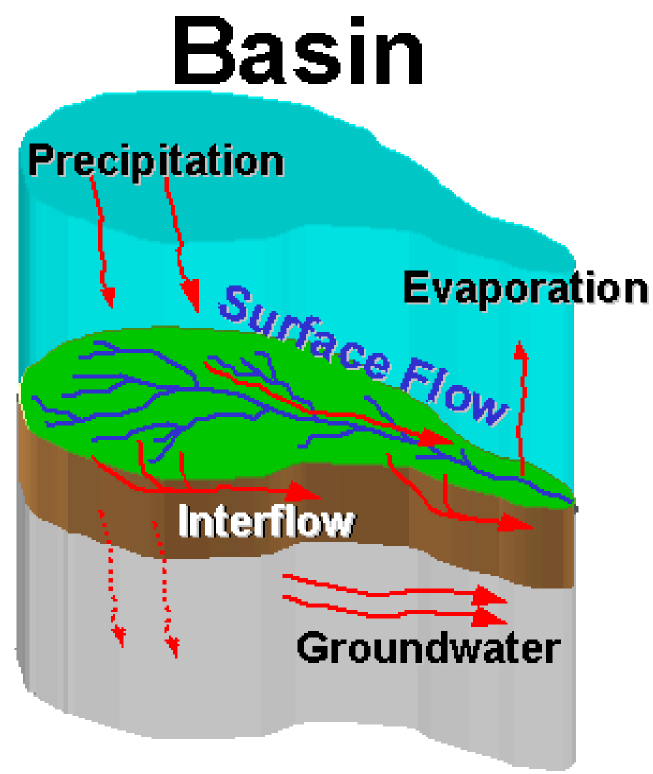
Chapter 2
Hydrologic Processes

Basin Characteristics

- Basin characteristics define system's response.

- For any section on a river, the area above that section which gives all its surface waters to this river passing through that section is called the basin (drainage basin, catchment, watershed)



Basin Characteristics

Geomorphologic Characteristics
- Area
- Shape
- Slope

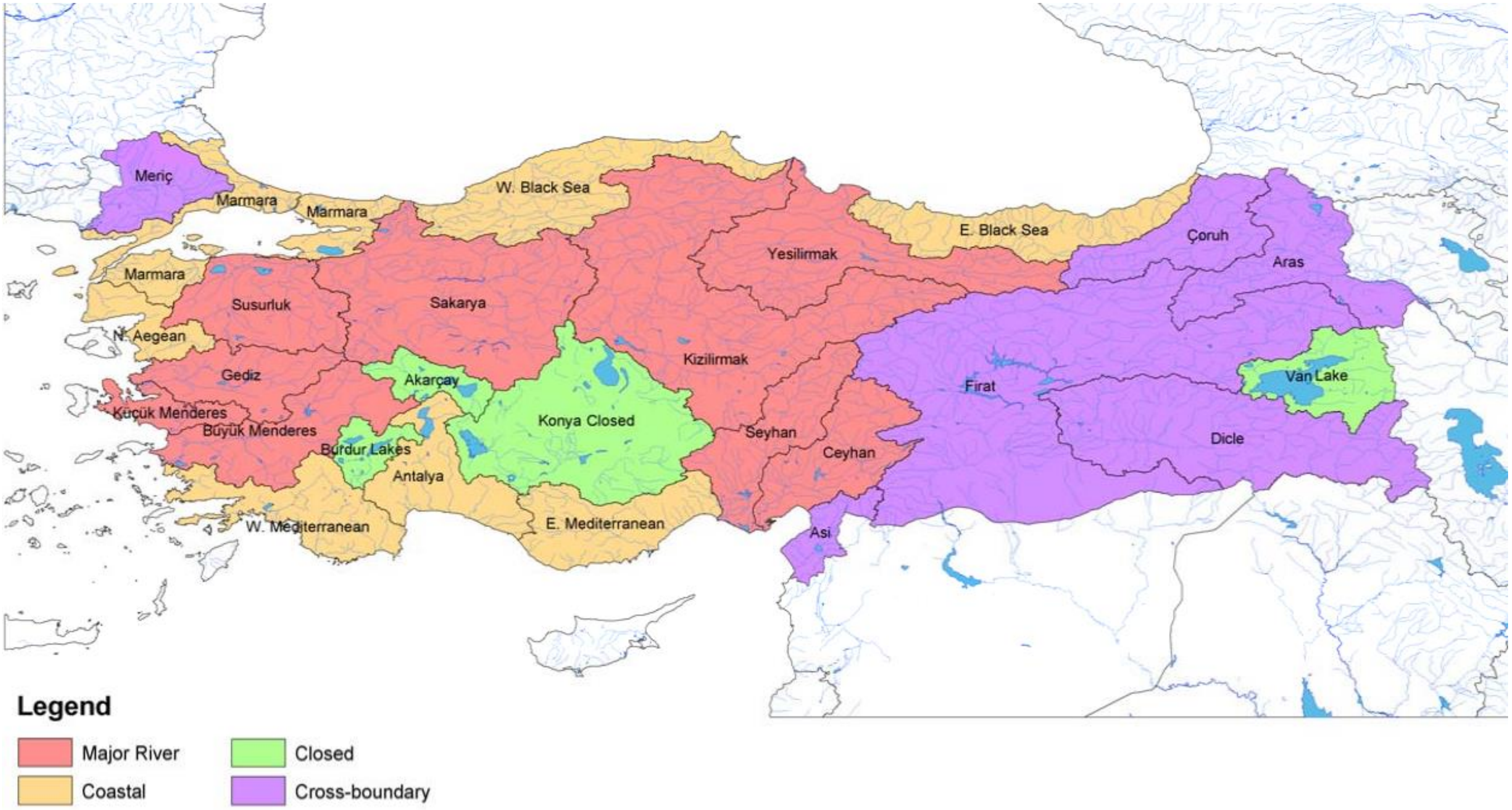
constant

Hydrologic Characteristics
- Stream shape
- Infiltration capacity
- Vegetal cover
- Soil physics

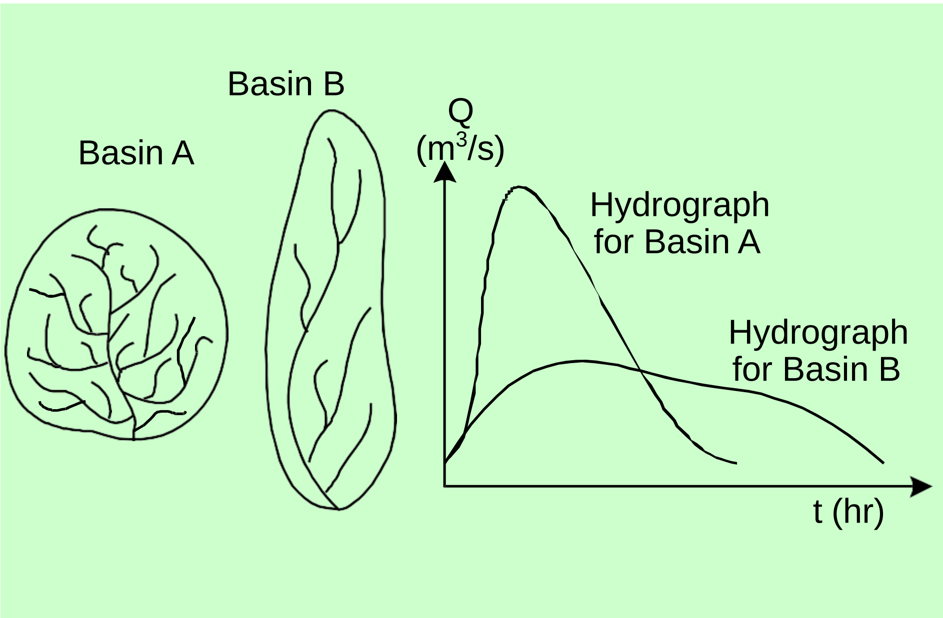
change with time
(i.e. one storm to another, one season to the next)

Perimeter = Boundary = Basin Divide (Passes through highest points between adjacent basins)

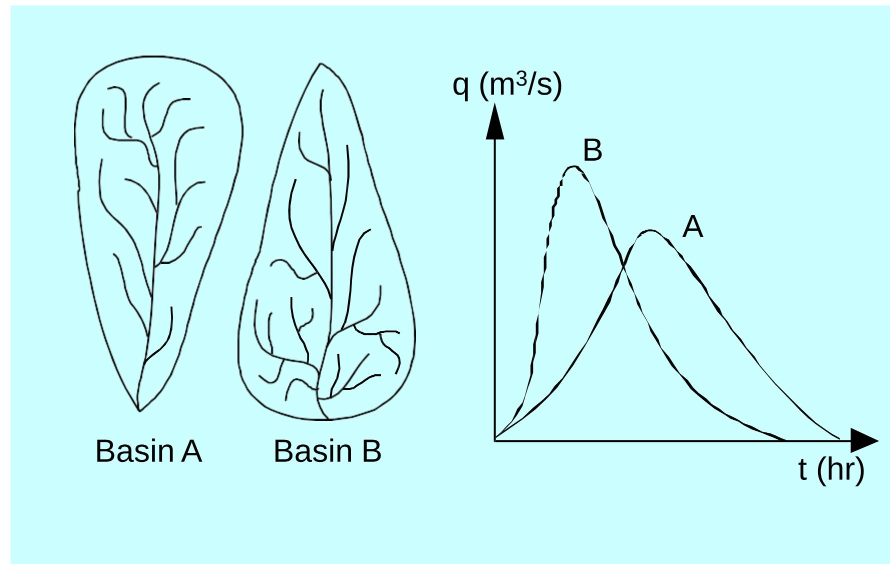
Situation in Turkey



Shape & Orientation



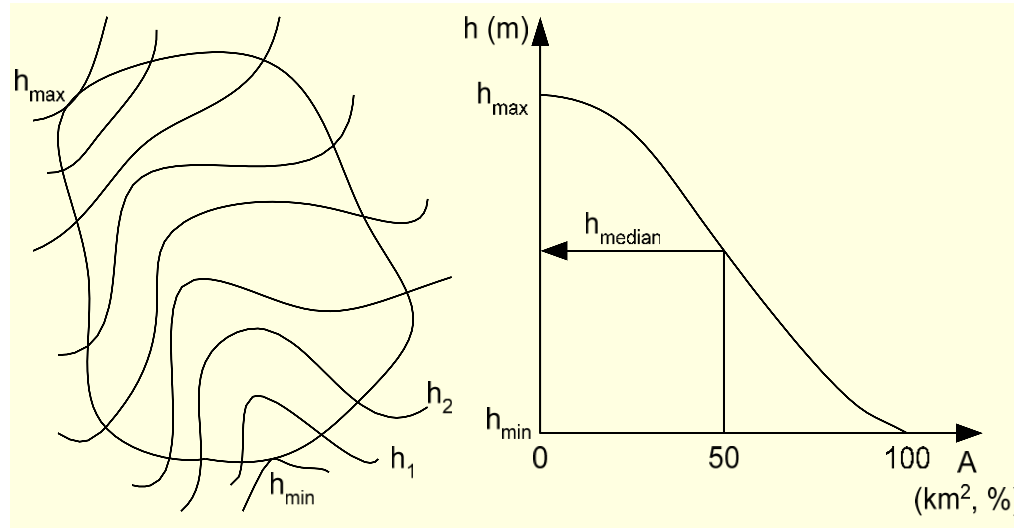
Response of the basin to ppt
for circular and elongated basins



