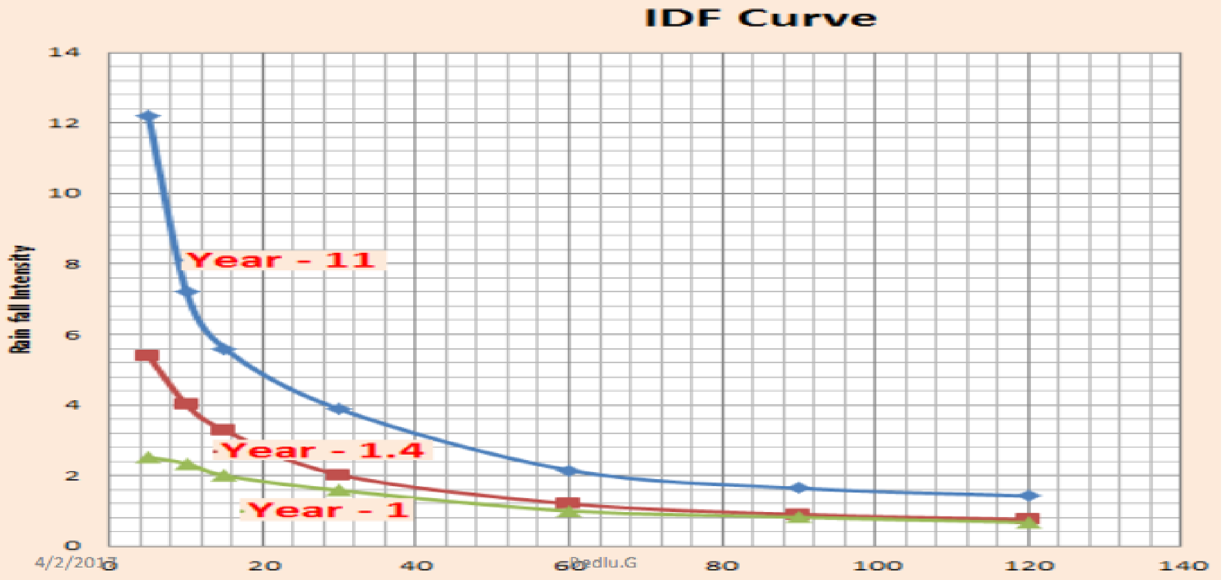
For frequency=1.0 years

Duration in minutes (1)	Ppt in cm (2)	Av.intensityin cm/hr col(2)*60/col (1) (3)
5	0.21	0.21*60/5=2.52
10	0.39	0.39*60/10=2.34
15	0.50	0.50*60/15=2.00
30	0.79	0.79*60/30=1.58
60	1.09	1.09*60/60=1.00
90	1.23	1.23*60/90=0.82
120	1.34	1.34*60/120=0.67

For frequency=1.4 years

Duration in minutes (1)	Ppt in cm (2)	Av.intensityin cm/hr col(2)*60/col (1) (3)
5	0.45	0.45*60/5=5.40
10	0.68	0.68*60/10=4.01
15	0.82	0.82*60/15=3.28
30	1.01	1.01*60/30=2.02
60	1.20	1.20*60/60=1.20
90	1.36	1.36*60/90=0.90
120	1.51	1.51*60/120=1.42

- The three curves corresponding to three frequencies can then be plotted by using the above values



Derivation of IDF equation

- The IDF formulae are the empirical equations representing a relationship between maximum rainfall intensity as a dependent variable and other parameters of interest; for example the rainfall duration and frequency as independent variables.
- There are several commonly used functions relating those variables which found in the literature of hydrology applications (see Chow (1988).
- To derive an equation for calculating the rainfall intensity (I) for the regions of interest, there are some required steps for establishing an equation to suit the calculation of rainfall intensity for a certain recurrence interval and specific rainfall period which depends mainly on the results obtained from the IDF curves. Two approaches were tried to estimate the equation parameters;
- By applying the logarithmic conversion, where it is possible to convert the equation into a linear equation, and thus to calculate all the parameters related to the equation.