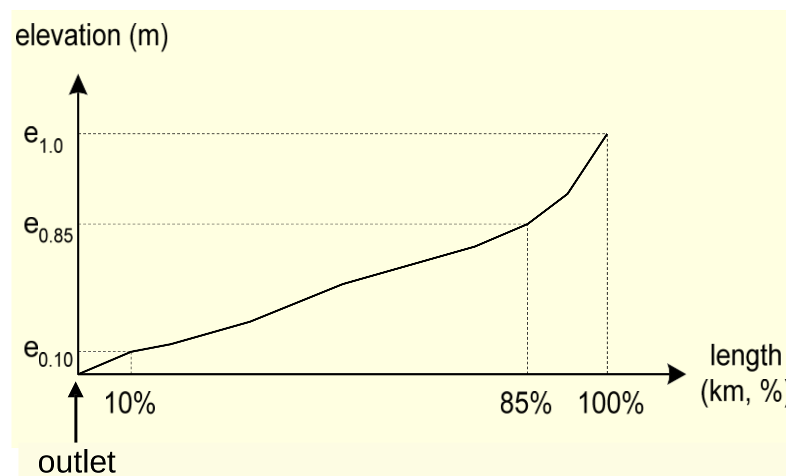
Early or late peak in hydrograph wrt
the orientation of a pear-shaped basin

Gradient

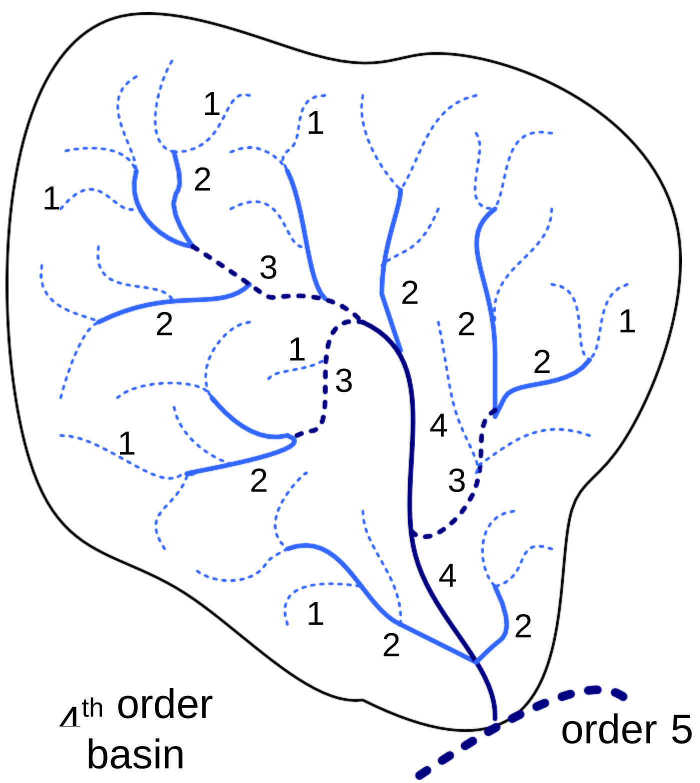
- Area-elevation (hypsometric) curve



- Relief
  - Max. relief (diff. between highest and lowest points)
  - Max. basin relief (diff. between highest on the boundary and lowest points)
- Slope of the river bed is found from the longitudinal profile of the river.



Drainage Characteristics



Horton's Ordering System
first, second, third, …

- Highest order is the order of the basin
- Scale of map!

Bifurcation Ratio = $R_b = \dfrac{N_u}{N_{u+1}}$

N_u and N_{u+1} are the number of streams of orders u and $u+1$, resp.

It gives information about the shape of the basin & also about the shape of the hydrograph.

Drainage characteristics of the Basin

U	N_u	$\log N_u$
1	55	-
2	22	-
3	9	-
.	.	.
.	.	.
.	.	.
n	1	-

$$R_{b(1,2)} = \frac{N_1}{N_2}$$

$$R_{b(2,3)} = \frac{N_2}{N_3}$$

Their average€

R_b of basin

OR

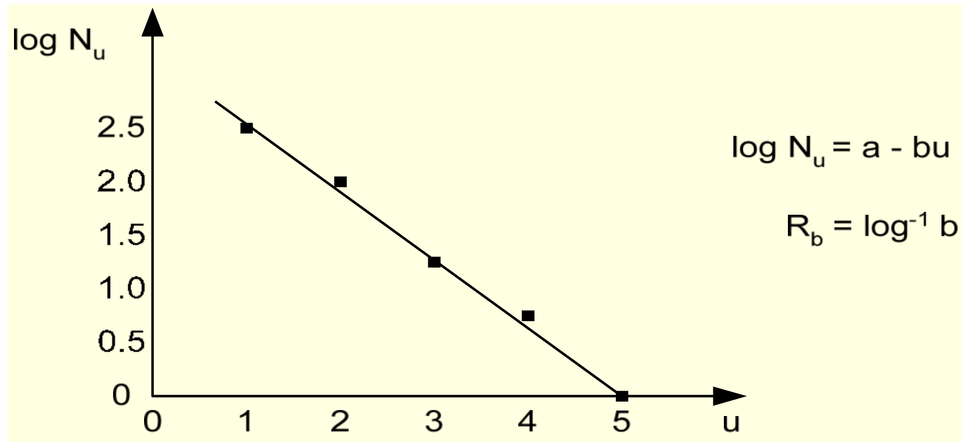


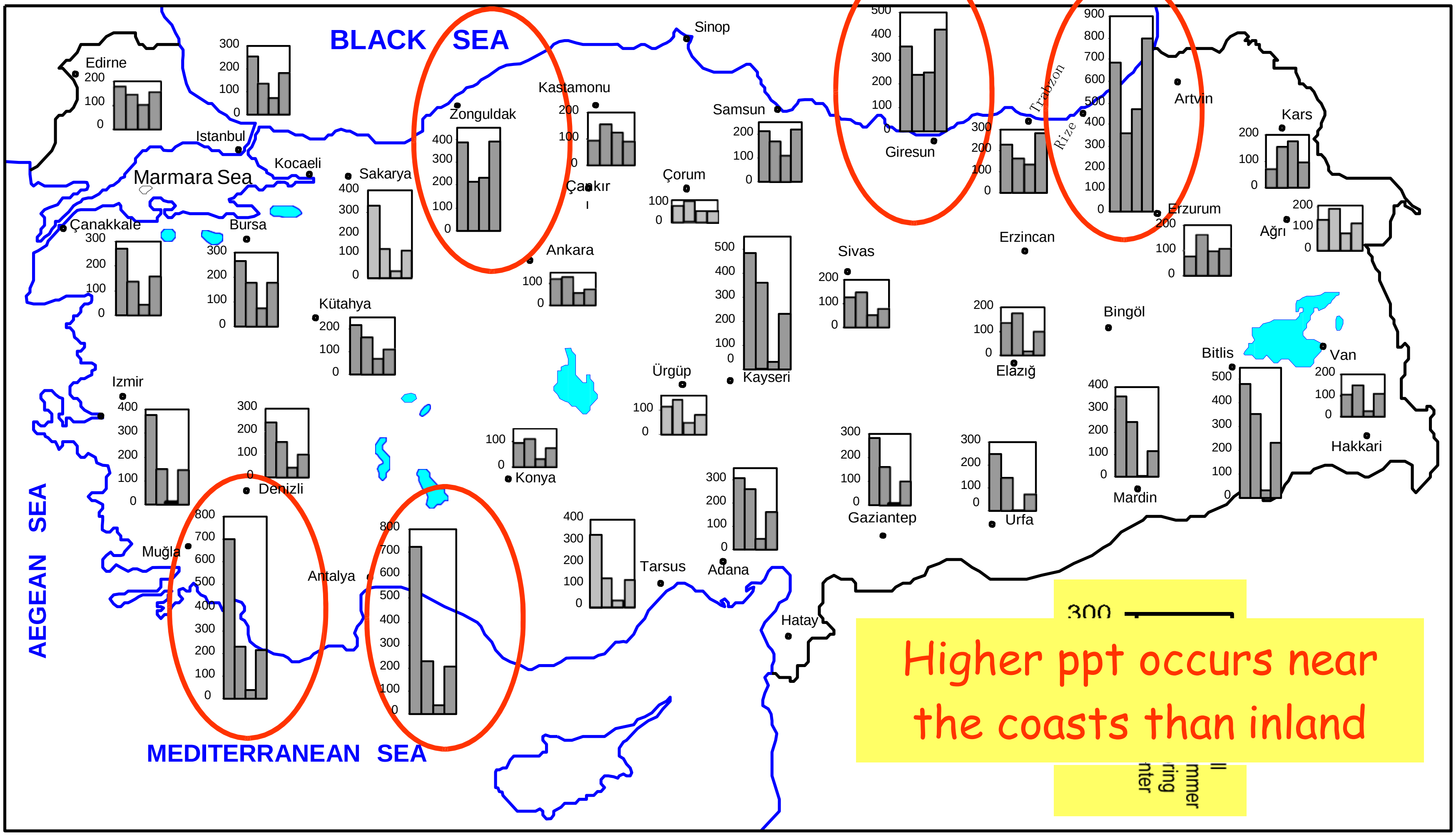
Figure 6.11 Bifurcation ratio

$$-b = \frac{\log N_{u+1} - \log N_u}{(u+1) - u}$$

$$b = \log \frac{N_u}{N_{u+1}} = \log R_b$$

$$R_b = \log^{-1} b$$

PRECIPITATION € varies in area & in time



Higher ppt occurs near the coasts than inland

Figure 3.1 Distribution of seasonal rainfall in Turkey

PRECIPITATION

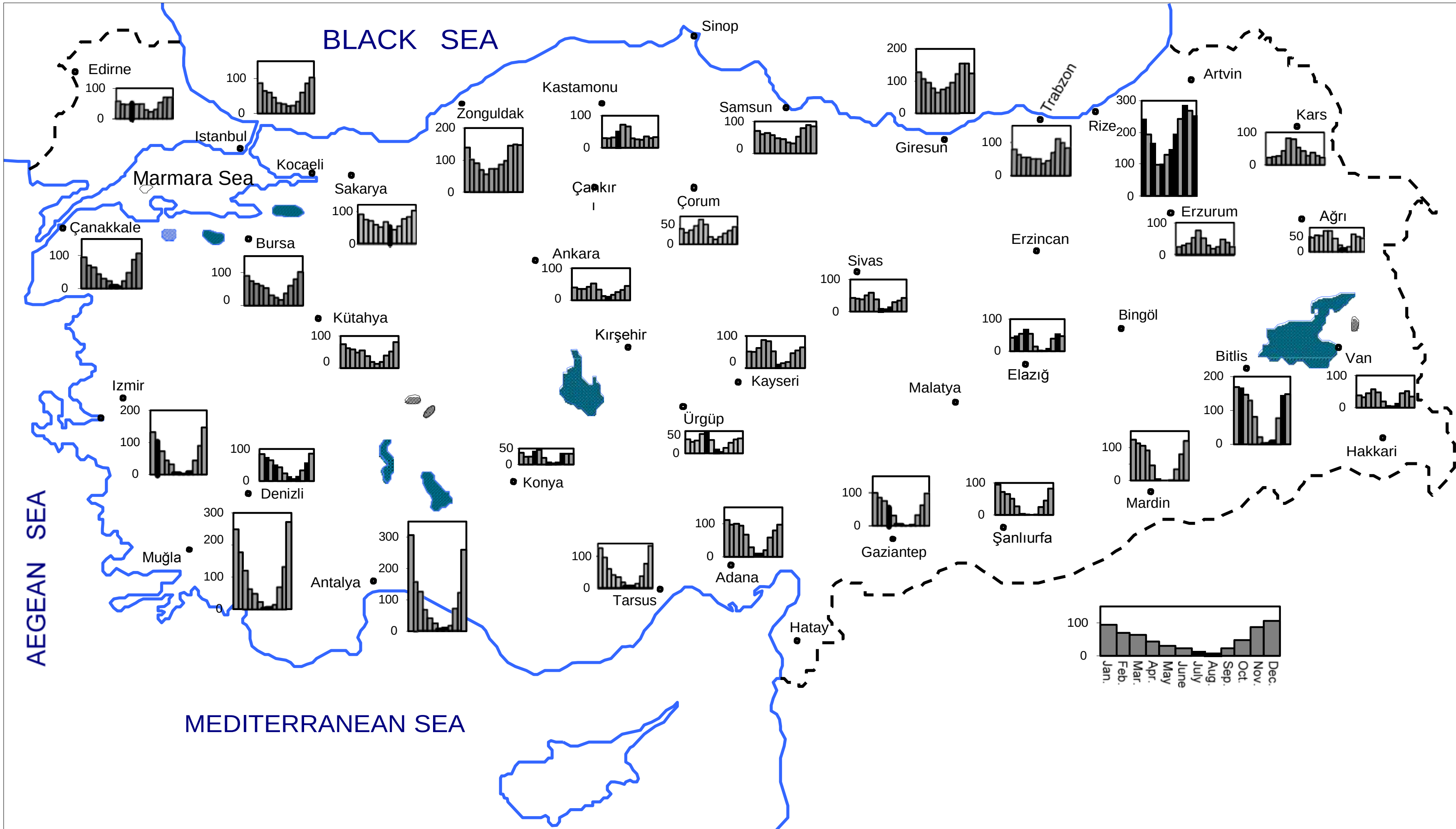
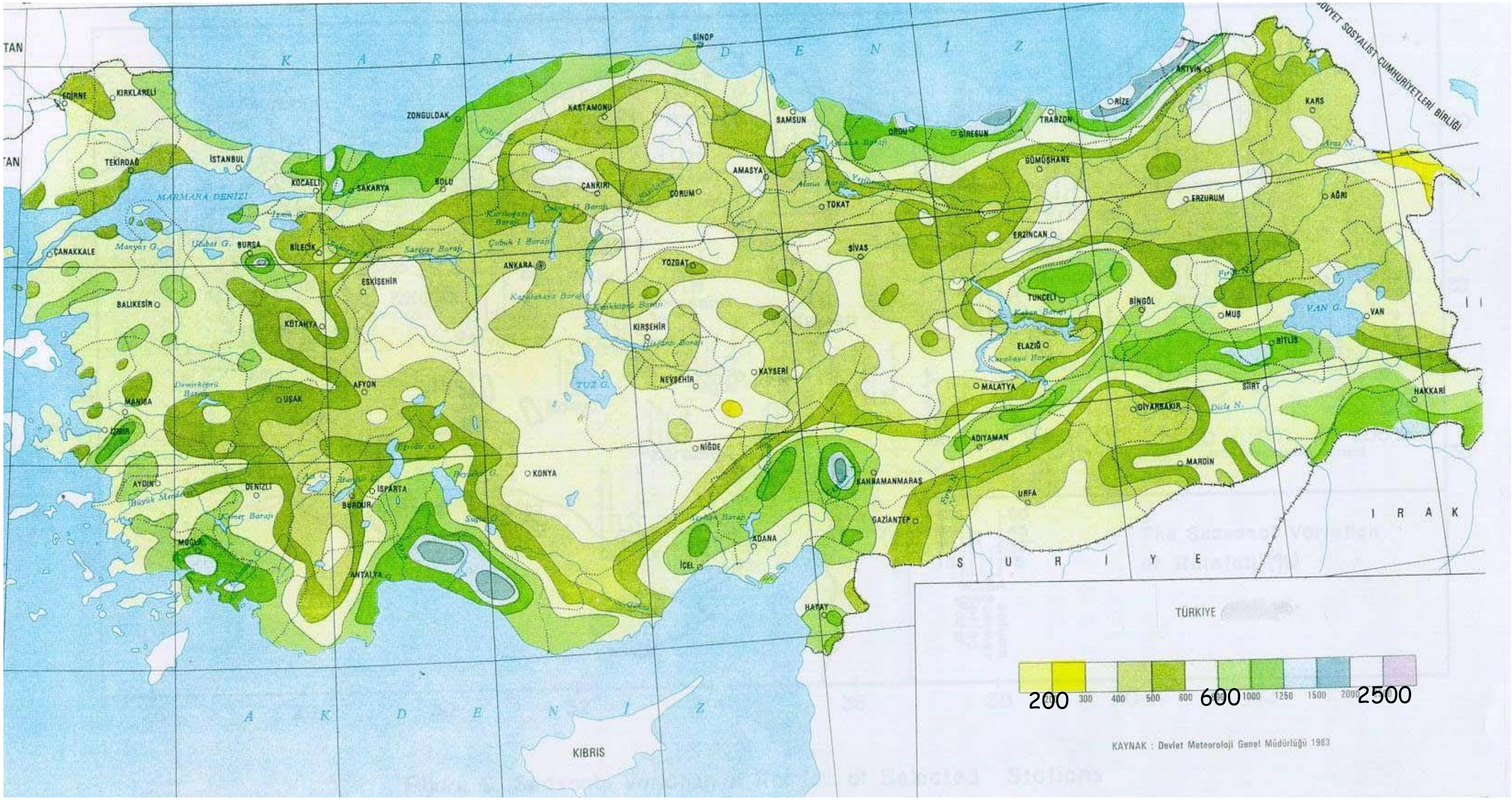


Figure 3.2 Distribution of monthly rainfall (mm) in Turkey

Distribution of mean annual rainfall



MEASUREMENT OF PRECIPITATION

- TOTAL DEPTH WITHIN A CERTAIN PERIOD OF TIME
- ITS VARIATION IN THIS PERIOD WITH THE FOLLOWING

TYPES OF MEASURING INSTRUMENTS:

1. NON-RECORDING RAIN GAGES
2. RECORDING RAIN GAGES

http://www.fotolibra.com/gallery/451724/homemade-rain-gauge/

Rainfal intensity can be calculated

http://wb8.itrademarket.com/pdimage/78/987978_raingaugehd2013-2013-d_m_uk.jpg

Weighing Gauges (recording rain gauge)

- Generally a daily chart is used for the diagrams
- For remote locations weekly charts can also be used (revolving drum completes one revolution in seven days)
- Weekly charts donot have the same detail as daily charts.

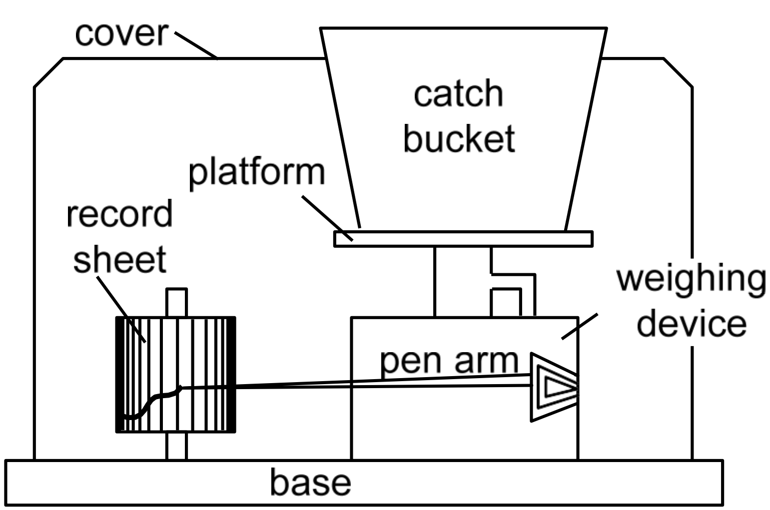


Figure 3.5a Recording rain gauge (Weighing type)

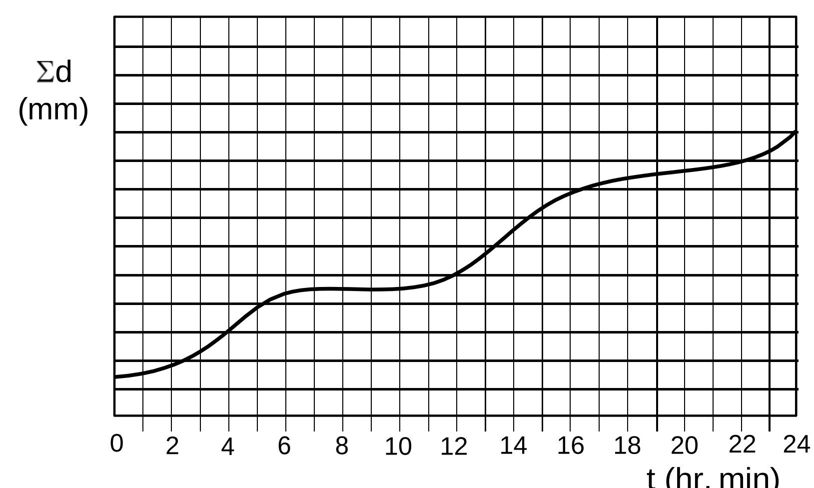
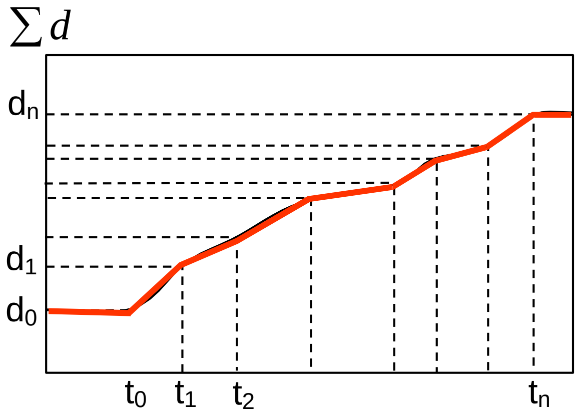


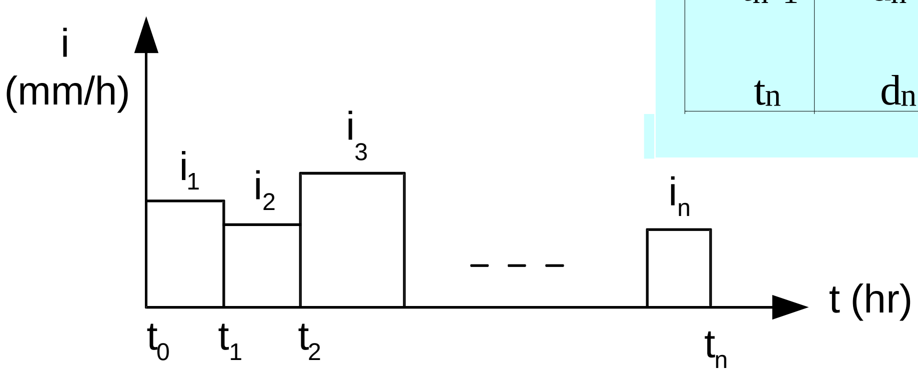
Figure 3.5b Recorded diagram

Hyetograph from a Recorded Diagram



Recorded diagram

Time (min)	Σ Depth (mm)	$\otimes t$ (min)	$\otimes d$ (mm)	Intensity (mm/hr)
t_o	d_o			
		$\otimes t_1=t_1-t_o$	$\otimes d_1=d_1-d_o$	$i_1=(\otimes d_1/\otimes t_1)/60$
t_1	d_1			
		$\otimes t_2=t_2-t_1$	$\otimes d_2=d_2-d_1$	$i_2=(\otimes d_2/\otimes t_2)/60$
t_2	d_2			
.	.	.	.	.
.	.	.	.	.
t_{n-1}	d_{n-1}			
		$\otimes t_n=t_n-t_{n-1}$	$\otimes d_n=d_n-d_{n-1}$	$i_n=(\otimes d_n/\otimes t_n)/60$
t_n	d_n			