Table 1.2: Intercept coefficients for velocity versus slope relationship

Land cover/flow regime	k
Forest with heavy ground litter; hay meadow (overland flow).	0.076
Trash fallow or minimum tillage cultivation; contour or strip cropped; woodland (overland flow).	0.152
Short grass pasture (overland flow).	0.213
Cultivated straight row (overland flow).	0.274
Nearly bare and untilled (overland flow); alluvial fans in western mountain regions.	0.305
Grassed waterway (shallow concentrated flow).	0.457
Unpaved (shallow concentrated flow).	0.491
Paved area (shallow concentrated flow); small upland gullies.	0.619

Table 1.3: Manning's Roughness coefficient (n) for overland flow

Surface Description	n
Smooth asphalt	0.011
Smooth concrete	0.012
Ordinary concrete lining	0.013
Good wood	0.014
Brick with cement mortar	0.014
Vitrified clay	0.015
Cast iron	0.015
Corrugated metal pipe	0.024
Cement rubble surface	0.024
Fallow (no residue)	0.05
Cultivated soils	
Residue cover ≤ 20%	0.06
Residue cover > 20%	0.17
Range (natural)	0.13
Grass	
Short grass prairie	0.15
Dense grasses	0.24
Bermuda grass	0.41
Woods*	
Light underbrush	0.40
Dense underbrush	0.80

SCS Curve Number Method

- Calculates peak flow rate Q_p(mm) based on **drainage area**, **potential watershed storage** and **time of concentration**.

$$\mathbf{Q = (P - I_a)^2 / (P - I_a) + S} \quad \textit{flow depth}, \ Q_D(\text{mm}), \quad I_a = 0.2S$$

$$Q_D = \frac{(P - 0.2S_R)^2}{P + 0.8S_R}$$

The retention storage S_R (mm) is given by

$$S_R = 25.4\left[\frac{1000}{CN} - 10\right]$$

- CN is a curve number found in literatures. CN is given as a function of land use and hydrological soil group. *For mixed land cover areal average is used.*

$$q_p = q_u \, A_k \, Q_D$$

Unit peak flow q_u,

$$q_u = 0.000431 \times 10^{C_0 + C_1 \log t_c + C_2 [\log(t_c)]^2}$$

Additional correction factor is used to account for extreme ponding

$$q_a = q_p \, F_p$$

limitation

- Neither channel nor reservoir routing can be incorporated
- Basin should have one main channel or with nearly equal concentration time
- I_a/p should be 0.1-0.5
- T_c should be 0.1-10hr
- CN should be greater than 40
- Basin should have fairly homogenous CN vales

Hydrologic soil group based on infiltration rate

- *Group A*: Sand, loamy sand or sandy loam. Soils having a low runoff potential due to high infiltration rates. These soils primarily consist of deep, well-drained sands and gravels.
- *Group B*: Silt loam, or loam. Soils having a moderately low runoff potential due to moderate infiltration rates. These soils primarily consist of moderately deep to deep, moderately well to well drained soils with moderately fine to moderately coarse textures.
- *Group C*: Sandy clay loam. Soils having a moderately high runoff potential due to slow infiltration rates. These soils primarily consist of soils in which a layer exists near the surface that impedes the downward movement of water or soils with moderately fine to fine texture.
- *Group D*: Clay loam, silty clay loam, sandy clay, silty clay or clay. Soils having a high runoff potential due to very slow infiltration rates. These soils primarily consist of clays with high swelling potential, soils with permanently-high water tables, soils with a

Limitation of the SCS Method

- The basin should be fairly homogeneous CN value
- CN should be ≥ 40
- I_c should be between 0.1and 10hr
- I_a/p should be between0.1and 00.5
- Basin should have one main channel or branches with nearly equal times of concentration
- Neither channel nor reservoir routing can be incorporated
- F_p factor is applied only for pond and swamps that are not in the t_c flow path

Land Use Description	Average % impervious	Curve Numbers for Hydrologic Soil Group A	B	C	D
Fully developed urban areas (vegetation established)					
Lawns, open spaces, parks, golf courses, cemeteries, etc.					
Good condition; grass cover on 75% or more of the area		39	61	74	80
Fair condition; grass cover on 50 to 75% of the area		49	69	79	84
Poor condition; grass cover on 50% or less of the area		68	79	86	89
Paved parking lots, roofs, driveways, etc. (excl. right-of-way)		98	98	98	98
Streets and roads					
Paved with curbs and storm sewers (excl. right-of-way)		98	98	98	98
Gravel (incl. right-of-way)		76	85	89	91
Dirt (incl. right-of-way)		72	82	87	89
Paved with open ditches (incl. right-of-way)		83	89	92	93
Commercial and business areas	85	89	92	94	95
Industrial districts	72	81	88	91	93
Row houses, town houses, and residential with lots sizes 1/8 acre or less	65	77	85	90	92
Residential: average lot size					
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 acre	12	46	65	77	82
Developing urban areas (no vegetation established)					
Newly graded area		77	86	91	94
Western desert urban areas:					
Natural desert landscaping (pervious areas only)		63	77	85	88
Artificial desert landscaping (impervious weed barrier, desert shrub with 1- to 2-in sand or gravel mulch and basin borders).		96	96	96	96
Cultivated agricultural land					
Fallow					
Straight row or bare soil		77	86	91	94
Conservation tillage Poor		76	85	90	93
Conservation tillage Good		74	83	88	90

Table 1.4: Coefficients for SCS peak Discharge Method

Rainfall type	I_a/P	C_0	C_1	C_2
I	0.10	2.30550	-0.51429	-0.11750
	0.20	2.23537	-0.50387	-0.08929
	0.25	2.18219	-0.48488	-0.06589
	0.30	2.10624	-0.45695	-0.02835
	0.35	2.00303	-0.40769	-0.01983
	0.40	1.87733	-0.32274	0.05754
	0.45	1.76312	-0.15644	0.00453
	0.50	1.67889	-0.06930	0.0
IA	0.10	2.03250	-0.31583	-0.13748
	0.20	1.91978	-0.28215	-0.07020
	0.25	1.83842	-0.25543	-0.02597
	0.30	1.72657	-0.19826	0.02633
	0.50	1.63417	-0.09100	0.0
II	0.10	2.55323	-0.61512	-0.16403
	0.30	2.46532	-0.62257	-0.11657
	0.35	2.41896	-0.61594	-0.08820
	0.40	2.36409	-0.59857	-0.05621
	0.45	2.29238	-0.57005	-0.02281
	0.50	2.20282	-0.51599	-0.01259
III	0.10	2.47317	-0.51848	-0.17083
	0.30	2.39628	-0.51202	-0.13245
	0.35	2.35477	-0.49735	-0.11985
	0.40	2.30726	-0.46541	-0.11094
	0.45	2.24876	-0.41314	-0.11508
	0.50	2.17772	-0.36803	-0.09525

Example 1.1: The following existing and proposed land uses are obtained form certain catchment. Find the weightage runoff coefficient for the existing and proposed land conditions

Existing Condition			**Proposed condition**		
Land use	Area,ha	Runoff coeff.	Land use	Area,ha	Runoff coeff.
Unimproved grass	8.95	0.25	Paved	2.20	0.9
Grass	8.60	0.22	Lawn	0.66	0.15
			Unimproved grass	7.52	0.25
			Grass	7.17	0.22

Example 1.2:

1	25	0.005	Short grass pasture
2	43	0.005	Short grass pasture
3	79	0.006	Grassed waterway
4	146	0.008	380mm concrete pipe

Calculate time of concentration for each segment.

Example 2.3: The following physical and Hydrological conditions are obtained from certain catchment a rift valley basin.