Hyetograph

AREAL MEAN PRECIPITATION

PPT GAUGES $\longrightarrow$ POINT VALUES $\longrightarrow$ AREAL VALUES

METHODS: ARITHMETIC MEAN, THIESSEN POLYGONS, ISOHYETAL MAP

a) ARITHMETIC MEAN METHOD

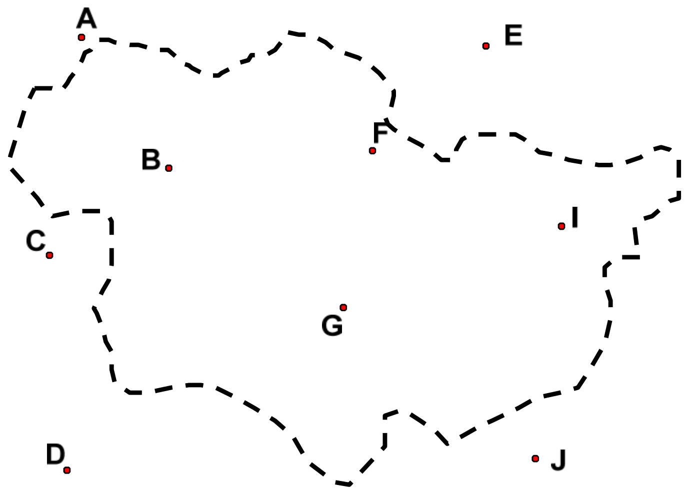
- TAKE ONLY INSIDE STATIONS
- GET SIMPLE AVERAGE

$$P_{ave} = \frac{\Sigma p_i}{n}$$

p_i = rainfall observed at the ith station

n = number of stations inside the basin

ARITHMETIC MEAN METHOD



Take ONLY inside stations

$$P_{ave} = \frac{P_B + P_F + P_G + P_I}{4}$$

AREAL MEAN PRECIPITATION

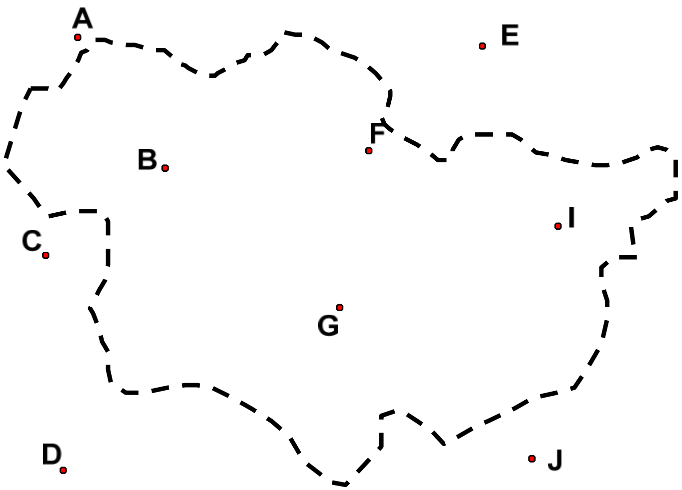
b) THIESSEN POLYGONS METHOD

- INCLUDE ADJACENT OUTSIDE STATIONS AS WELL
- CONNECT STATIONS BY STRAIGHT LINES TO MAKE EQUILATERAL TRIANGLES
- DRAW BISECTORS & OBTAIN POLYGONS
- GET WEIGHTED AVERAGE BY AREAS

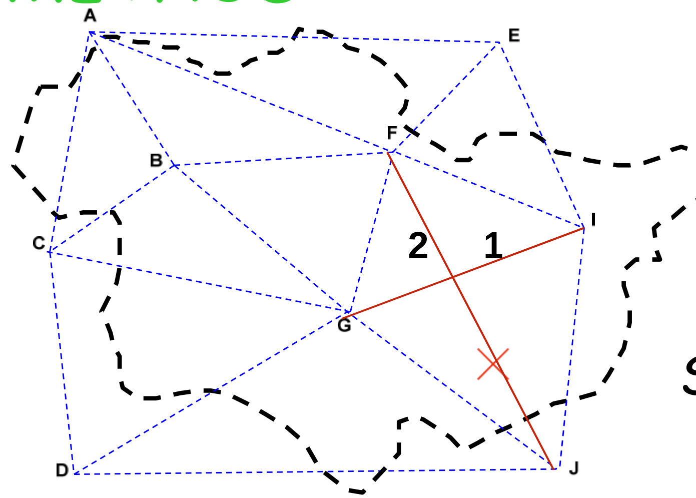
$$P_{ave} = \frac{\sum p_i a_i}{\sum a_i}$$

a_i =in-region portion of the area of the polygon surrounding this station

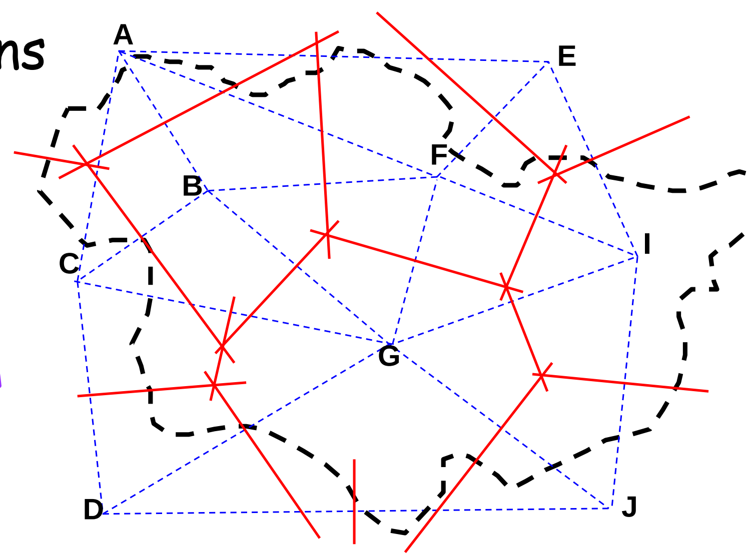
THIESSEN POLYGONS METHOD



Take all the stations



Stations are joined to obtain triangles



Bisectors are drawn to form polygons

$$P_{ave} = \frac{\sum p_i a_i}{\sum a_i}$$

AREAL MEAN PRECIPITATION

c) ISOHYETAL MAP METHOD

- PLOT ISOHYETS (EQUAL PRECIPITATION LINES)

  (ASSUME LINEAR CHANGE BETWEEN STATIONS)
- DETERMINE MEAN PRECIPITATION BETWEEN ISOHYETS
- GET WEIGHTED MEAN

$$P_{ave} = \frac{\sum \bar{p}_i a_i}{\sum a_i}$$

$\bar{p}_i$ =average precipitation between isohyets

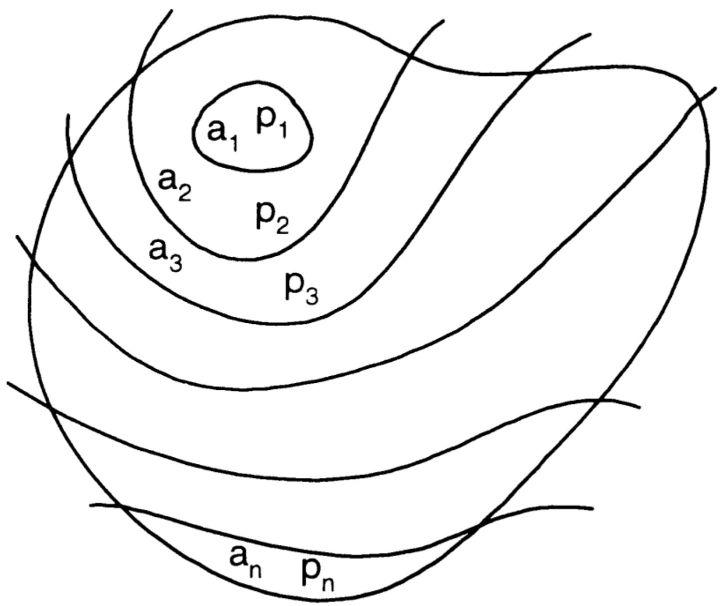
a_i =area between isohyets

DEPTH-AREA-DURATION (DAD) CURVES

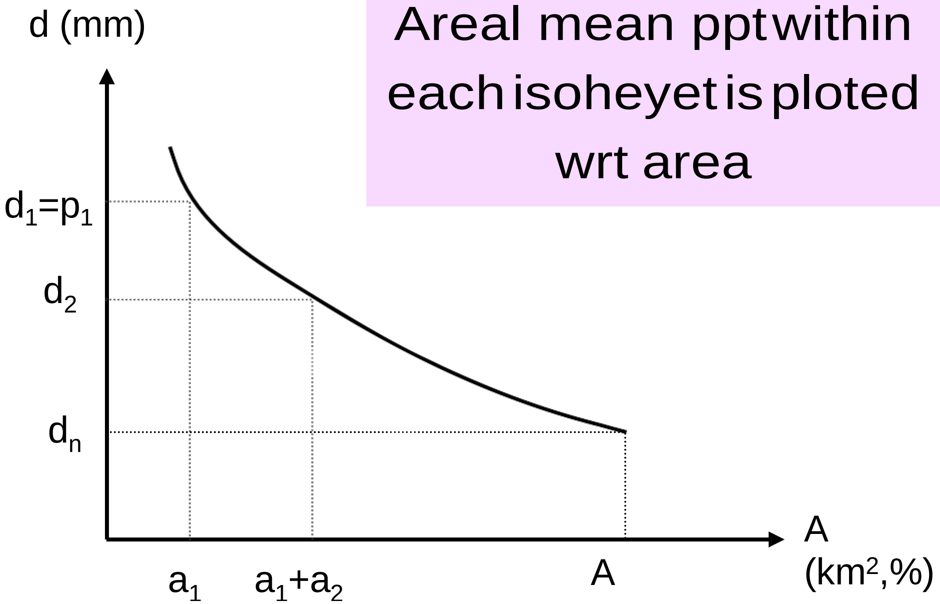
- STORM PRECIPITATION IS ANALYSED WITH RESPECT TO TIME AND AREA

- DAD ANALYSIS GIVES THE MAXIMUM AMOUNTS OF PRECIPITATION WITHIN VARIOUS DURATIONS OVER AREAS OF VARIOUS SIZES

DEPTH-AREA-DURATION CURVE FOR A PARTICULAR STORM DURATION



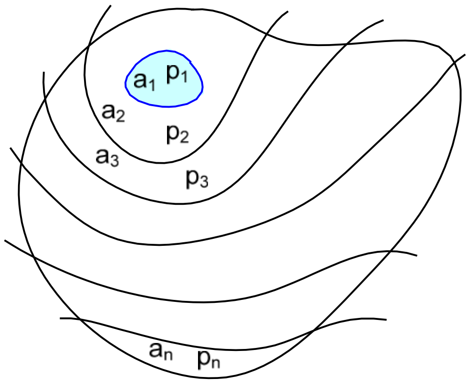
ISOHYETS OF A STORM
(with single major center)
OVER A BASIN



Areal mean ppt within each isoheyet is ploted wrt area

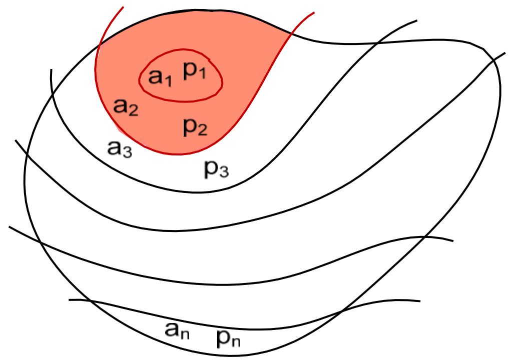
DEPTH-AREA-DURATION CURVE
for a single major center storm
for a particular storm duration

DEPTH-AREA-DURATION (DAD) CURVES



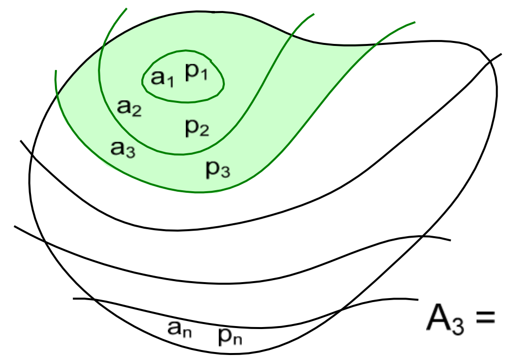
$A_1 = a_1$

$d_1 = p_1$



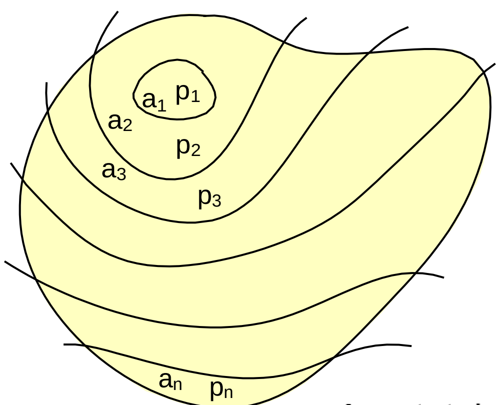
$A_2 = a_1 + a_2$

$$d_2 = \frac{p_1 a_1 + p_2 a_2}{a_1 + a_2}$$



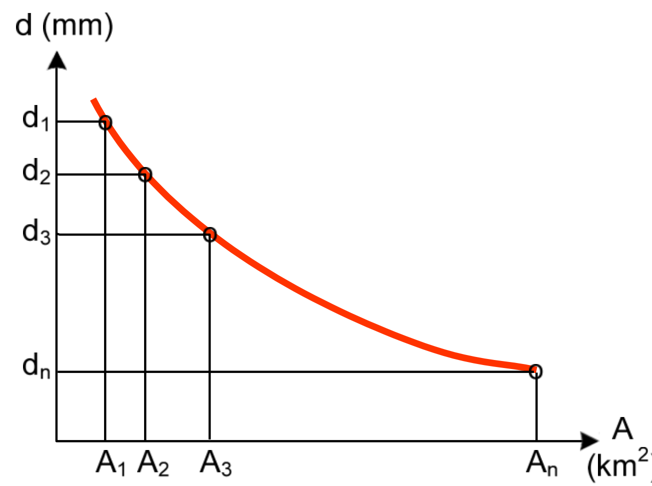
$A_3 = a_1 + a_2 + a_3$

$$d_3 = \frac{p_1 a_1 + p_2 a_2 + p_3 a_3}{a_1 + a_2 + a_3}$$



A_n = total area of the basin

d_n = areal mean value for the whole basin



To obtain the max. amounts of ppt. for a certain duration, it is necessary to take as many storms as possible with that duration and plot an enveloping curve to all the points obtained.

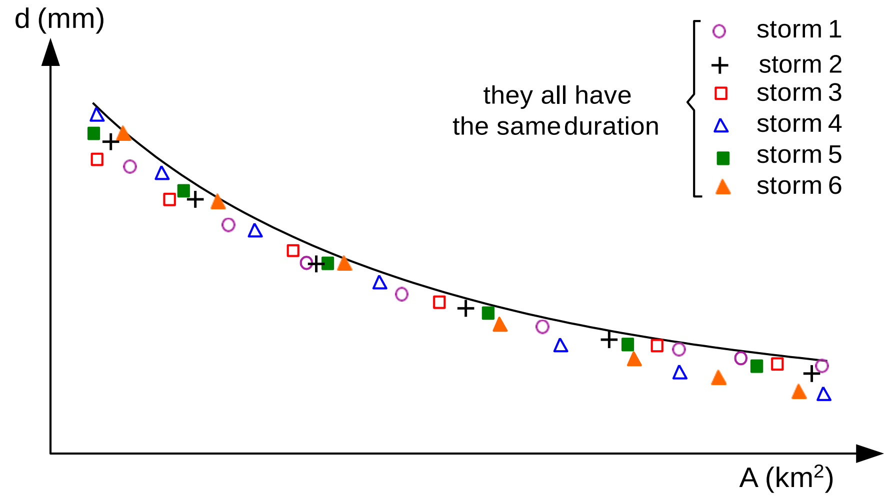
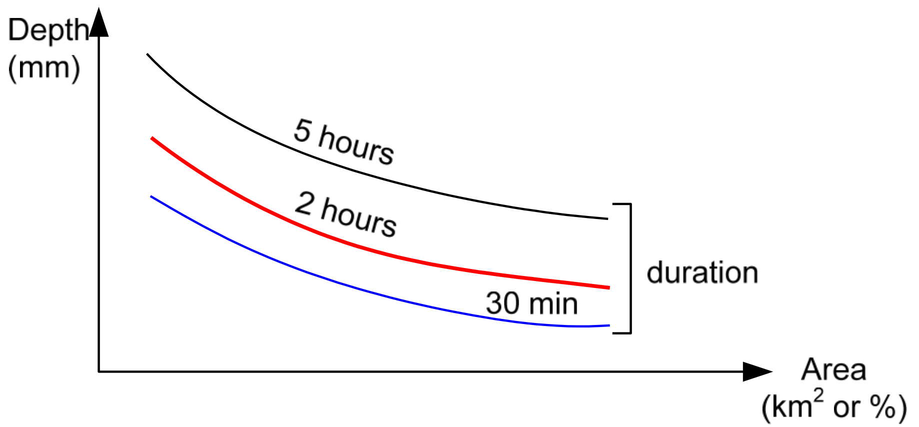


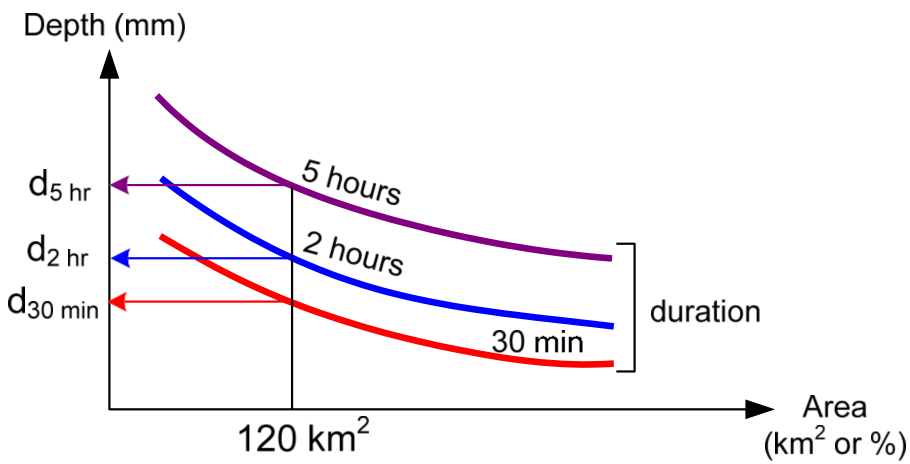
Figure 3.20 Depth - Area curve for a certain duration

When the same analysis is repeated for different duration storms, which occurred in the same area, a family of curves is obtained.



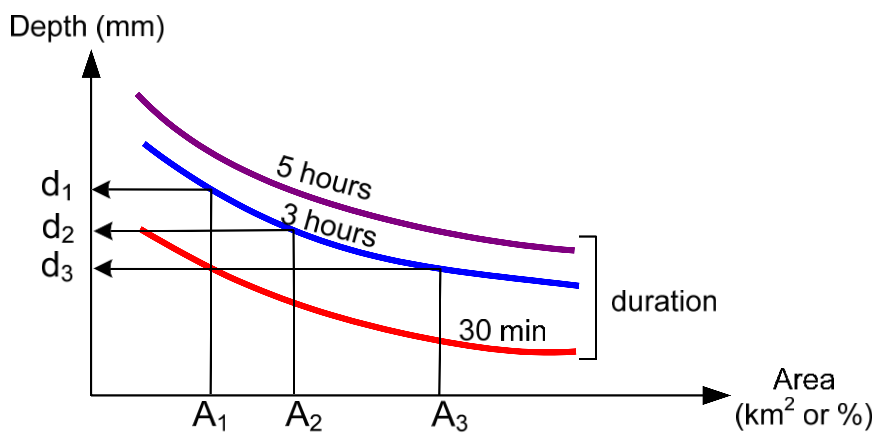
Depth-Area-Duration Curves

DEPTH-AREA-DURATION CURVES



For the same area:

as duration ↑ depth ↑



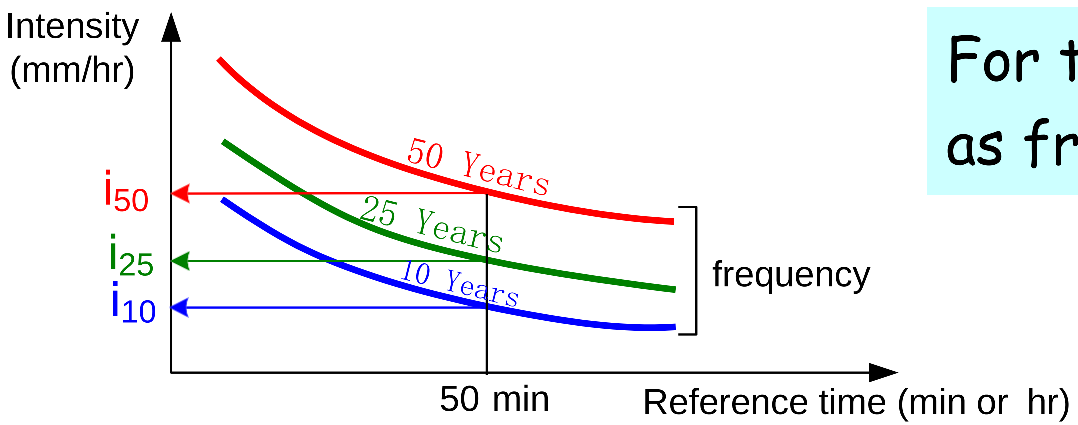
For the same duration:

as area ↑ depth ↓

Intensity-Duration-Frequency Curves

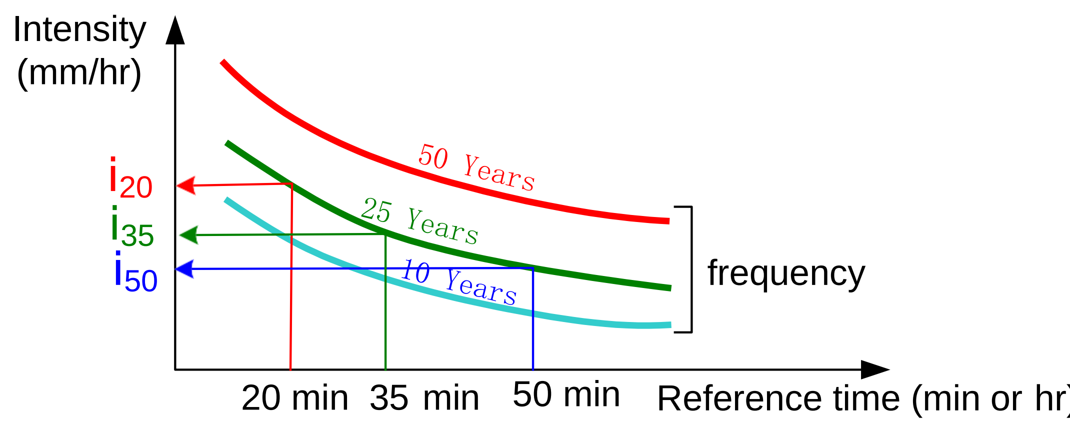
- In general, the higher the intensity of the rainfall the shorter the duration of it will be.
- Intensity - duration – frequency (I-D-F) relationship is important for engineers in designing hydraulic structures.
- It is shown by a family of curves.
- Each curve is drawn for a certain frequency, and indicates the change of intensity wrt the time interval called the reference time interval, (duration of the storm).

Intensity - Duration - Frequency Curves

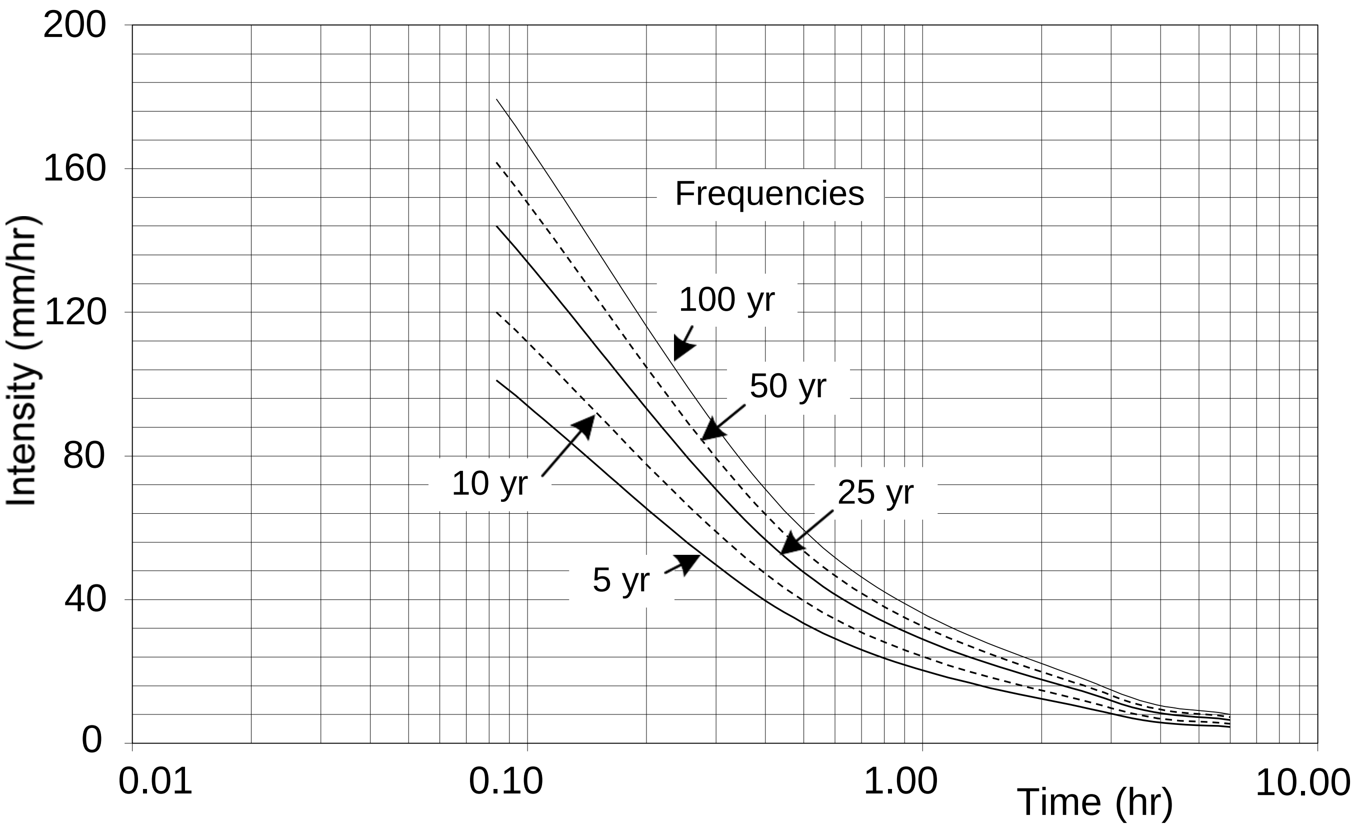


For the same duration:
as frequency ↑ intensity ↑

For the same frequency:
as duration ↑ intensity ↓



Statistical analysis of maximum storms (observed in the study area) are used to generate these curves!



Obtained from 37 years of data

Figure 3.24 Intensity-Duration-Frequency Curves for Ankara (on Semi-log scale)

These curves should be generated for every station.

RATIONAL FORMULA [$A<100\ km^2$]

- A method to relate rainfall on a basin to the corresponding runoff.
- Extensively used in urban hydrology to estimate peak flow.
- Very important parameter for storm water system design.

$Q_p \propto A^n$	n = power, A=area, Q_p=peak flow
$Q_p \propto i.A$	i = intensity (n=1)
$Q_p = C.i.A$	C = runoff coefficient

RATIONAL FORMULA

$$Q_p = 0.278CiA$$

$$Q_p = \frac{CiA}{3.6}$$

Q_p = peak flow (m^3/s)
C = runoff coefficient
i = average rainfall intensity (mm/hr)
Rain continues at least for t_c hours
t_c = time of concentration
A = area (km^2)

C is a function of surface characteristics
If surface conditions change € Divide into subareas

$$Q_p = 0.278 i \sum_{j=1}^{n} C_j A_j$$

A_j = areas of subbasins
C_j = runoff coeff.s for subbasins
n = number of subbasins

Rational Formula

- Time of concentration, t_c: time necessary for raindrops falling at the farthest point of the basin to flow to the outlet point.
- Intensity of rainfall i, is assumed to be constant during concentration time t_c, and the peak flow Q_p, occurs after the period t_c.
- Runoff coefficient, C is the least precise variable.

  Its use in the formula implies a fixed ratio of peak runoff rate to rainfall rate for the drainage basin, which in reality is not the case.

$$Q_p = 0.278CiA$$

Typical C coefficients for 5 to 10-yr frequency design

Description of area	Runoff coefficient	Description of area	Runoff coefficient
Business		Streets	
Downtown areas	0.70 – 0.95	Asphalt	0.70 – 0.95
Neighborhood areas	0.50 – 0.70	Concrete	0.80 – 0.95
		Brick	0.70 – 0.85
Residential		Drives and walks	0.75 – 0.85
Single-family areas	0.30 – 0.50		
Multiunits, detached	0.40 – 0.60	Roofs	0.75 – 0.95
Multiunits, attached	0.60 – 0.75		
Residential (suburban)	0.25 – 0.40	Lawns; soil:	
Apartment dwelling areas	0.50 – 0.70	Flat, 2%	0.05 – 0.10
		Average, 2-7%	0.10 – 0.15
Industrial		Steep, 7%	0.15 – 0.20
Light areas	0.50 – 0.80		
Heavy areas	0.60 – 0.90	Lawns; Heavy soil:	
Railroad yard areas	0.20 – 0.40	Flat, 2%	0.13 – 0.17
Parks and cemeteries	0.10 – 0.25	Average, 2-7%	0.18 – 0.22
Playgrounds	0.20 – 0.35	Steep, 7%	0.25 – 0.35
Unimproved areas	0.10 – 0.30		

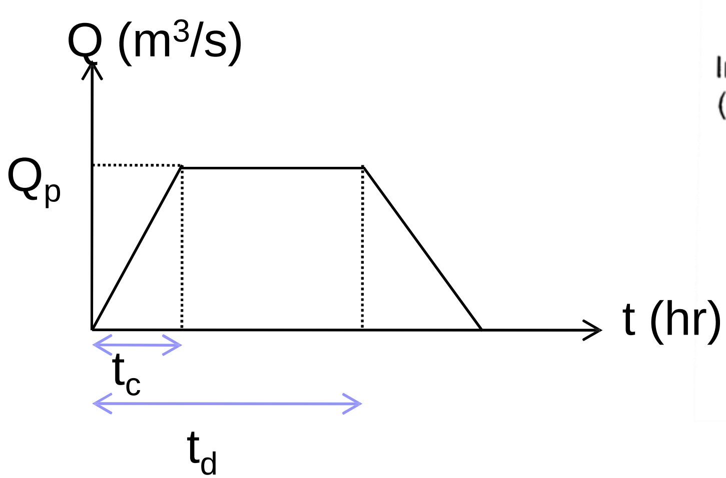
RATIONAL FORMULA

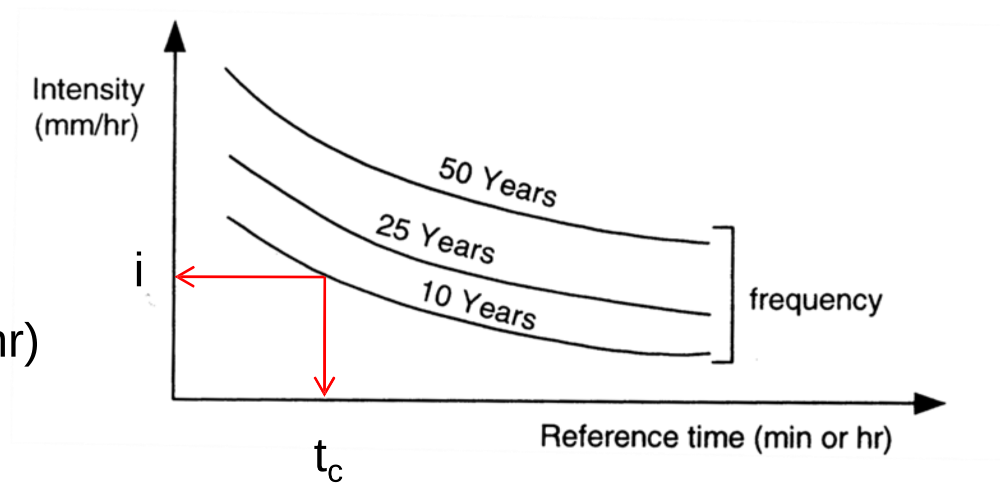
STEPS IN COMPUTATION:

1. ESTIMATE t_c
2. ESTIMATE C
3. SELECT A RETURN PERIOD T_r AND DETERMINE i FROM I-D-F CURVES FOR THAT REGION
4. DETERMINE Q_p USING THE FORMULA

RATIONAL FORMULA

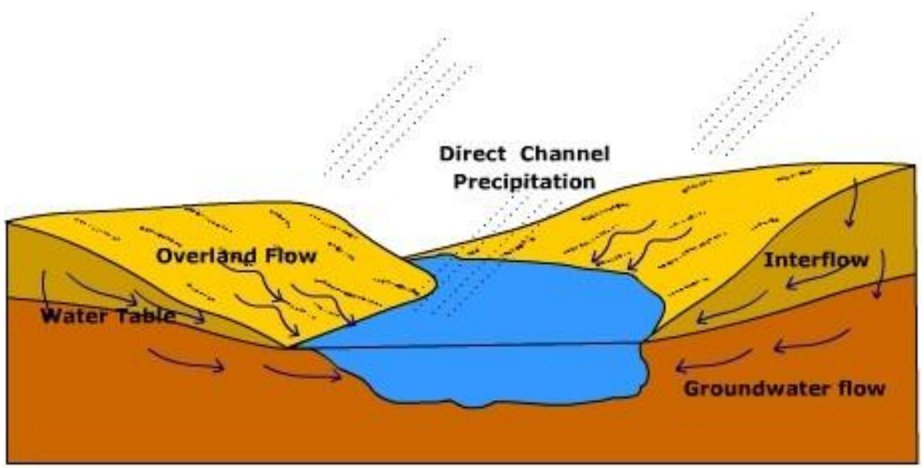
- Rational formula requires estimation of C and i
- C is the least precise variable & it depends on
  - Imperviousness
  - Slope
  - Vegetation
  - Ponding characteristics of the surface





STREAMFLOW

- The most important element of hydrologic cycle
- Basin converts precipitation into streamflow
  - Basin = Drainage Basin = Catchment = Watershed = Subbasin
  - Area = Drainage Area
  - Perimeter = Boundary = Basin Divide

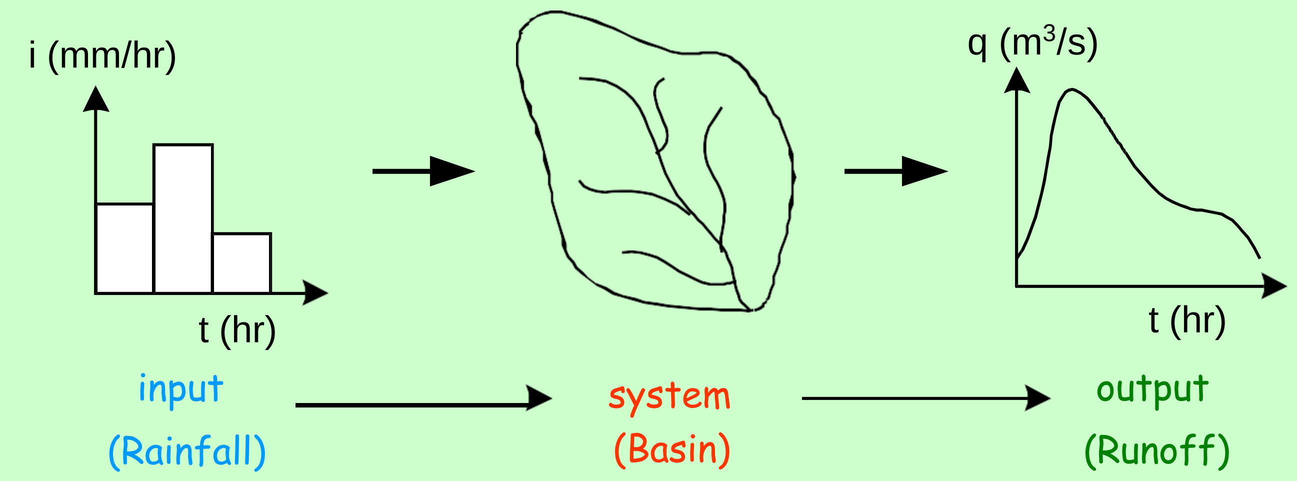


http://www.uwsp.edu/geO/faculty/ritter/geog101/textbook/fluvial_systems/channel_geometry_and_flow.html

Streamflow

Most important element of hydrologic cycle for the hydrologist because streams are the best renewable sources of water for all kinds of demands.

Streamflow = f(meteorological factors, basin characteristics, human activities)



Basin as a system

STREAMFLOW

Geology and Soil Characteristics

Paved Surfaces ⬆ Infiltration ⬇

Fine Textured Soil ⬆ Infiltration ⬇

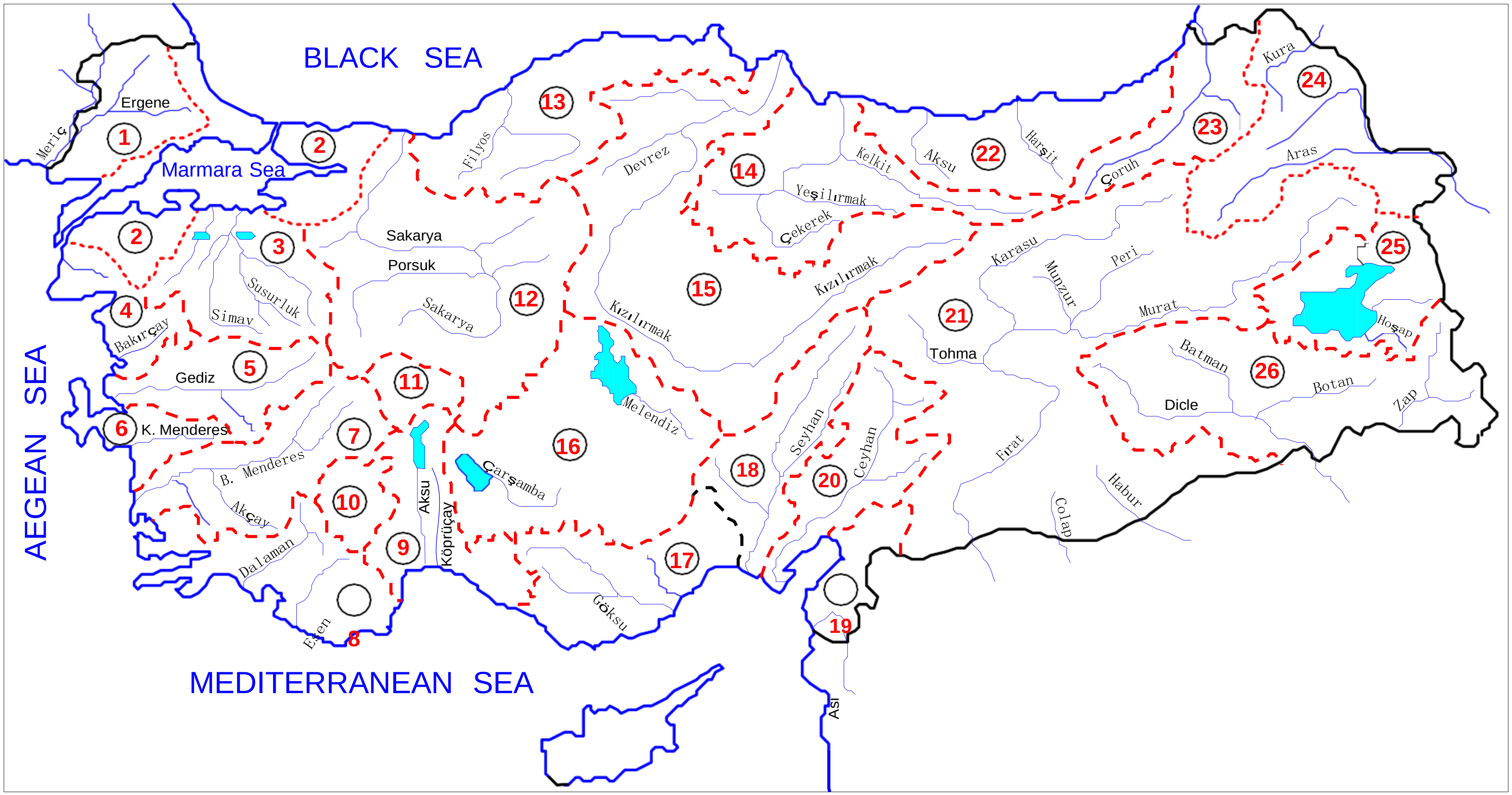


Figure 4.1 Streamflow measuring regions in Turkey

Types of Regions

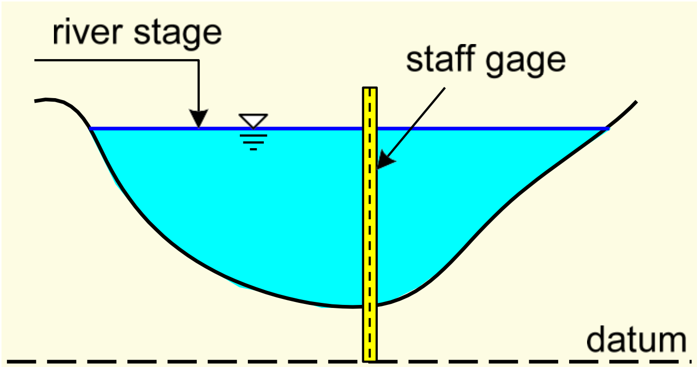
Estimation of rates or volumes of flow is necessary

Measurement of stage :

- Non-recording (Manual)
- Recording

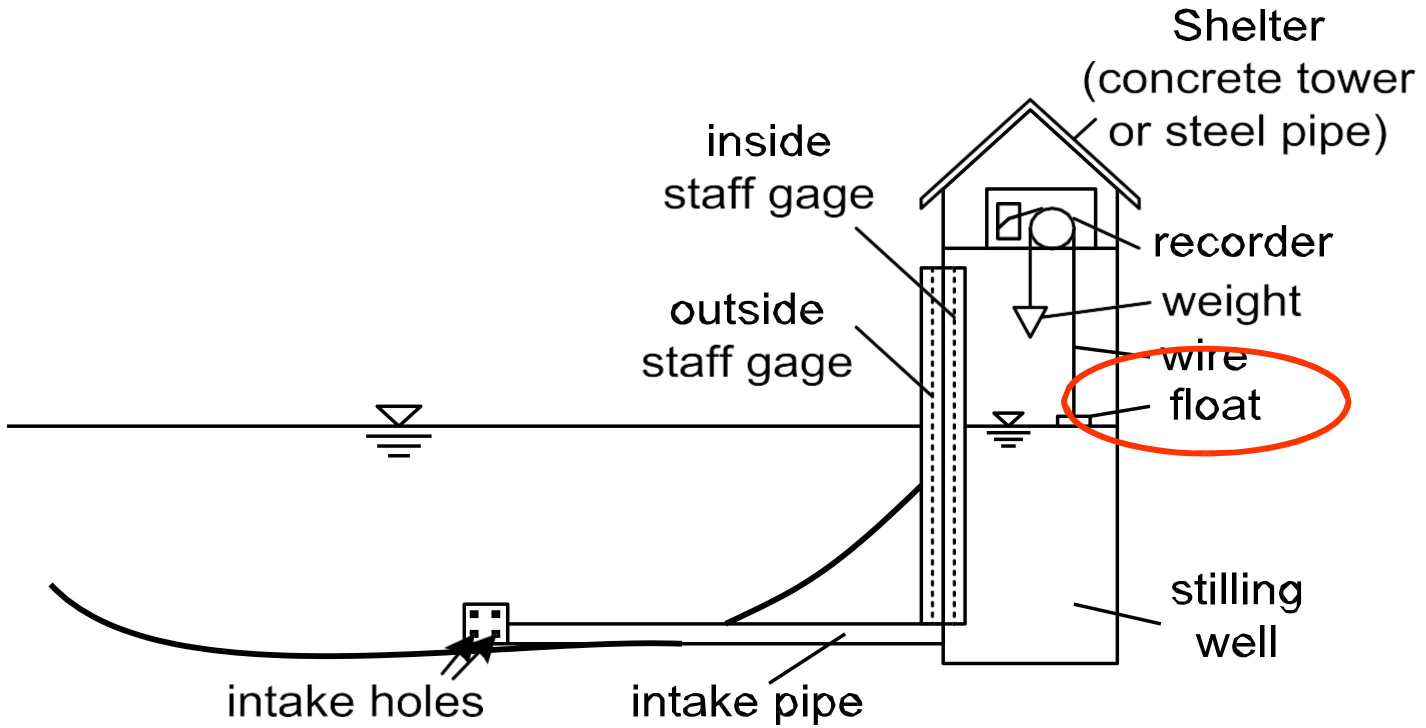
Gages

Stage is elevation above a zero datum (arbitrary)