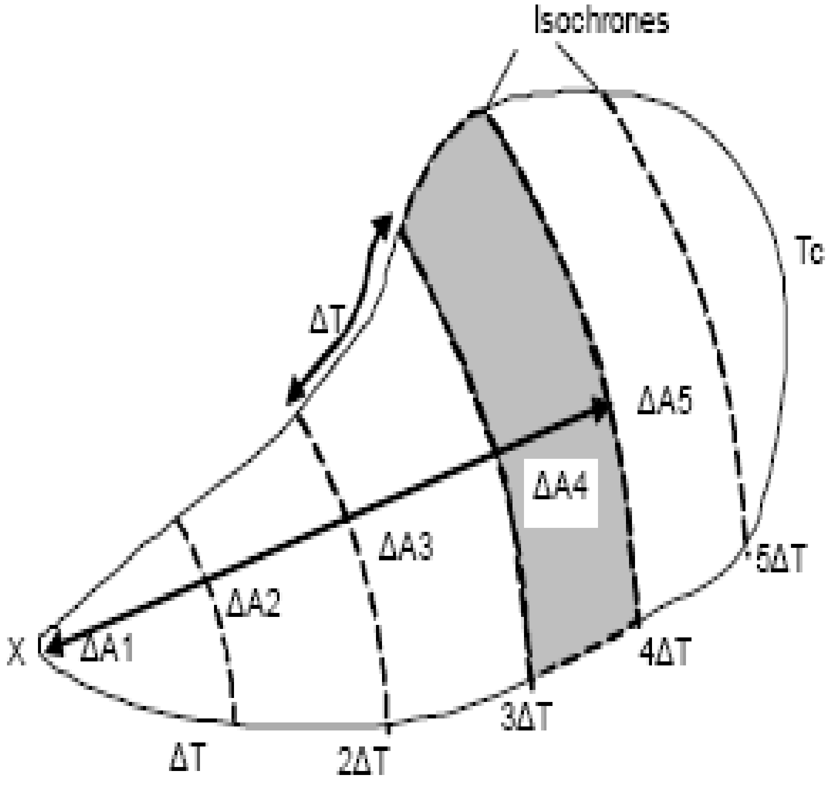
→ 3.3 sq.km of fair condition open space and 2.8sq.km of large lot residential
→ Negligible pond and swamp land
→ Hydrologic soil type C
→ Average antecedent moisture conditions
→ Time of concentration is 0.8hr
→ 24hr,type II rainfall distribution of 10years return period is 150mm

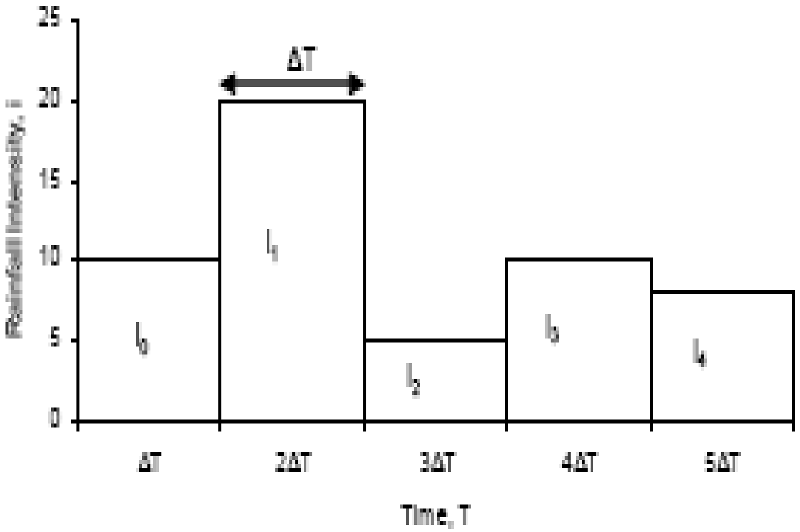
Find the 10years peak flow using SCS method.

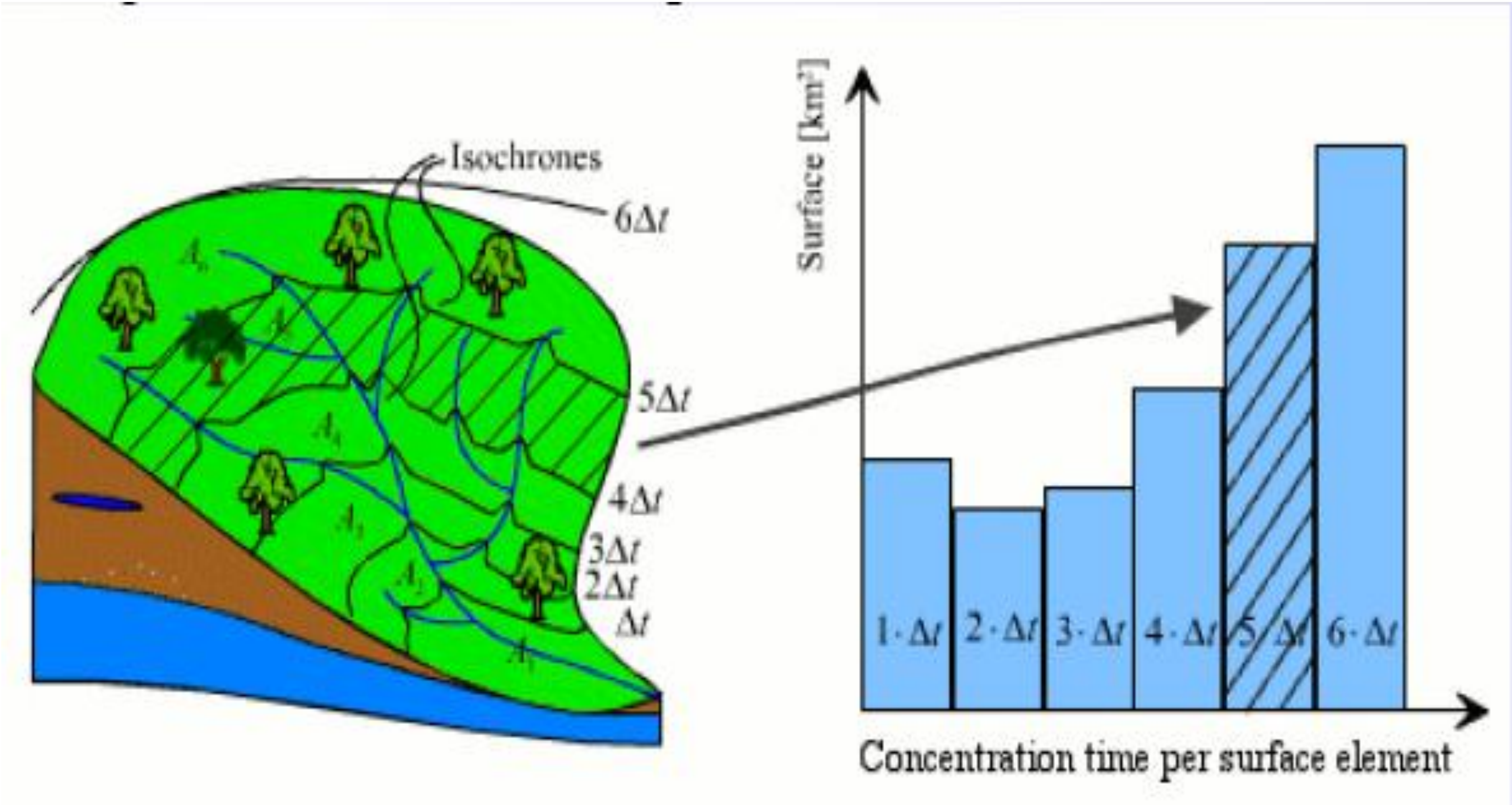
Time-Area Method

The watershed is divided in to areas with the same time of travel *(**isochrones**-time contours)* ***Its modified rational formula***

- Can be used to estimate the hydrograph






Isochrones
6Δt
5Δt
4Δt
3Δt
2Δt
Δt
Surface [km²]
1 · Δt
2 · Δt
3 · Δt
4 · Δt
5 · Δt
6 · Δt
Concentration time per surface element

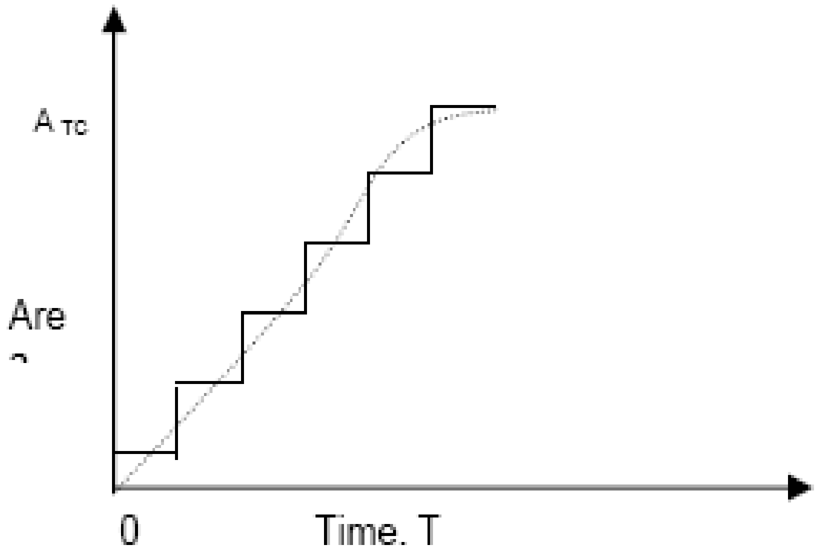
Time-Area Method

The equation is given by:

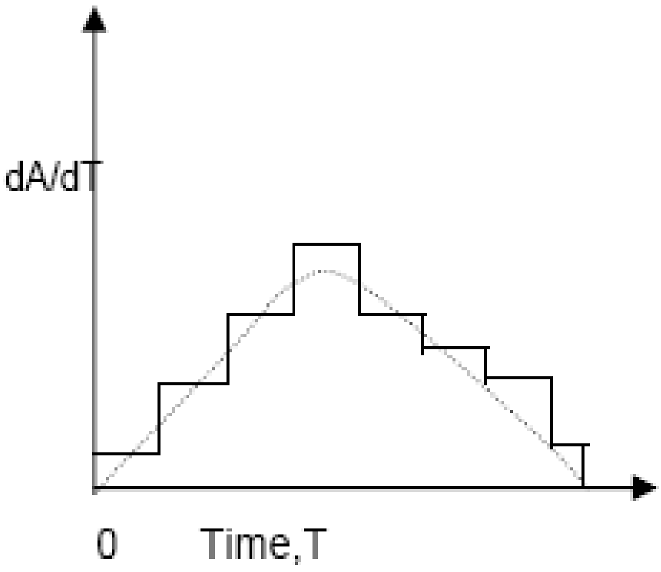
$$Q_T = \sum_{k=1}^{T} i_{(T-K)} \, \Delta A_{(k)}$$

So that considering T4

$$Q_4 = I_3 \, \Delta A_1 + i_2 \Delta A_2 + i_1 \Delta A_3 + i_0 \, \Delta A_4$$



b) Time-area curve

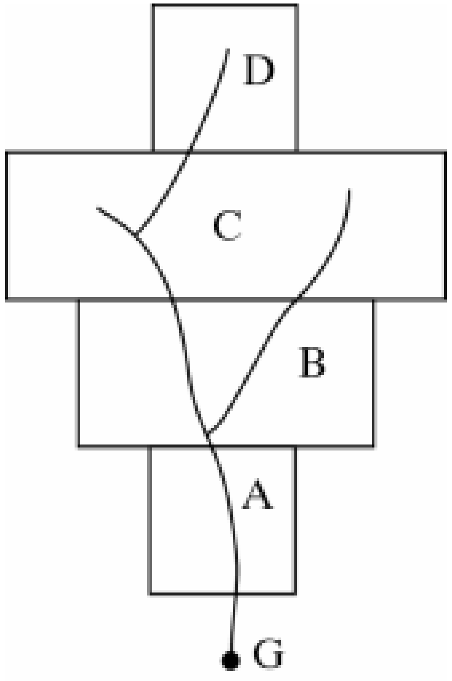


c) Time-area concentration curve

Example.1.4:

A watershed is divided into sections as shown below. Runoff from each section will contribute to flow at gauge G as indicated in the table.

For an <u>excess</u> rainfall intensity of 0.5 in/hr falling uniformly for 5 hrs, determine the resulting direct runoff hydrograph (DRO).



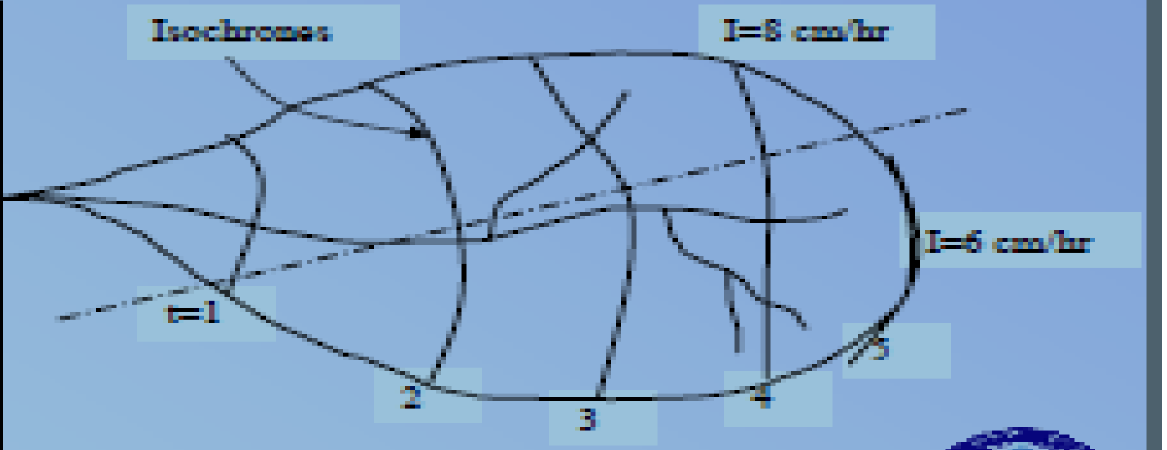
	A	B	C	D
Area [ac]	100	200	300	100
Time to G [hr]	1	2	3	4

Time	Hyeto. coord.	Basin	time to G	Area	$P_1 A_n$	$P_2 A_n$	$P_3 A_n$	$P_4 A_n$	$P_5 A_n$	Hydro graph
0										0
1	0.5	A	1	100	50					50
2	0.5	B	2	200	100	50				150
3	0.5	C	3	300	150	100	50			300
4	0.5	D	4	100	50	150	100	50		350
5	0.5					50	150	100	50	350
6							50	150	100	300
7								50	150	200
8									50	50
9										0

Home study

1. On a catchment where the travel time concept can be applied, a rain of two hours precipitated. An analysis of the depths shows that due to some orographic effect the area can roughly be divided into two rainfall zones. The upper zone in the figure receives 8 cm/hr as average net intensity; the lower one gets 6 cm/hr. the isochrones are also indicated in the figure. Assume runoff coefficient for upper zone and lower zone are 0.5 and 0.7 respectively. The areas in between isochrones are:

Travel time Hours	Area (square kilometers)	
	Upper zone	Lower zone
0 –1	5.0	1.1
1 –2	7.1	4.8
2 –3	4.4	4.6
3 –4	2.9	6.1
4 –5	1.1	4.8



Compute the first five ordinates of the direct runoff generated by the given storm of 2 hours.

Home study

- A watershed is 40% wooded (good condition) and 60% residential (1/4-ac lots). The watershed has 50% soil group B and 50% soil group C. Determine the runoff volume if the rainfall is 7 in. Assume antecedent moisture condition number II.

Land Use	Soil Group	Fraction of Area	CN
Wooded	B	0.4(0.5) = 0.2	55
	C	0.4(0.5) = 0.2	70
Residential	B	0.6(0.5) = 0.3	75
	C	0.6(0.5) = 0.3	83

Thank You !!!