Recording Gage

Ex: float-type water-stage recorder



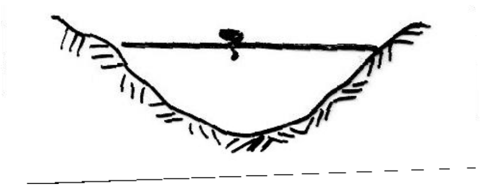
Discharge Computation

Stage Record $\xrightarrow[\text{calibration}]{\text{by}}$ Discharge Record

- Calibration is accomplished by relating
  - Field measurements of discharge

    with

    river stage values



$$Q = a \times v$$

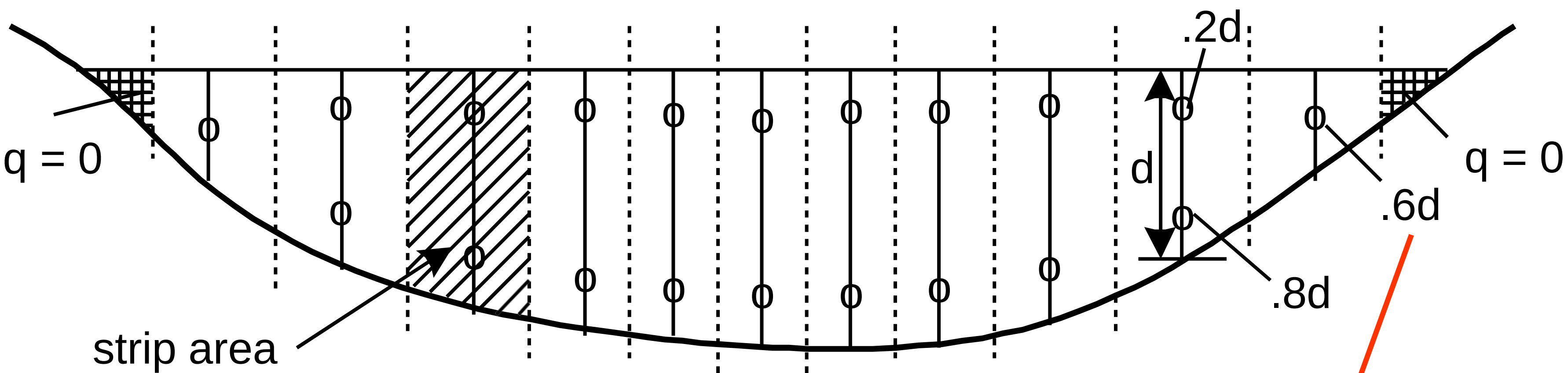
Q = discharge
a = area
v = velocity

- Velocity measurement is necessary & it is done by current meter

$$v = a + bN$$

a, b = constants of the instrument
N = number of revolutions per second

In practice stream is divided into a number of vertical sections (strips) ⇨ No section should have more than 10% of total flow!



$$q_i = a_i \times v_{i,mean}$$

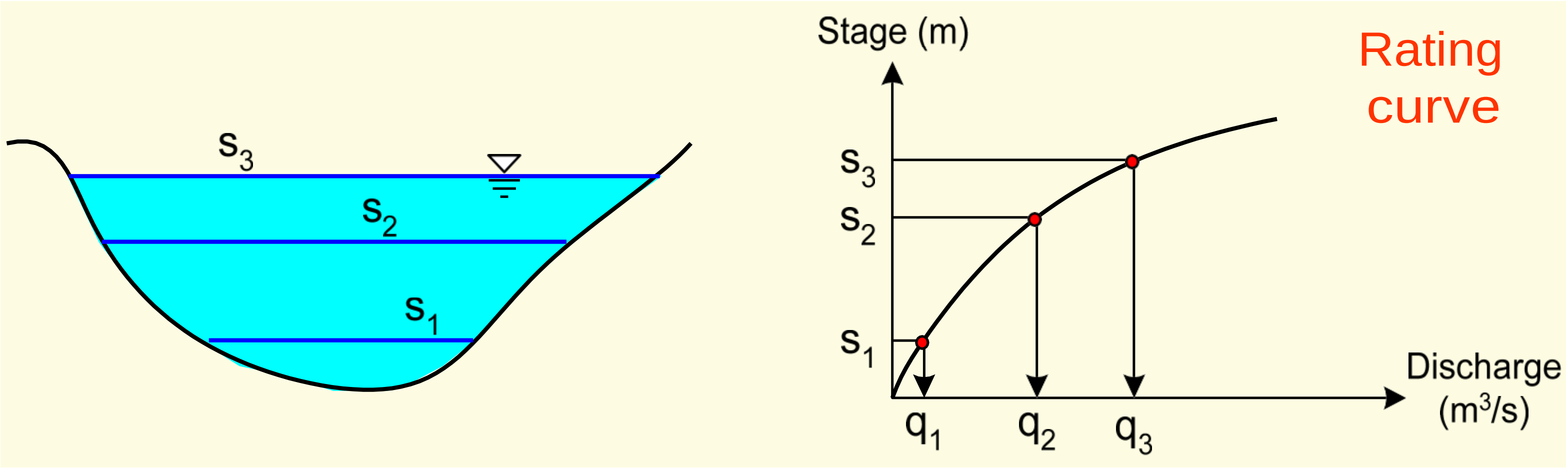
One measurement at 0.6d if water is shallow

$$v_{mean} = v_{0.6d} = \frac{v_{0.2d} + v_{0.8d}}{2}$$

$$Total\ discharge,\ Q = \sum q_i = \sum (a_i \times v_i)$$

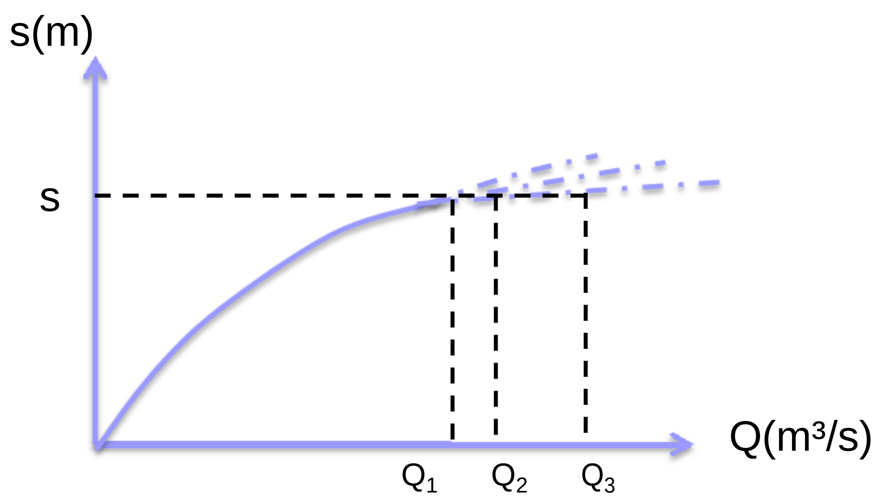
Obtaining Rating Curve

- Take different stages
- Determine discharge for each stage
- Plot them against each other



Extension of Rating Curve – to obtain flood discharges

In extension, a small change in slope will cause a very large change in discharge.



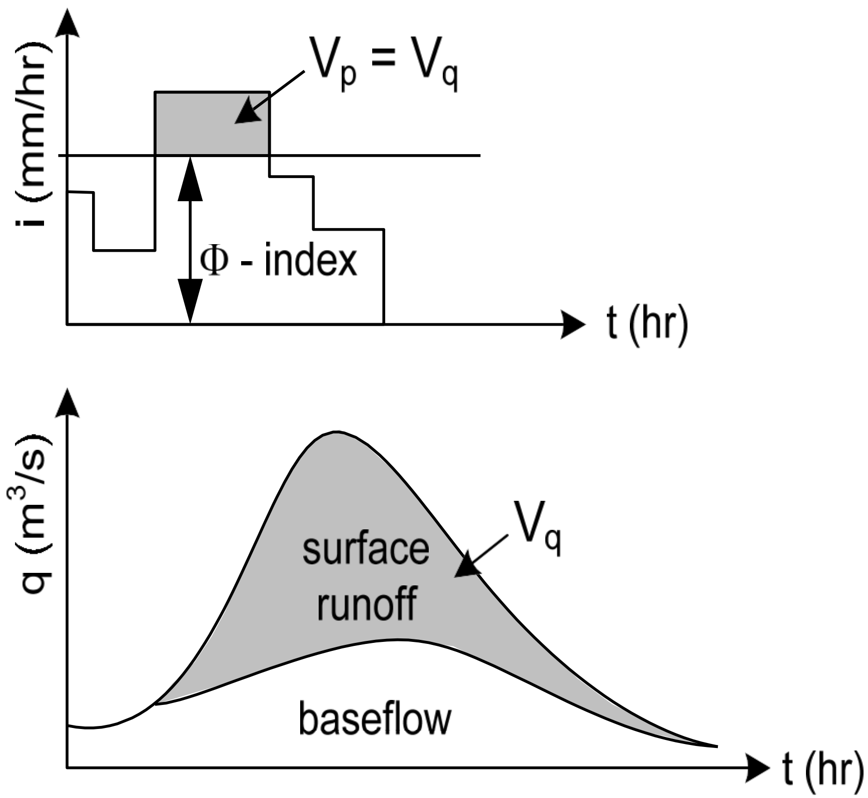
$$q = k \times (s - a)^b$$

Parabolic Assumption

q = discharge (m^3/s)
s = stage (m)
k = constant
a,b = constants
a = difference between datum & zero flow elevation

Interpretation of Streamflow Data

Φ - index € indicates the average infiltration rate above which the depth (or volume) of rainfall is equal to depth (or volume) of surface runoff.



$$V_p = V_q \;\; (d_p = d_q)$$

$V_p(d_p)$ = Volume (depth) of effective precipitation

$V_q(d_q)$ = Volume (depth) of surface runoff

- An example for the Φ-index: