HYDROLOGY

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A Hand-note On

HYDROLOGY

CE 307

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Topics

Theory
Introduction
Precipitation
Run off
Stream gauging
Ground water
Well design
Hydrogaphs
Water loss
Flood estimation & control
Flood routuing

Problems
Introduction & precipitation
Run off
Stream gauging
Ground water
Hydrograph
Water loss

CE-307

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Introduction

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090063

07, 05, 04, 03, 02, 99

Q-1: Define Hydrology.

Hydrology:

Hydrology is a branch of earth science. The word 'Hydrology' is derived from Greek word "hydro" and "logos" which means water and science respectively. Thus hydrology is the science of water. The complete defination of hydrology can be written as—

" Hydrology is the science which deals with the occurrence, distribution and disposal of water on the planet earth, it is the science which deals with the various phases of the hydrologic cycle.

Q-2: Explain the scope of hydrology in water resource development.

Scope of Hydrology:

The study of hydrology helps us to know:

(i) The maximum probable flood that may occur at a given site and its frequency, this is required for the safe design of drains, bridges and culverts, dams and reservoirs, channels and other flood control structures.

(ii) The water yield from a basin - its occurrence, quantity and frequency etc. This is necessary for the design of dams, municipal water supply, water power, river navigation etc.

(iii) The groundwater development for which a knowledge of the hydrogeology of the area i.e of the formation soil, recharge facilities like streams and reservoirs, rainfall pattern, climate, cropping pattern etc are required.

(iv) The maximum intensity of storm and its frequency for the design of a drainage project in the area.

02, 04

Q-3: What are the basic data required for hydrological studies? Name the agencies from which the data can be obtained.

Hydrological Data:

For the analysis and design of any hydrologic project adequate data and length of records are necessary. The basic hydrological data required are:

i) Climatological data
ii) hydro-meteorological data like temperature, wind velocity, humidity etc.

iii) precipitation records.

iv) stream-flow records

v) seasonal fluctuation of ground water table or piezometric heads.

vi) evaporation data

vii) cropping pattern, crops and their consumptive use

viii) water quality data of surface streams and ground water

ix) Geomorphologic studies of the basin like area, shape and slope of the basin, mean and median elevation.

x) Hydrometeorological characteristics of the basin.

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~~Q-4: What are the basic hydrological requirements for a river basin development?~~

~~Hydrometeorological characteristics of the basin:~~

These data can be obtained from the following agencies:

i) BWDB (Bangladesh Water Development Board)

ii) BMD (Bangladesh Meterological Department)

iii) IMD (International Meterological Department)

iv) SPARSO

v) BADC (Bangladesh Agricultural Development corporation)

vi) SAARC ~~vii) Hydrological equation~~

-34

Q-4: what are the basic hydrological requirements for a river basin development?

Hydrometeorological characterisation of the basin:

i) Average annual rainfall (a.a.r), long term precipitation, space average over the basin using isohyets and several other methods.

ii) Depth-area-duration (DAD) curves for critical storms.

iii) cropping pattern-crops and their seasons.

iv) Daily, monthly and annual evaporation from water surfaces in the basin.

v) water balance studies of the basin

vi) Soil conservation and methods of flood control

vii) Cronic problems in the basin due to a flood-menacing River or silt-menacing River

viii) Isohyetal maps - Isohytes may be drawn for long-term average, annual and monthly precipitation for individual years and months.

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02

Q-5: What is hydrologic equation. Write down the scope of it.

Hydrologic Equation:

The hydrologic equation is simply the statement of the law of conservation of matter and is given by -

$$I = O + \Delta S$$

where,

I = Inflow

O = Outflow

ΔS = Change in storage

This equation states that during a given period, the total inflow into a given area must equal the total outflow from the area plus the change in storage. This is known as water balance study.

Scope:

While solving this equation, the groundwater is considered as an integral part of the surface water and it is the subsurface inflow and outflow that pose problems in the water balance studies of a basin,

02

Q-6: Explain the difference between evaporation, transpiration and evapotranspiration.

Evaporation	Transpiration	Evapotranspiration
i) Conservation of water on its liquid phase to vapour phase is called evaporation.	i) The process by which the living plants leave water from their leaves is called transpiration.	i) combined process in which both evaporation and transpiration take place is called evapotranspiration.
ii) It is caused by temperature effect.	ii) It is caused due to repiration process of plants.	ii) It takes place by the combination of repiration and temperature effect.
iii) Expressed as a depth.	iii) Expressed as a ratio called transpiration ratio.	iii) Expressed as a depth over the area

Q-7: What are the importance of hydrology in water development.

Importance of hydrology in water development:

i) It gives an estimate of water resources potential of the river basin.

ii) It provides an idea about probability of flood occurrence, their pattern and magnitude.

iii) The dependable yields for irrigation and hydro electric power stations can be determined.

iv) Spillway capacity, dam height, dam safety etc. can be designed.

v) Formulation of flood control measures can be carried out.

vi) It helps in improvement of navigations, sediment carrying capacity etc.

vii) It gives a guideline for erosion control.

viii) Maximum expected flood discharge and its volume entering a reservoir can be determined.

08

Q-8: "The hydrologic cycle is an unending process" - explain.

We know that the hydrologic cycle is the combination of three successive phases such as—

i) Evaporation and evapotranspiration

ii) Precipitation and

iii) Run off

These three phases occurs continuously and never stops. Water is always evaporating from lake, sea, river and other water bodies due to temperature. This process may be stopped only if temperature is nullified which is not possible and thus evaporation must continue. The evaporated water is condensed in the atmosphere to some height and in the precipitation phase, it comes to earth surface. Due to slope of earth surface some of these water flows over the land called run off. Ultimately the water returns back to the sea and again evaporation takes place. Similarly condensation, precipitation and runoff occurs again and again. And hence maintaining the law of conservation of mass, the phases of hydrologic cycle continue. Therefore, we can say that the hydrologic cycle is an unending process.

09, 07, 03, 00

Q-9: "Hydrology is a highly inter-disciplinary science" - Justify it.

Hydrology uses various principles from other branches of science like physics, chemistry, Biology, Geology, Fluid mechanics, Mathematics, Statistics etc which indicates that it is a highly inter-disciplinary subject.

As water is transported into air, hydrology interacts with science related to air such as Hydrometeorology, Meteorology and climatology. When hydrology deals with surface water, it includes the knowledge from Limnology, Glaciology, Oceanology etc.

As water affects plants and animals, hydrology extends into plant ecology, Biohydrology, Hydrobiology etc.

Similarly when hydrology deals with ground water. It includes Agronomy, Hydrogeology, Geophysics etc.

The other branches of science such as Forestry, Geograph, Water supply, Hydropower, Economics, Political science etc. have also influence on Hydrology. So, it may be concluded that - "Hydrology is a highly inter-disciplinary science."

09,07,00

Q-10: Is your district affected by floods or droughts? Explain how hydrology is useful in proposing the measures to mitigate the natural disasters.

Yes, my district Bogra is affected by both flood and drought. The knowledge of hydrology is useful in proposing the measure to mitigate these natural disasters.

Hydrology provides the essential information about the probability of natural disasters. Various flood control structures are constructed on the basis of the information provided by hydrology. On the other hand, the techniques of flood routing is essential for planning an economic flood control project. Not only flood control, if adequate hydrometeorological information is available, drought and other natural disasters can also be mitigated.

The above discussion makes it clear that hydrology is very useful in mitigating natural disasters.

Q-11: List out various practical applications of hydrology. Describe them in brief.

The subject 'Hydrology' has a lot of practical applications in our life. Some of them are listed below:

i) Design of hydraulic structure:
The design of any structure related to water such as spillway, dam, culvert, bridges etc largly depends on the knowledge of hydrology.

ii) Municipal and industrial water supply:
The availability of water is often the most important factor in locating suitable f place for industries and it has considerable effect on the growth of municipalities. Hydrology helps us to ensure water supplys availability.

iii) Irrigation:
Storage of water is one of the most important factors for development of irrigation for which evaporation, seepage and other losses must be considered. Hydrology helps to measure these losses.

iv) Hydropower:
Hydrologic studies are essential for the planning of any water-power department.

v) Flood control:

The techniques of flood routine is essential for an economic planning of flood control project which can be known from the study of hydrology.

VI) Navigation:

To solve the hydrologic problems in navigation project some essential informations are required which are supplied by hydrology.

VII) Erosion and sediment control:

The problems in erosion control is mainly related to overland flow and infiltration which are studied in hydrology.

02, 07

Q. Define and explain hydraulic cycle with the help of a neat sketch.

Hydraulic cycle:

The hydraulic cycle is defined as a water transfer cycle, in which water is transferred from the ocean or sea to the atmosphere, then from atmosphere to the earth and ultimately again return back to the sea.

Phases of hydraulic cycle:

There are three important phases of hydraulic cycle. They are-

i) Evaporation and evapotranspiration
ii) Precipitation
iii) Run off

They are described below:

i) Evaporation and evapotranspiration:

These two are processed by the fact that water or moisture from water-body or soil surface is removed continuously under temperature effect. Evaporation takes place at the surface of ponds, rivers, lakes and oceans. Transpiration takes place incase of tree leaves, cropped land, forests etc.

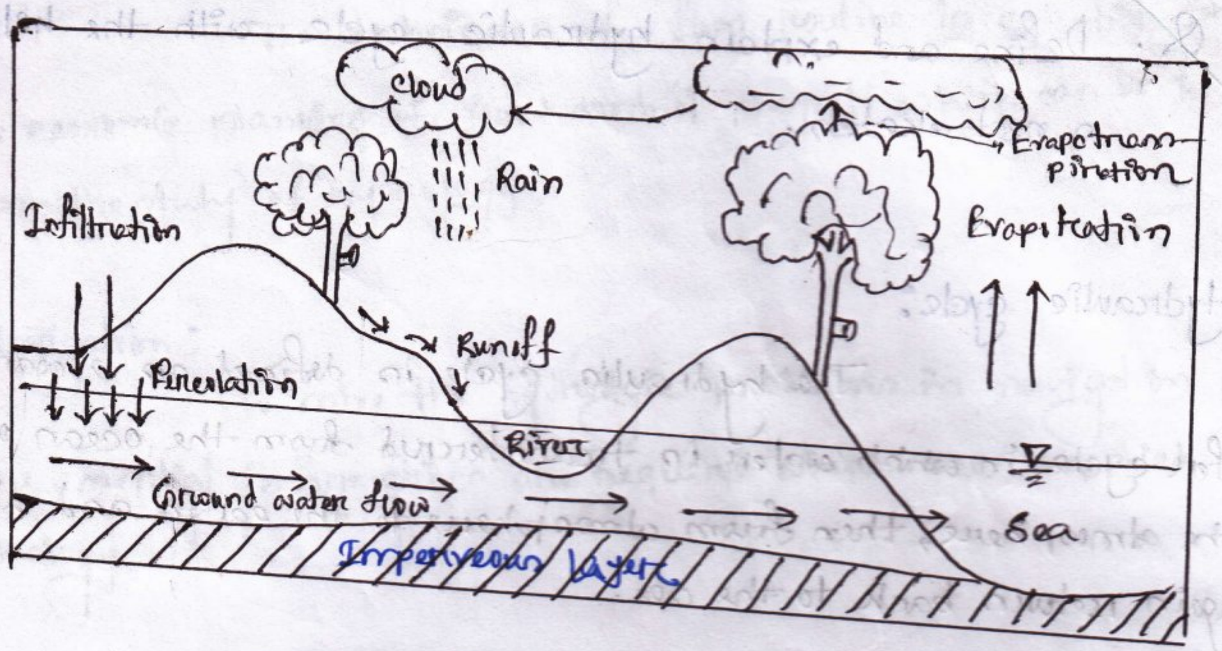


Fig: Hydraulic or hydrologic cycle

ii) Precipitation:

Precipitation takes place due to lifting of evaporated moisture into the atmosphere and subsequently formation of clouds at some heights. Water from these clouds comes in surface in different forms of precipitation and is distributed among oceans, rivers, lakes etc.

iii) Runoff:

During precipitation, a portion of precipitated water flows over the land which is called run-off. It is the most important phase of hydrologic cycle in civil engineering point-of-view as the civil engineers are concerned with storage of runoff for irrigation and other uses.

Q. Write down different forms of precipitation.

Forms of precipitation:

Precipitation occurs in the following different forms:

* Drizzle: a light steady rain in fine drops (0.5mm) and intensity < 1 mm/hr.

* Rain : the condensed water vapour falling in drops (in size > 0.5 mm but < 6mm) from the clouds.

* Snow : ice crystals resulting from water vapour condensed to ice.

* Snow flakes: ice crystal fused together

* Dew : Moisture condensed from atmosphere in small drops on cool surfaces,

* Frost : a feathery deposit of ice.

* Fog : a thin cloud of varying size formed near the surface.

08

Q. A watershed has a network of five raingauges. Annual rainfall recorded by these gauges is given for a year. Calculate optimum number of raingauges for a 10% error in estimate of mean annual rainfall.

Solution:

Raingauge:	1	2	3	4	5
Annual rainfall (cm):	50	82	73	64	105

Solution:

Raingauge	Annual rainfall (cm) x_i	$\bar{x} = \frac{\sum x_i}{n}$	$(x_i - \bar{x})$	$(x_i - \bar{x})^2$
1	50		-24.8	615.04
2	82		7.2	51.84
3	73	74.8	-1.8	3.24
4	64		-10.8	116.64
5	105		30.2	912.04

$n = 5$ $\quad \sum_{i=1} x_i = 374$ $\quad \sum (x_i - \bar{x})^2 = 1698.8$

Standard deviation, $\sigma = \sqrt{\frac{\sum_{i=1}^{5} (x_i - \bar{x})^2}{n-1}} = \sqrt{\frac{1698.8}{5-1}} = 20.61$ cm

Co-efficient of variation, $C_v = \frac{\sigma}{\bar{x}} = \frac{20.61}{74.8} \times 100 = 27.55\%$.

Optimum number of raingauges, $N = \left(\frac{C_v}{\varepsilon}\right)^2 = \left(\frac{27.55}{10}\right)^2 = 7.59 \simeq 8$. (Ans).

02

Q: Determine the optimum number of raingauge station in the watershed of 500 km^2 with allowable error 10%.

Station :	A	B	C	D	E	F
Rainfall (cm) :	800	1040	780	450	650	350

Solution:

Station	Rainfall (cm) x_i	$\bar{x} = \frac{\sum x_i}{n}$	$(x_i - \bar{x})$	$(x_i - \bar{x})^2$
A	800		121.67	14803.59
B	1040		361.67	130805.19
C	780	678.33	101.67	10336.79
D	450		−228.33	52134.59
E	650		−28.33	802.59
F	350		−328.33	107800.59

$n = 6$ $\quad \sum_{i=1}^{6} x_i = 4070$ $\quad \sum (x_i - \bar{x})^2 = 316683.34$

Standard deviation, $\sigma = \sqrt{\frac{\sum_{i=1}^{6} (x_i - \bar{x})^2}{n-1}} = \sqrt{\frac{316683.34}{6-1}} = 251.67$

Co-efficient of variation, $C_v = \frac{\sigma}{\bar{x}} \times 100 = \frac{251.67}{~~4070~~\ 678.33} \times 100 = ~~6.18\%~~$

$= 37.10\%$

∴ Optimum number of raingauge, $N = \left(\frac{C_v}{\varepsilon}\right)^2 = \left(\frac{~~6.18~~\ 37.10}{10}\right)^2$

$= 13.77$

$\simeq 14.$

(Ans).

01

Q. In a certain river basin, there are six raingauge stations, annual rainfall having 42.4, 53.6, 67.8, 78.5, 82.7 and 95.5 cm respectively. Determine optimum number of raingauge stations to limit the error to 10% and indicate how you distribute them.

Solution:

Stations	Annual rainfall (cm) x_i	$\bar{x} = \frac{\sum_{}^{6} x_i}{n}$	$(x-\bar{x})$ cm	$(x-\bar{x})^2$ cm^2
A	42.4		−27.68	766.18
B	53.6		−16.48	271.59
C	67.8	70.08	−2.28	5.20
D	78.5		8.42	70.90
E	82.7		12.62	159.26
F	95.5		25.42	646.18

$n=6$ $\quad \sum_{i=1}^{6} x_i = 420.5$ $\quad \sum(x_i-\bar{x})^2 = 1919.31$

Standard deviation, $\sigma = \sqrt{\frac{\sum_{i=1}^{6}(x_i-\bar{x})^2}{n-1}} = \sqrt{\frac{1919.31}{6-1}} = 19.59$ cm

Co-efficient of variation, $C_v = \frac{\sigma}{\bar{x}} \times 100 = \frac{19.59}{70.08} \times 100 = 27.96\%$.

$\therefore$ Optimum number of raingauge, $N = \left(\frac{C_v}{\varepsilon}\right)^2 = \left(\frac{27.96}{10}\right)^2$

$= 7.82 \simeq 8.$

(Ans).

Existing no. of raingauge = 6

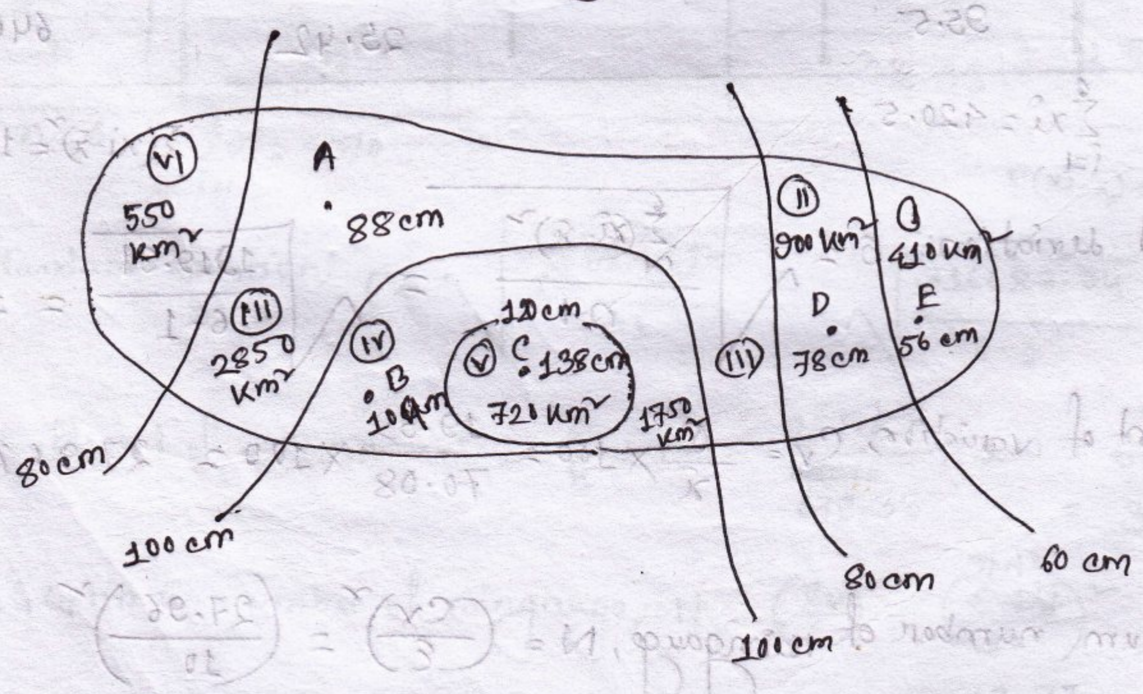
Optimum " " = 8

∴ Additional " " = 8 − 6 = 2

These two additional raingauges are distributed according to the proportion of areas of different zones formed in a isohyetal map of the river basin.

07

Q. For a basin, annual rainfall data and isohyets are given. Determine optimum number of raingauges stations to limit the error in the mean rainfall to 10%. Also distribute the additional gauges, if any what is percentage accuracy of existing network?



Solution :

Station	Normal annual rainfall (cm) x	$\bar{x} = \frac{\sum x_i}{n}$	$(x-\bar{x})$ cm	$(x-\bar{x})^2$ cm^2
A	88		-4.8	23.04
B	104		11.2	125.44
C	138	92.8	45.2	2043.04
D	78		-14.8	219.04
E	56		-36.8	1354.24
n = 5	$\sum_{i=1}^{5} x_i = 464$			$\Sigma = 3764.8$ cm^2

Standard deviation, $\sigma = \sqrt{\frac{\sum(x_i-\bar{x})^2}{n-1}} = \sqrt{\frac{3764.8}{5-1}} = 30.68$ cm

Co-efficient of variation, $C_v = \frac{\sigma}{\bar{x}} \times 100 = \frac{30.68}{92.8} \times 100 = 33.06\%$.

Optimum number of raingauge, $N = \left(\frac{C_v}{\varepsilon}\right)^2 = \left(\frac{33.06}{10}\right)^2 = 10.93$
$\simeq 11$. (Ans).

Existing number of raingauge = 5

Optimum " " " = 11

∴ Additional " " " = 11 − 5 = 6

Distribution of additional raingauges:

Zone	Area Km^2	Area, as decimal of total area	N X Area as decimal	Rounded as	Existing rain gauge	Additional rain gauge
(i)	410	0.06	0.66	1	1	0
(ii)	900	0.12	1.32	1	1	0
(iii)	2850	0.40	4.4	4	1	3
(iv)	1750	0.24	2.64	3	1	2
(v)	720	0.10	1.1	1	1	0
(vi)	550	0.08	0.88	1	0	1

$\Sigma = 7180$

Accuracy of existing network:

Existing number of raingauge, $n = 5$

Coefficient of variation, $C_v = 33.06\%$.

$$n = \left(\frac{C_v}{\varepsilon}\right)^2$$

$$\Rightarrow \sqrt{n} = \frac{C_v}{\varepsilon} \Rightarrow \varepsilon = \frac{C_v}{\sqrt{n}} = \frac{33.06}{\sqrt{5}} = 14.78\%$$

∴ Accuracy of existing network = $(100 - 14.78)$

$= 85.22\%$.

(Ans).

05

Q. consider a rectangular area whose (x,y) co-ordinates are (0,0), (4,0), (0,4) and (4,4). The area is 4km wide and 4 km long. The area has 4 raingauges. The location of the gauges and rainfall data are:

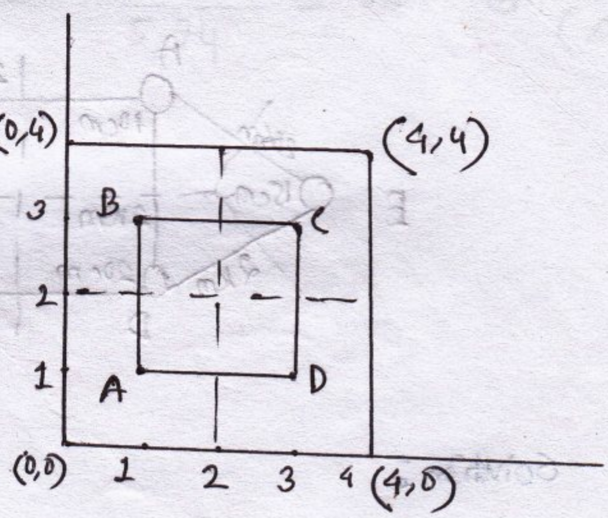
Raingauge	(x,y) km, km	Rainfall (cm)
A	(1, 1)	5
B	(1, 3)	10
C	(3, 3)	8
D	(3, 1)	12

Determine mean rainfall by Thiessen Polygon method.

Solution:

Let us plot the area and raingauge stations in a graph paper.

Let us join A, B, C, D and draw perpendicular bisector of AB BC, CD and AD to form Thiessen Polygon.



Area of outer square $= 4 \times 4 = 16 \text{ km}^2$

" " inner " $= 2 \times 2 = 4 \text{ km}^2$

" " each corner $= \frac{1}{4}(16-4) = 3 \text{ km}^2$

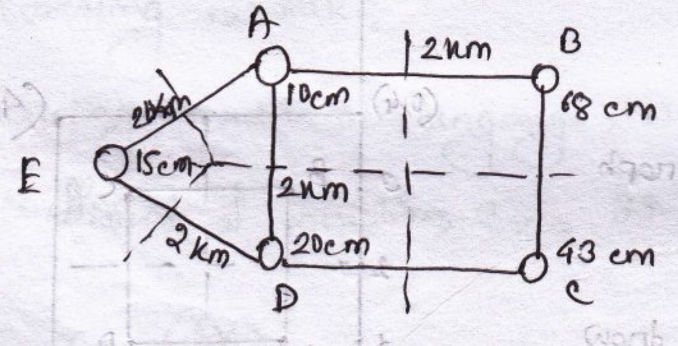
Station	Area km^2	Precipitation P, cm	PA km^2-cm
A	3	5	15
B	3	10	30
C	3	8	24
D	3	12	36

$\Sigma A = 12\ km^2$

$\Sigma PA = 105\ km^2\text{-cm}$

$\therefore$ Mean precipitation $= \frac{\Sigma PA}{\Sigma A} = \frac{105}{12} = 8.75$ cm. (Ans).

Q. Find the mean precipitation by Thiessen polygon method.



Solution:

Let us draw the Thiessen Polygon by drawing perpendicular bisector of the side.

Area of outer square $= 2 \times 2 = 4\ km^2$

Area of each inner " $= \frac{1}{4} \times 4 = 1\ km^2$

Area of triangle $= \frac{\sqrt{3}}{4}(2)^2 = 1.73\ km^2$

$\frac{1}{3}$ Area of triangle $= \frac{1}{3} \times 1.73 = 0.58\ km^2$

Station	Area, A km^2	Precipitation, P cm	PA $km^2 cm$
A	1+0.58=1.58	10	15.8
B	1	68	68
C	1	43	43
D	1+0.58=1.58	20	31.6
E	0.58	15	8.7

$\Sigma A = 5.74$ $\Sigma PA = 167.1$

Mean precipitation $P_{ave} = \frac{\Sigma PA}{\Sigma A} = \frac{167.1}{5.74} = 29.11$ cm (Ans).

Precipitation

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06

Q-1: Define precipitation.

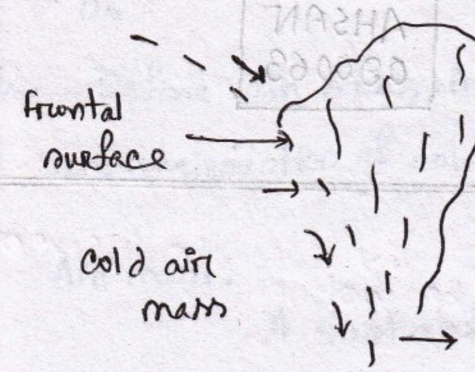
Precipitation:
From the hydrological view point any form of moisture reaching the earth's surface from the atmosphere is called precipitation.

Q-2: Discuss different types of precipitation.

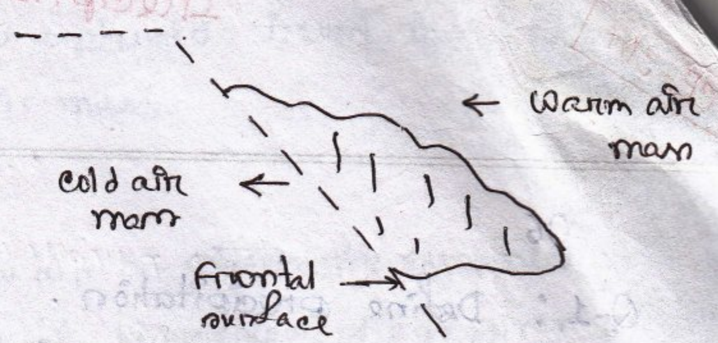
Types of precipitation:
There are mainly four types of precipitation. They are discussed below:

i) Convectional precipitation:
This type of precipitation is in the form of local whirling thunder storms and is typical of the tropics.

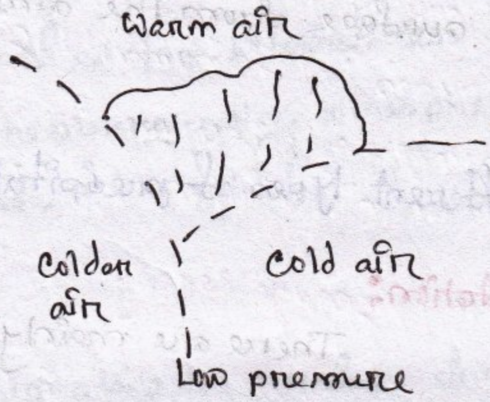
ii) Frontal precipitation:
If a cold air mass drives out a warm air mass it is called a 'cold front' and if a warm air mass replaces the retreating cold air mass it is called a 'warm front'. On the other hand if the two air masses are drawn simultaneously towards a low pressure area, the front developed is stationary and is called a "stationary front". Cold fronts move faster than warm fronts and usually overtake them.



cold front



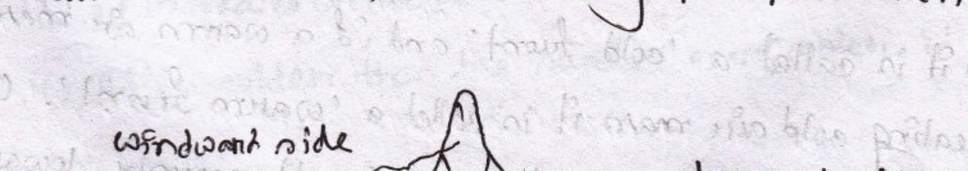
warm front



Stationary front

Fig: Frontal precipitation

iii) ~~Ortho~~ Orographic precipitation: The mechanical lifting of moist air over mountain barriers, causes heavy precipitation on the windward side.



Orographic precipitation

accumulation - জমা হওয়া

iv) Cyclonic precipitation:
This type of precipitation is due to lifting of moist air converging into a low pressure belt i.e due to pressure differences created by the unequal heating of the earth's surface.

06

Q-3: Explain the formation of precipitation.

Formation of precipitation:
There are four essential requisities for the formation of precipitation as-

i) Accumulation of moisture:
The simple principle of conservation of mass requires that a balance must be maintained between evaporation and precipitation. So, water is accumulated in atmosphere by evaporation and transpiration.

ii) Cooling:
There are three types of cooling:
a) cyclonic cooling
b) Orographic cooling and
c) convective cooling

orographic - পর্বত সম্বন্ধীয়

iii) condensation:
condensation takes place when the air is not saturated and contains small particles of substance that have an affinity to water. These particles act as nuclei in the condensation process.

iv) Growth of droplets:

when the condensation nucleus attracts water, a droplet of water is produced and its size increases continuously. In about 24 hours, it becomes a drop of about 3mm. Its size further increases by collision with each other. When the droplets grows enough it comes to surface of earth as anyone form of precipitation.

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Q- : Discuss about different types of recording raingauges.

Types of recording rain gauges:

There are three types of recording rain gauges. They are -

i) Tipping bucket gauge
ii) Weighing gauge
iii) Float gauge

i) Tipping bucket rain-gauge:

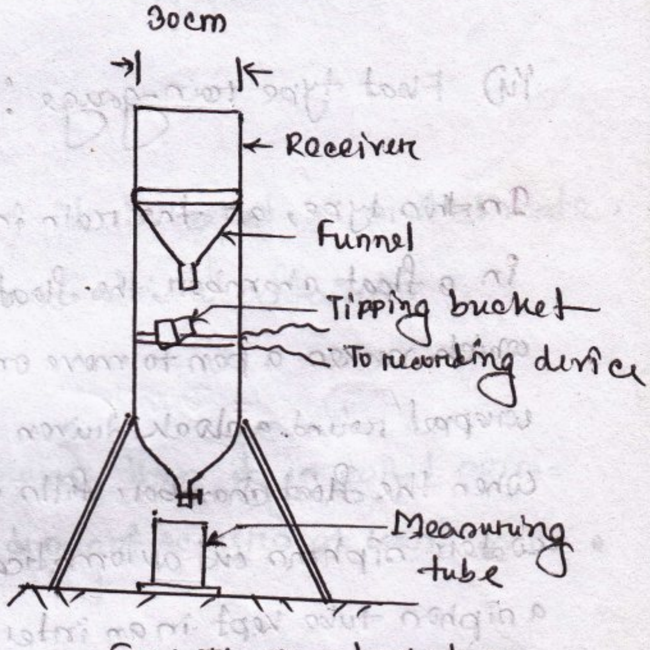


Fig: Tipping bucket gauge

This consist of a cylindrical receiver 30cm diameter with a funnel inside. Just below the funnel a pair of tipping buckets is pivoted such that when one of the bucket receives a rainfall of 0.25mm it tips and empties into a tank below, while the other bucket takes its position and the process is repeated. The tipping of the bucket actuates an electric circuit which causes a pen to move on a chart wrapped round a drum which revolves by a clock mechanism. This type cannot record snow.

ii) weighing type rain-gauge :

In this type of rain-gauge when a certain weight of rainfall is collected in a tank which rests on a spring-lever balance, it makes a pen to move on a chart wrapped round a clock-driven drum, The rotation of the drum sets the time scale while the vertical motion of the pen records the cumulative precipitation .

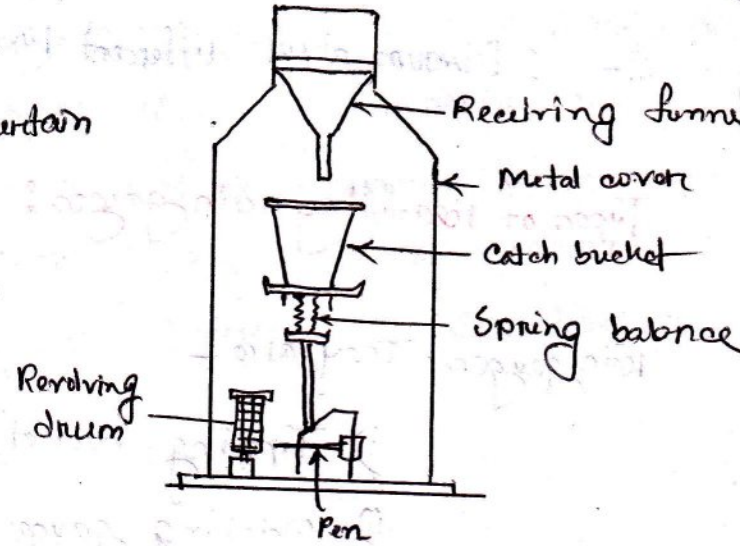


Fig: weighing gauge

iii) Float type rain-gauge :

In this type, as the rain is collected in a float chamber, the float moves up which makes a pen to move on a chart wrapped round a clock driven drum. When the float chamber fills up, the water siphons out automatically through a siphon tube kept in an interconnected siphon chamber. The clockwork revolves the drum once in 24 hours. The clock mechanism needs rewinding once in a week then the chart wrapped round the drum is also replaced.

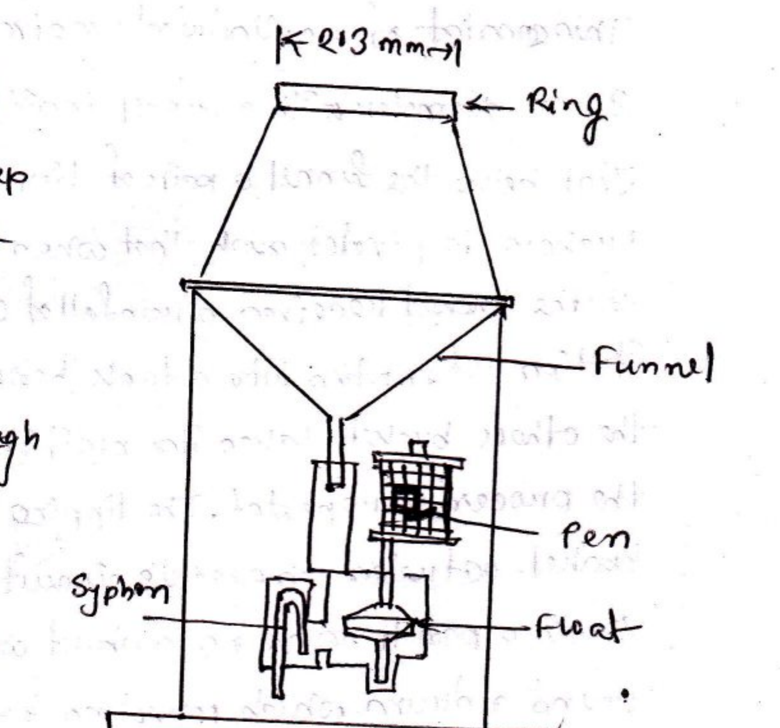


Fig: Float type-gauge

08,07

Q- : Write short notes on the following:

i) A.A.R ii) Isohyten iii) Arid, semi-arid and humid regions

iv) Index of wetness

i) A. A. R (Average Annual Rainfall):

The mean of yearly rainfall observed for a period of 35 consecutive years is called the average annual rainfall (a.a.r)

ii) Isohyten:

A line joining the places having the same a.a.r is called an isohyten.

iii) Arid:

If the a.a.r < 40 cm then it is called arid climate. In an arid climate, a drought is a normal state of affairs.

Semi-arid:

If the a.a.r is 40 to 75 cm then it is called semi-arid climate. In a semi-arid climate, a drought occurs at least once a year except in abnormal years.

Humid or standard:

If the a.a.r > 75 cm, then it is called semi humid or standard climate. In a humid climate, a drought does not occur in ordinary years.

$$\text{Index of wetness} = \frac{P}{A.A.R}$$

iv) Index of wetness:

The ratio of rainfall in a particular year to the a.a.r is called the "index of wetness". For example, an index of wetness of 60% in a particular year indicates a rainfall deficiency of 40%.

Q- : What are the factors a.a.r depends upon.

The a.a.r of a place depends upon:

i) Distance from the ocean
ii) Direction of the prevailing winds
iii) The mean annual temperature
iv) Altitude of the place
v) Its topography - (প্রাকৃতিক সম্মুখ স্থানের বিবরণ)

Altitude = উচ্চতা

Prevailing = অবিরাম

Ex-2.1: (Raghunath-25)

Rain-gauge station D was inoperative for part of a month during which a storm occurred. The storm rainfall recorded in the three surrounding stations A, B and C were 8.5, 6.7 and 9.0 cm, respectively. If the a.a.r for the stations are 75, 84, 70 and 90 cm, respectively, estimate the storm rainfall at station D.

Solution:

$N_D = 90$ cm $\quad N_A = 75$ cm, $N_B = 84$ cm $\quad N_C = 70$ cm

$P_A = 8.5$ cm $\quad P_B = 6.7$ cm $\quad P_C = 9.0$ cm

$\left\{ \frac{N_D - N_A}{N_D} \times 100 = \right.$

$$P_D = \frac{1}{m}\left[\frac{N_D}{N_A} \times P_A + \frac{N_D}{N_B} \times P_B + \frac{N_D}{N_C} \times P_C\right]$$

$$= \frac{1}{3}\left[\frac{90}{75} \times 8.5 + \frac{90}{84} \times 6.7 + \frac{90}{70} \times 9\right]$$

$$= 9.65 \text{ cm.}$$

(Ans).

Ex-5.12 (Reddi):

Rainguage station X did not function for a part of a month during which a storm occurred. The storm produced rainfalls of 84, 70 and 96 mm at these surrounding stations A, B and C respectively. The normal annual rainfalls at the station X, A, B and C are respectively 770, 882, 736 and 944 mm. Estimate the missing storm rainfall at station X.

Solution:

$N_x = 770$ mm $N_a = 882$ mm $N_b = 736$ mm $N_c = 944$ mm

$P_a = 84$ mm $P_b = 70$ mm $P_c = 96$ mm

$$P_x = \frac{1}{m}\left[\frac{N_x}{N_a}P_a + \frac{N_x}{N_b}P_b + \frac{N_x}{N_c}P_c\right]$$

$$= \frac{1}{3}\left[\frac{770}{882}\times 84 + \frac{770}{736}\times 70 + \frac{770}{944}\times 96\right]$$

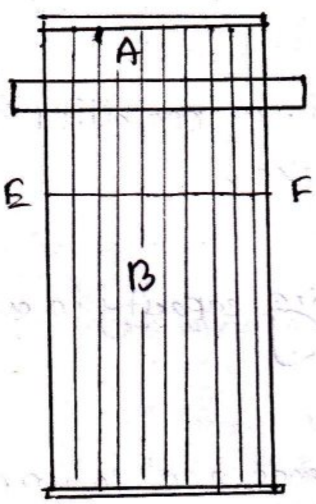
$$= 75 \text{ mm}$$

(Ans).

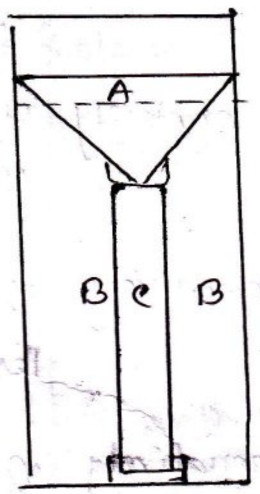
: Explain the components and working of a U.S weather Bureau raingauge / non-recording raingauge.

Components of U.S weather Bureau raingauge:

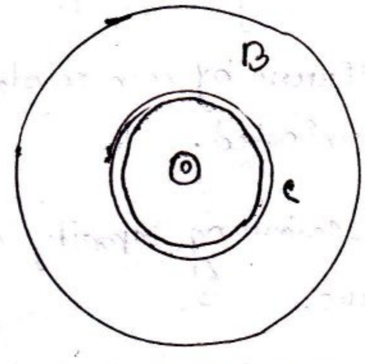
The U.S weather Bureau raingauge consist of a can B, 8″ in diameter and 24″ in depth. It is fitted over a copper receiver A, whose top rim is a knife edge. and bottom consist of a funnel. A measuring tube C under the funnel takes water from the funnel. A measuring stick 24″ long, $\frac{3}{8}$″ wide. and $\frac{1}{8}$″ thick computes the equipment. The cross-section area of measuring stick is exactly one tenth of the opening area of the receiver.



Elevation



vertical section



Section E-F

Working of U.S weather Bureau Raingauge:

The rainwater carried by the funnel is collected in the tube. The tube filled with water and containing measuring stick represents 2″ rainfall. If the days rainfall exceeds 2″, the excess water overflows into the 8″ can. In such cases, when the observer makes the reading, he first submerges the measuring ~~into~~ stick, empties the measuring tube and pours excess water into the tube for measurement.

07

Q- Distinguish between recording and non-recording raingauges giving example of them used in Bangladesh.

Recording raingauge	Non-recording raingauge
i) It can measure duration of rainfall.	i) Duration of rainfall cannot be measured.
ii) Initial cost is more than that of non-recording raingauge.	ii) Initial cost is comparatively less.
iii) Error by man-mistake is completely eliminated.	iii) There is a possibility of error by man-mistake.
iv) Measuring capacity is comparatively more.	iv) Measuring capacity is comparatively less.
v) Maintenance cost is comparatively high.	v) Maintenance cost is comparatively less.
vi) Rainfall in hilly area can be measured accurately.	vi) Rainfall data in hilly area cannot be measured accurately.

99,08,03,06,08

Q- : what factors you consider in selecting a site for a raingauge station.

Factors for selecting site of a raingauge station:

The following are the important factors to be considered in selecting a site for a raingauge station:

i) The gauge shall be placed on a level ground, not upon a slope or never on a wall or roof.

ii) The site should be on open place.

iii) The distance of raingauge from any obstacle should be greater than twice of height of obstacle.

iv) Site should be easily accessible at all times.

v) In hills, site should be chosen where it is best shielded from wind action. (কুয়েট/রুয়েট)

vi) Site should be away from continuous wind forces.

vii) The gauge should be truly vertical

viii) The percent of total number of raingauge stations of any basin should be self-recording.

ix) The observer must visit the site regularly to ensure its proper readiness for measurement.

00

Q- : Write down the advantages and disadvantages of recording type raingauge.

Advantages:

i) It provides a detail information about the rainfall such as rainfall depth and its duration.

ii) There is no need of an attendant to measure rainfall amount with respect to time.

iii) The error in rainfall data by man mistakes is completely eliminated.

iv) It is the only means to record the rainfall data in hilly areas.

v) It provides information about onset and cessation of rainfall.
(আরম্ভ) (থামা)

vi) It represents the entire rainfall information in graphs which helps in storm analysis.

vii) Measuring capacity is more.

viii) Provides more authentic result.
(প্রকৃত)

Disadvantages:

i) It's cost is more than that of a non-recording raingauge

ii) It requires a regular service for proper working.

iii) Maintenance cost is comparatively high.

iv) Additional precautions are required to operate the gauge.

v) Recording of rainfall data may be interrupted due to some mechanical fault.

01, 03, 05, 09

Q : Explain how you would determine the optimum number of raingauges to be erected in a given basin.

Optimum rain-gauge network design:

The procedure for determining the optimum number of raingauge to be installed in a given basin is explained below:

i) Mean annual rainfall is calculated from the data recorded at existing rain gauge station by using the relation;

$$\bar{P} = \frac{\sum_{i=1}^{n} P_i}{n} = \frac{P_1 + P_2 + \dots \dots + P_n}{n}$$

where, $\bar{P}$ = mean annual rainfall

n = total number of raingaugs

$P_1, P_2, \dots, P_n$ = annual rainfall recorded in station 1, 2, .. n etc respectively.

ii) The standard deviation σ is determined from existing stations record using the relation,

$$\sigma = \sqrt{\frac{\sum_{i=1}^{n} (P_i - \bar{P})^2}{n-1}}$$

iii) coefficient of variation C_v is calculated as,

$$C_v = \frac{\sigma}{\bar{P}} \times 100$$

iv) Optimum number of raingauges required to install is calculated from the following relation

$$N = \left(\frac{C_v}{\mathcal{E}}\right)^2$$

where, C_v = coefficient of variation of the rainfall of the existing rain gauge stations.

$\mathcal{E}$ = percentage allowable error

N = optimum number of raingauges required.

Q. Define wet year and dry year.

Wet year/ Good year:

The year in which rainfall is greater than mean rainfall is called wet year or good year.

According to Bland Ford, wet year = $(1.24 \text{ to } 2.54)\bar{x}$

According to Alexander Binnie, wet year = $1.51\bar{x}$.

Dry year/Bad year:

The year in which rainfall is less than mean rainfall is called bad year. According to Bland Ford in a bad year rainfall should be 0.27 to 0.78 times of a.a.r.

Mean Areal Depth of Precipitation :

i) Arithmatic average method

ii) Thiessen polygon method

iii) The isohyetal method

i) Arithmatic average method :

It is obtained by simply averaging arithmetically the amounts of rainfall at the individual rain-gauge stations in that area.

i.e,

$$P_{ave} = \frac{\sum P_1}{n}$$

where, P_{ave} = average depth of rainfall over the area

$\sum P_1$ = sum of rainfall amounts at individual rain-gauge stations

n = number of rain-gauge stations in the area.

ii) Thiessen polygon method :

In this method, the stations are plotted in a map and joined by straight lines, perpendicular bisectors are drawn to the straight lines and several polygons are formed. Mean areal depth is determined as-

$$P_{ave} = \frac{\sum_{i=1}^{n} P_i A_i}{\sum_{i=1}^{n} A_i}$$

where, $P_i = P_1, P_2, P_3 \ldots P_n$ = Rainfall at the stations inside polygon 1, 2, 3, ... n respectively

$A_i = A_1, A_2, A_3 \ldots A_n$ = Area of polygon 1, 2, 3 respectively

iii) The isohyetal method :

In this method, point rainfalls are plotted in a map and isohyet are drawn. Average rainfall between two successive isohytes taken as average of two isohyetal value are weighted with the area between the isohyets, added up and divided by total area which gives mean areal depth. Mathematically,

$$P_{ave} = \frac{\sum_{i=1}^{n} A_{i-(i+1)} P_{i-(i+1)}}{\sum_{i=1}^{n} A_{i-(i+1)}}$$

Here, $P_{i-(i+1)} = \frac{P_i + P_{i+1}}{2}$

$\sum A_{i-(i+1)}$ = Area between isohyet i and isohyet $(i+1)$

☐ Arithmetic average method :

If the normall annual precipitations at the adjacent stations are within 10% of the normall rainfall of the station under consideration, then the missing rainfall data may be estimated as a simple arithmetic average of the rainfalls at the adjacent gauges. Thus, if the missing precipitation at station X is P_x and $P_1, P_2, \ldots P_m$ are the rainfalls at the m surrounding raingauges,

$$P_x = \frac{1}{m}(P_1 + P_2 + \ldots \ldots + P_m)$$

☐ Normal ratio method :

If the normall annual rainfalls at the surrounding gauges differ from the normal annual rainfall of the station by more than 10%, the normal ratio method is preferred. In this method the rainfall values at the surrounding stations are weighed by the ratio of the normal annual rainfalls. That is,

$$P_x = \frac{1}{m}\left[\frac{N_x}{N_1}P_1 + \frac{N_x}{N_2}P_2 + \ldots \ldots + \frac{N_x}{N_m}P_m\right]$$

where, N_x is the normall annual rainfall at station X and $N_1, N_2, \ldots N_m$ are the normall annual rainfalls at the m surrounding gauges.

☐ Weighted average of four stations:

This method consists of the following steps:

i) Four quardant are fixed by North - South and East - West lines passing through the station with missing data.

ii) In each quardant a nearest raingauge station is selected.

iii) Weight applicable to each station is computed as the reciprocal of square of distance from origin to the station.

iv) Rainfall data in each station is multiplied by respective weight and added.

v) Missing data is computed by dividing the sum by sum of weights.

Mathematically,

$$P_x = \frac{\left[\frac{1}{r_1^2}P_1 + \frac{1}{r_2^2}P_2 + \frac{1}{r_3^2}P_3 + \frac{1}{r_4^2}P_4\right]}{\left[\frac{1}{r_1^2} + \frac{1}{r_2^2} + \frac{1}{r_3^2} + \frac{1}{r_4^2}\right]}$$

Q : Describe the procedure of double mass-curve analysis.

Procedure for double mass-curve analysis:

i) The doubtful station, say A, is marked and the group of stations surrounding it are identified.

ii) A table is prepared in which the first column represents the year in decreasing order i.e it starts with the latest year of station A.

iii) Yearly precipitation of values of station A are written in second column.

iv) In the third column the cumulative rainfall of second column are entered.

v) Mean yearly precipitation of the group of stations surrounding station A are computed and entered in the fourth column against the year of col 1.

vi) In column five, cumulative precipitation of the group of stations of column four are computed.

vii) A graph is plotted taking the cumulative rainfall of the group of station as abscissa and cumulative rainfall of the station A as ordinate. Consecutive points are joined by straight line.

viii) If the consistency of the station A has undergone changes from any year, then it can be noticed from the slope of the plot. The line joining the initial points of the graph are extended by a dotted line and correction is computed.

IX) Rainfall of subsequent years from the year of deviation are corrected by multiplying the correction factor.

Q- : Describe the procedure of isohyetal method.

Procedure of Isohyetal Method:

i) A map of the basin is drawn to scale.

ii) All gauge stations in and around the basin are accurately located on the map.

iii) Depth of precipitation recorded at each station are marked on the map.

iv) Isohyets are drawn by eye ~~estim~~ approximation.

v) Area between successive isohyets within the basin is measured.

vi) Average precipitation between two successive isohyets multiplied by the area bounded by them should be computed for all isohyets covering the area.

vii) Sum of all such products over the entire basin divided by the total area of the basin given a average precipitation.

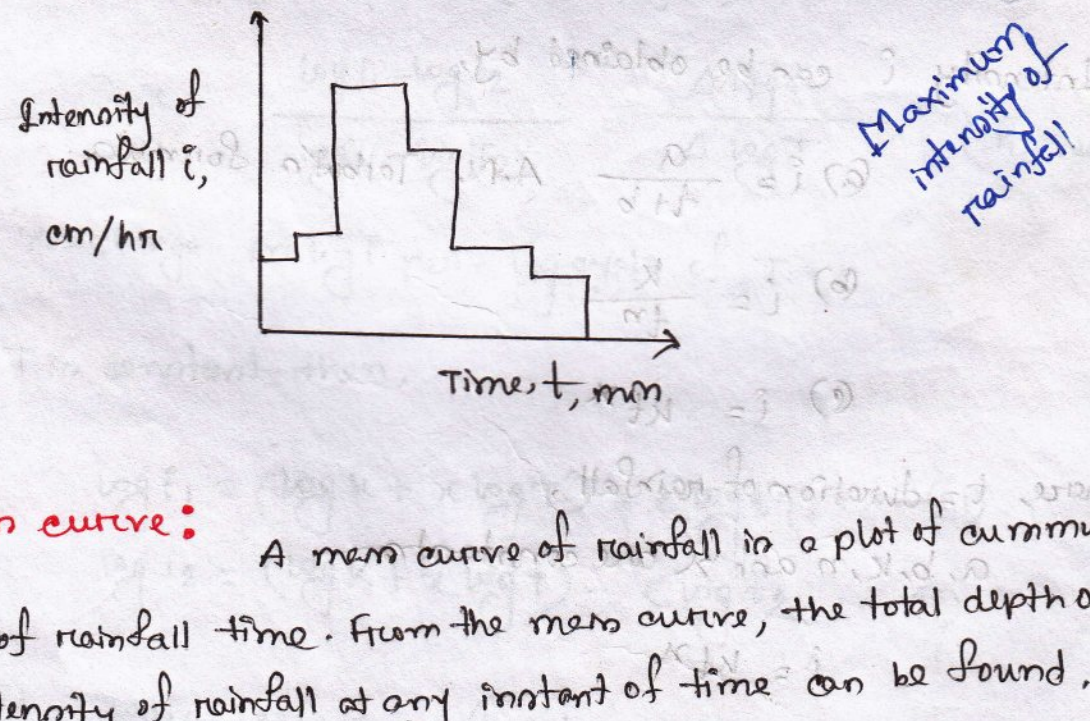
Q- : What do you mean by graphical representation of rainfall.

GRAPHICAL REPRESENTATION OF RAINFALL:

The variation of rainfall with respect to time may be shown graphically by ⓐ a hyetograph and ⓑ a mass curve.

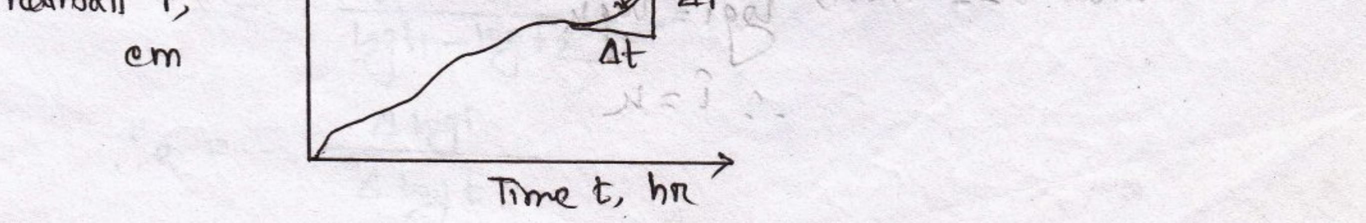
ⓐ Hyetograph:

A hyetograph is a bar graph showing the intensity of rainfall with respect to time. It is useful in determining the maximum intensities of rainfall during a particular storm as is required in land drainage and design of culverts.



ⓑ Mass curve:

A mass curve of rainfall is a plot of cummulative depth of rainfall time. From the mass curve, the total depth of rainfall and intensity of rainfall at any instant of time can be found.



Q- : What are the characteristics of a rainstorm.

Characteristics of rainstorm:

The characteristics of a rainstorm are—

i) intensity (cm/hr)

ii) duration (min, hr or days)

iii) frequency (once in 5 years or once in 10, 20, 40, 60 or 100 years)

iv) areal extent (i.e area over which it is distributed).

Analysis of rainfall data:

Intensity i can be obtained by,

(a) $i = \frac{a}{t+b}$ A.N. Talbot's formula

(b) $i = \frac{k}{t^n}$

(c) $i = kt^x$

where, t = duration of rainfall,

a, b, k, n and x are constants

$$i = kt^x$$

$$\Rightarrow \log i = \log k + x \log t$$

when $t = 1$ then, $\log i = \log k$

$$\therefore i = k$$

Q- : From Sherman formula proved that; $x = \frac{\Delta \log i}{\Delta \log T}$ and $e = -\frac{\Delta \log i}{\Delta \log t}$

we know from Sherman formula that,

$$i = \frac{KT^x}{t^e}$$

$$\Rightarrow \log i = (\log K + x \log T) - e \log t$$

when t is constant then,

$$\log i_1 = (\log K + x \log T_1) - e \log t \quad \text{---(i)}$$

$$\log i_2 = (\log K + x \log T_2) - e \log t \quad \text{---(ii)}$$

(i) - (ii) $\Rightarrow$ $\log i_1 - \log i_2 = x(\log T_1 - \log T_2)$

$$\Rightarrow x = \frac{\log i_1 - \log i_2}{\log T_1 - \log T_2} = \frac{\Delta \log i}{\Delta \log T} \quad \text{(Proved).}$$

when, x = change in $\log i$ per log cycle of T

T is constant then,

$$\log i_1 = (\log K + x \log T) - e \log t_1 \quad \cdots \text{(iii)}$$

$$\log i_2 = (\log K + x \log T) - e \log t_2 \quad \cdots \text{(iv)}$$

(iii) - (iv) $\Rightarrow$ $\log i_1 - \log i_2 = -e(\log t_1 - \log t_2)$

$$\Rightarrow e = -\frac{\log i_1 - \log i_2}{\log t_1 - \log t_2}$$

$$\therefore e = -\frac{\Delta \log i}{\Delta \log t}$$

If there are a total number of n items and the order number or rank of any particular storm is m, then the recurrence interval T of that storm magnitude is given by one of the following equations:

(a) California method, $T = \frac{n}{m}$

(b) Hazen's method, $T = \frac{n}{m - \frac{1}{2}}$

(c) Kimball's method, $T = \frac{n+1}{m}$

and the Frequency F of that storm magnitude is given by

$$F = \frac{1}{T} \times 100\%.$$

* The probability that a T-year storm may not occur in any series of N years is,

$$P_{(N,0)} = (1-F)^N$$

and that it may occur is,

$$P_{EX} = 1-(1-F)^N$$

where, P_{EX} = probability of occurance of a T-year storm in N-years

Ex-2.6 (Raghunath)

The annual rainfall at a place for a period of 10 years from 1961 to 1970 are respectively 30.3, 41.0, 33.5, 34.0, 33.3, 36.2, 33.6, 31.2, 35.5, 36.3 . Determine the mean and median values of annual rainfall for the place.

Solution:

i) Mean $= \frac{\Sigma x}{n}$

$$= \frac{30.3+41+33.5+34+33.3+36.2+33.6+30.2+35.5+36.3}{10}$$

$= 34.39$ cm (Ans).

ii) Median:

Arrange the samples in the ascending order

30.2, 30.3, 33.3, 33.5, 33.6, 34, 35.5, 36.2, 36.3, 41

No of items = 10

∴ Median $= \frac{33.6+34}{2}$

$= 33.8$ cm (Ans).

Ex-2.7 (Raghunath):

The following are the rain gauge observations during a storm, construct:

a) mass curve of precipitation

b) hyetograph

c) maximum intensity duration curve and develop a formula

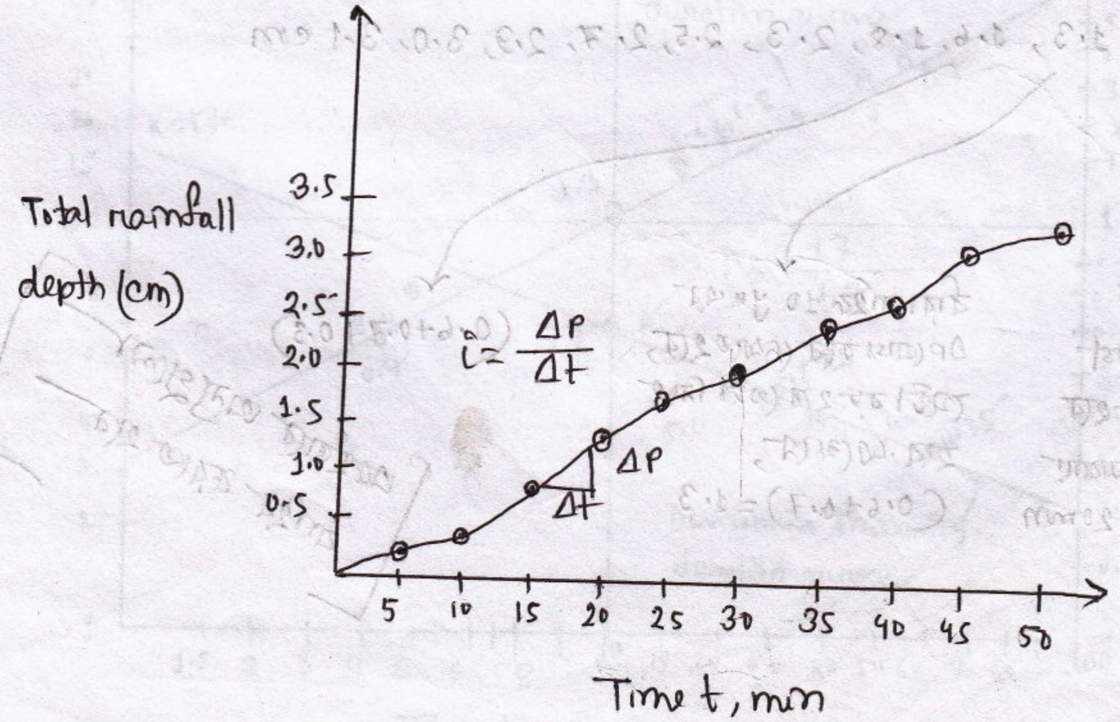
d) maximum depth duration curve

Time since commencement of storm (min)	Accumulated rainfall (cm)
5	0.1
10	0.2
15	0.8
20	1.5
25	1.8
30	2.0
35	2.5
40	2.7
45	2.9
50	3.1

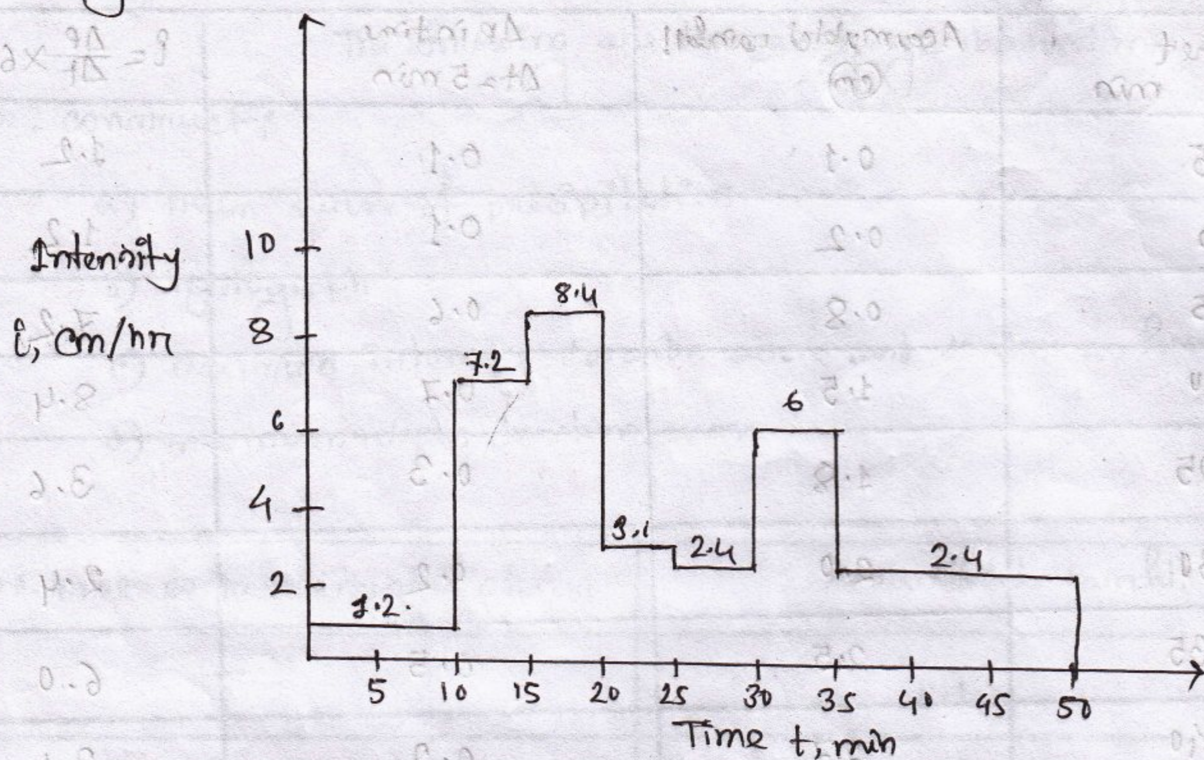
Solution:

Time t min	Accumulated rainfall (cm)	Δp in time Δt = 5 min	$i = \frac{\Delta p}{\Delta t} \times 60$
5	0.1	0.1	1.2
10	0.2	0.1	1.2
15	0.8	0.6	7.2
20	1.5	0.7	8.4
25	1.8	0.3	3.6
30	2.0	0.2	2.4
35	2.5	0.5	6.0
40	2.7	0.2	2.4
45	2.9	0.2	2.4
50	3.1	0.2	2.4

a) Mass curve:



b) hyetograph :



c) Maximum depth duration curve :-

By inspection of time (t) and accumulated rainfall (cm) the maximum rainfall depth during

5, 10, 15, 20, 25, 30, 35, 40, 45 and 50 min durations are

0.7, 1.3, 1.6, 1.8, 2.3, 2.5, 2.7, 2.9, 3.0, 3.1 cm

এটা আসলে 5 এর ΔP থেকে করে, যেটা বড় হবে সেটা, 0.7 সবচেয়ে বেশি যখন t = 20 min

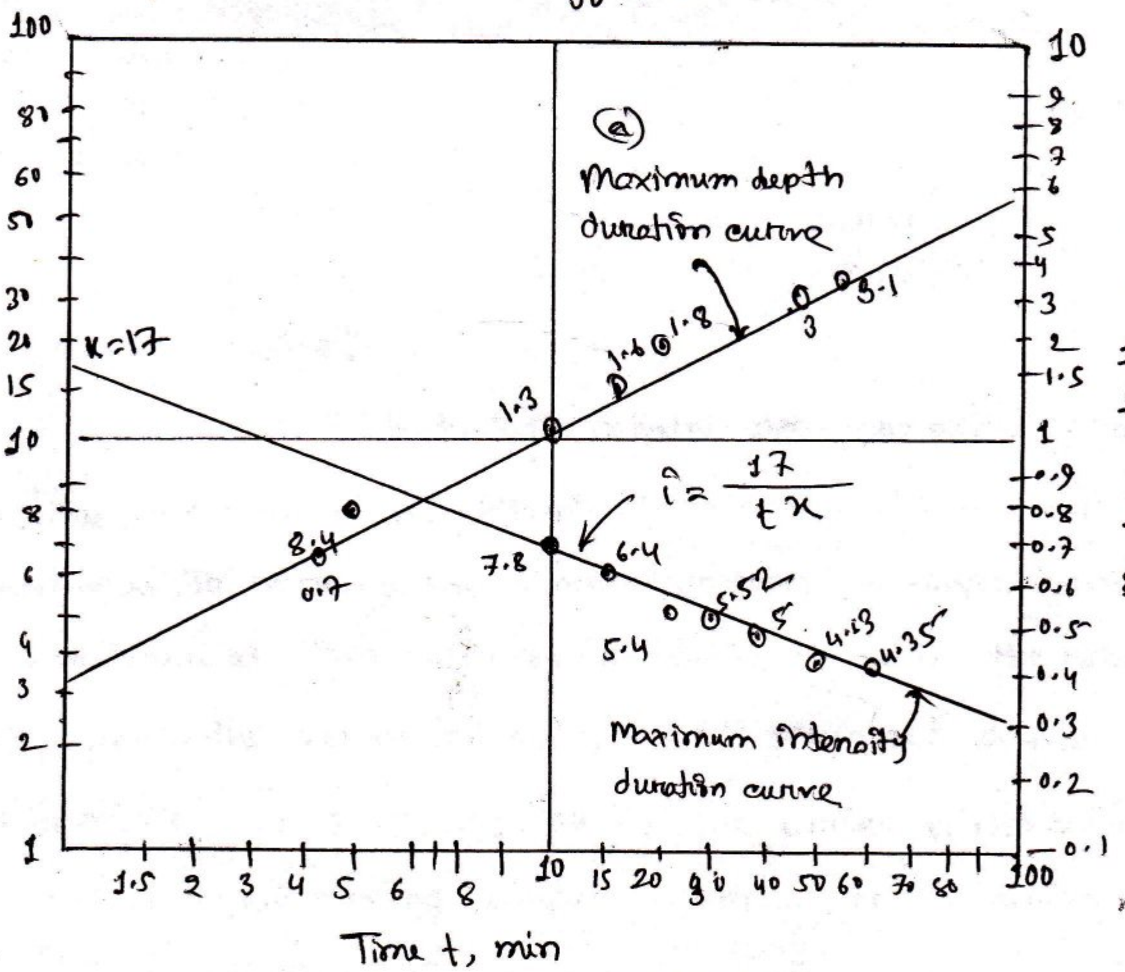
কিন্তু এখানে 10 এর জন্য ΔP যোগ করে দেখতে হবে, যেটা বড় হবে সেটা নিতে হবে, এখানে, (0.6+0.7) = 1.3

(0.6+0.7+0.3)

একইভাবে অন্যগুলো বাহির করতে হবে

d) Maximum intensity duration curve:

ΔP (cm)		$i = \frac{\Delta P}{\Delta t} \times 60$ (cm/hr)
0.7	–	$\frac{0.7}{5} \times 60 = 8.4$
1.3	–	$\frac{1.3}{10} \times 60 = 7.8$
1.6	–	$\frac{1.6}{15} \times 60 = 6.4$
1.8	–	$\frac{1.8}{20} \times 60 = 5.4$
2.3	–	$\frac{2.3}{25} \times 60 = 5.52$
2.5	–	$\frac{2.5}{30} \times 60 = 5$
2.7	–	$\frac{2.7}{35} \times 60 = 4.63$
2.9	–	$\frac{2.9}{40} \times 60 = 4.35$
3.0	–	$\frac{3}{45} \times 60 = 4$
3.1	–	$\frac{3.1}{50} \times 60 = 3.72$



Q – : Write short note on PMP.

PMP (Probable Maximum Precipitation):

Probable maximum precipitation (PMP) is defined as the estimate of the extreme maximum rainfall of a given duration that is physically possible over the basin under critical hydrological and meteorological conditions.

Two available methods of PMP estimation are—

i) Statistical procedure

ii) Meteorological approach

The concept of PMP is very important in estimating the maximum probable flood in the safe design of flood control structures, spillways for dams etc.

Q – : Write short note on moving average curve.

Moving Average Curve:

In hydrology, rainfall data are plotted chronologically between time in X-axis and precipitation in Y-axis. A rain event is associated with randomness. To overcome the random component, a simple moving average of order 3 or 5 is used. This helps to isolate the trend in the rainfall data. From the graph, the wet period mean, overall mean and dry period mean can be identified. If x_1, x_2, x_3, x_4, x_5 are annual precipitation at a station and a 5 year moving average is applied to the series the following moving mean are computed

$$X_1 = \frac{x_1+x_2+x_3+x_4+x_5}{5}$$

$$X_2 = \frac{x_2+x_3+x_4+x_5+x_6}{5}$$

Q- : What are the limitations of Thissen Polygon method.

Limitations of Thissen Polygon method:

i) If the network of a basin is changed i.e if there is an addition or removal of a station from the basin, then a new thissen diagram is to be drawn,

ii) Orographic features are not accounted for

iii) A linear variation of precipitation between two stations is assumed, whereas the precipitation is influenced by a large number of meteorological and catchment characteristics.

iv) Topographic influences and other barriers are not considered,

Q. Discuss about common errors in rainfall measurements.

Common errors in rainfall measurements:

i) The data obtained from the measurement of rainfall, using non-recording type raingauge, may be erroneous due to displacement of water level by measuring scale. This error ranges upto 2%.

ii) Some volume of water is lost in wetting of initially dried surfaces of the measuring gauge, which depends upon the roughness and dryness of the surface.

iii) Atmospheric temperature also yields some error by increasing the evaporation loss.

iv) Splashing of water from the collecting funnel, yields some error.

v) Inaccurate recording of the observation, produces errors in the measurement.

vi) Frictional effect in recording mechanism, introduces erroneous result.

vii) The obstructions like trees, building etc. create the errors by affecting the wind pattern of the location.

Q. What is meant by probable maximum precipitation? Describe methods of estimating PMP. What are its design applications.

Probable maximum precipitation:

Probable maximum precipitation (PMP) is defined as the estimate of the extreme maximum rainfall of a given duration that is physically possible over the basin under critical, hydrological and meteorological conditions.

Methods of estimating PMP:

Two available methods of PMP estimation are –

i) Statistical procedure
ii) Meteorological approach

i) Statistical procedure:

The statistical approach of PMP uses the following shown equation

$$PMP = \bar{P} + K\sigma$$

where, $\bar{P}$ = mean of annual maximum values
σ = standared deviation
K = frequency factor (5–35)

This method gives a rough estimate of the magnitude of the event

ii) Meteorological approach :

In meteorological approach, the storm experience of the basin is maximised by taking all the storms of the basin and adjoining areas which are meteorologically homogenious. Steps involved in obtaining PMP are—

a) Depth area duration analysis of major storms of the region

b) Maximisation of the storm

c) enveloping the maximised values of all the storms to obtain DAD curve of PMP.

(Depth Area Duration)

Q. What are the importance of analysis of rainfall data.

Importance of analysis of rainfall data:

i) It provides an estimate of future rainfall trend.

ii) Determines the rainfall intensity and occurrence of flood producing storms.

iii) Adjustment of rainfall data can be made.

iv) Seasonal and annual rainfall variation can be determined.

v) The maximum and minimum rainfall are also determined.

vi) Rainfall distribution at various frequencies can be studies.

08

Q. Explain the methodology of raingauge installation. (Suresh - 33)

The ~~ex.~~ following points should be kept in view for installing the raingauges:

i) The ground surface must be level.

ii) The site should be such that, it can represent the entire watershed.

iii) The wind affected area should be avoided for locating the raingauge.

iv) The site should be open.

06,04

Q. What is raingauge density? How does it affect the accuracy of rainfall measurement.

Raingauge density:

The number of raingauges to be installed in a given area is commonly known as raingauge density.

Effect of raingauge density on rainfall measurement:

The accuracy of rainfall measurement largely depends on the number of raingauges and the number of raingauge stations installed in the area. If the number of raingauge for a particular area is increased, then percentage of error in rainfall measurement is reduced.

The specification for raingauge density is given below:

Area	Raingauge density
Plains	1 in 520 km^2
Elevated region	1 in 260 – 390 km^2
Hilly and very heavy rainfall area	1 in 130 km^2 with 10% of raingauge stations

Since the catching area of a raingauge is limited and very small compared to areal extent of a storm, it is obvious that to get an accurate measurement raingauge density should be as large as possible.

Q. Define air mass, air front and the occluded front. Discuss the characteristics of cold and warm air mass.

Air mass:

A vast and deep body of the air in which the temperature and humidity characteristics are relatively homogenious at any given elevation is called an air mass.

Air front: The surface of contact between two adjacent air masses or between an air mass and the surrounding atmosphere is called a frontal surface or simply air front.

Occluded front:

Sometimes along the surface front there may be a cold front and warm front. On certain occasions a cold front may overtake a warm front in such a manner that the warm air between them is displaced upward, Then it is called an occluded front.

characteristics:

Cold air mass:

I) It is heated from below therefore it is often unstable

ii) It is colder than the surface over which it moves.

warm air mass:

I) It is cooled from below and becomes more | stable.

ii) It is warmer than the surface over which it moves,

CE-307

Runoff

and its computation

AHSAN HABIB
090063

Q. Define runoff. (S-14б)

Runoff :

A part of precipitation flows over the land called runoff.

Runoff may be defined as, that portion of rainfall which makes its way towards the rivers, streams oceans etc.

Runoff = surface runoff + Base flow

Q. Discuss about different type of runoff. (S-14б)

Types of runoff :

Runoff is broadly classified into following three types –

i) Surface runoff

ii) Sub-surface runoff and

iii) Base flow

i) Surface runoff :

It is that portion of rainfall which enters the streams, channels etc, immediately after occurring the rainfall.

ii) Sub-surface runoff:

It is that amount of rainfall, which first leaches into the soil and then starts flowing laterally without joining the water-table to the streams, rivers etc, called as sub-surface runoff.

iii) Base flow:

It is a delayed flow, defined as that part of rainfall, which after falling over the ground surface, percolates into the soil and meets to the water table and finally joins to the streams, ocean etc.

**** Q. Define distribution co-efficient.

Distribution co-efficient:

The distribution coefficient can be defined as the ratio of maximum rainfall at a point to the mean rainfall of the concern catchment. i.e,

$$C_d = \frac{\text{Maximum rainfall amount}}{\text{Mean rainfall}}$$

The effect of rainfall distribution on runoff can be presented by a term known as 'distribution coefficient'.

Q. What are the factors affecting runoff.

Factors affecting runoff:

The various factors which affect the runoff from a drainage basin depend upon the following characteristics:

1) Storm characteristics:

i) Type or nature of storm and season
ii) Intensity
iii) Duration
iv) Areal extent (distribution)
v) Frequency
vi) Antecedent precipitation
vii) Direction of storm movement

SMBS

2) Meteorological characteristics:

i) Temperature
ii) Humidity
iii) Wind velocity
iv) Pressure variation

3) Basin characteristics:

i) Size
ii) Shape
iii) Slope
iv) Altitude
v) Topography
vi) Geology
vii) Land use
viii) Orientation
ix) Type of drainage net
x) Proximity to ocean & mountain ranges

4) Storage characteristics:

i) Depressions
ii) Pools and ponds
iii) Stream
iv) Channels
v) Check dams
vi) Upstream reservoir
vii) Flood plains

03 Distinguish between ↓

Q. Define : Depression storage, detention storage.

Depression storage:
When the overland flow starts, some flowing water is held in puddles (ডোবা), pits (কূপ) and small ponds, this water stored is called depression storage. For most basin it lies between 10 and 50 mm

Detention storage:
The volume of water in transit in the overland flow which has not yet reached the stream channel is called surface detention or detention storage.

Q. Define bank storage with figure.

Bank storage:

The portion of runoff in a rising flood in a stream which is absorbed by the permeable boundaries of the stream above the normal phreatic surface is called bank storage.

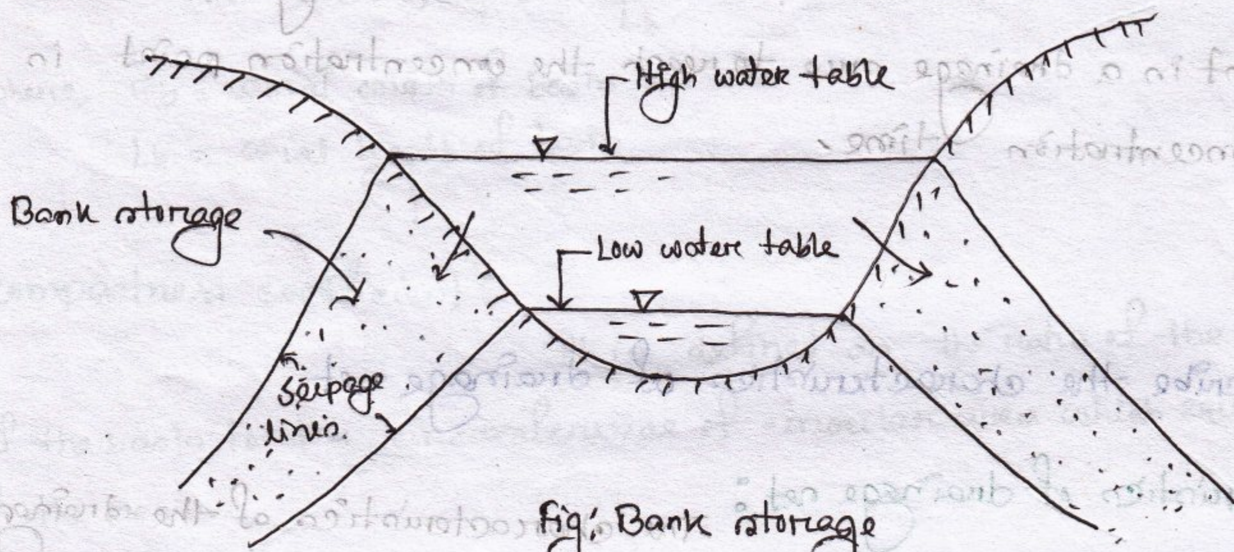


Fig: Bank storage

Q. Discuss catchment characteristics.

07

Drainage basin:/ Catchment area:

The entire area of a river basin whose surface runoff drains into the river in the basin is considered as a hydrologic unit and is called drainage basin, watershed or catchment area of the river flowing.

Drainage divide: The boundary line, along a topographic ridge, separating two adjacent drainage basins is called drainage divide.

Concentration point or measuring point:

The single point or location at which all surface drainage from a basin comes together or concentrates as outflow from the basin in the stream channel is called concentration point or measuring point.

Concentration time:

The time required for the rain falling at the most distant point in a drainage area to reach the concentration point is called the concentration time.

Q. Describe the characteristics of drainage net.

Characteristics of drainage net: The characteristics of the drainage net may be physically described by -

i) the number of streams
ii) the length of streams
iii) Stream density
iv) drainage density

Q. Define: form factor, compactness coefficient, elongation ratio, circularity ratio.

Form factor: It is defined as the ratio of the axial width of basin to the axial length of basin.

$$\text{Form factor, } F_f = \frac{W_b}{L_b}$$

where, W_b = axial width of basin
L_b = axial length of basin

Compactness coefficient: It is defined as the ratio of the perimeter of the basin to the circumference of circular area which equals the area of the basin.

$$\text{Compactness coefficient, } C_c = \frac{P_b}{2\sqrt{\pi A}}$$

where, P_b = perimeter of the basin
$2\sqrt{\pi A}$ = circumference of circular area which equals the area of the basin

Elongation ratio: It is defined as the ratio of the diameter of a circle of the same area as the basin to the maximum basin length. The values range from 0.4 to 1.0

$$E_r = \frac{2R}{L_b}$$

Q. Define stream density, drainage density.

Stream density:

The stream density of a drainage basin is expressed as the number of streams per square kilometre.

$$\text{Stream density, } D_s = \frac{N_s}{A}$$

where, N_s = number of streams, A = area of the basin

Drainage density:

Drainage density is expressed as the total length of all streams channels per unit area of the basin.

$$\text{Drainage density, } D_d = \frac{L_s}{A}$$

where, L_s = total length of all stream channels in the basin

Average stream slope:

Average stream slope is the ratio of the total fall of the longest water course to the length of the longest water course.

$$\text{Average stream slope} = \frac{\text{total fall of the longest water course}}{\text{length of the longest water course}}$$

Circularity ratio:

It is defined as the ratio of the basin area to the area of a circle having the same perimeter as the basin. The values range from 0.2 to 0.8.

$$C_R = \frac{A}{\pi R^2}$$

Q. In the fern-shaped catchments the time of concentration is more where in case of fan-shaped catchments it is less – why?

A fan-shaped catchment produces greater flood intensity since all the tributaries are nearly of the same length and hence the time of concentration is nearly the same and is less.

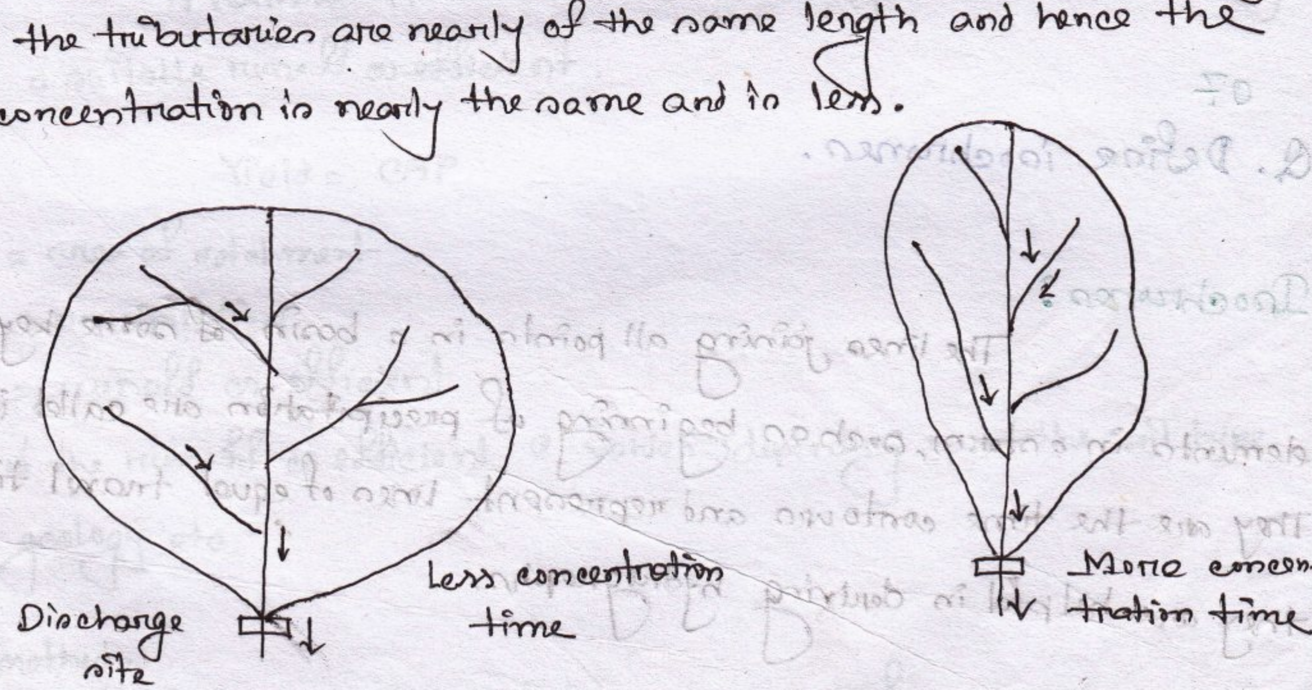


fig: Fan and fern shaped catchments

whereas in the fern-shaped catchments, the time of concentration is more and the discharge is distributed over a long period.

Q. Define intermittent and perennial streams.

Intermittent streams:

If the G.W.T lies above the bed of the stream during the wet season but drops below the bed during the dry season, the stream flows during wet season but becomes dry during dry seasons. Such streams are called intermittent streams.

Perennial streams:

In the case of perennial streams, even in the most severe droughts, the G.W.T never drops below the bed of the stream and therefore they flow throughout the year. For power development a perennial stream is the best.

07

Q. Define isochrones.

Isochrones:

The lines joining all points in a basin of some key time elements in a storm, such as beginning of precipitation are called isochrones. They are the time contours and represent lines of equal travel time and they are helpful in deriving hydrographs.

Q. What are the various runoff estimation methods? Explain the rational method.

Runoff Estimation:

The runoff from rainfall may be estimated by the following methods.

i) Empirical formulae, curves and tables
ii) Infiltration method
iii) Rational method
iv) Overland flow hydrograph
v) Unit hydrograph method.

OUR ES

Rational Method:

A rational approach is to obtain the yield of a catchment by assuming a suitable runoff co-efficient.

Yield = CAP

where, A = area of catchment
P = precipitation
C = runoff co-efficient

The value of the runoff co-efficient C varies depending upon the soil type, vegetation, geology etc.

In this method,

i) Drainage area is divided into a number of sub-areas
ii) From the known concentration times for different areas, runoff contribution from each area is calculated.

iii) A suitable value of runoff coefficient is chosen and runoff is calculated.

07

Q. Define maximum flood discharge.

Maximum flood discharge:

It is the discharge in times of flooding of the catchment area i.e. when the intensity of rainfall is greatest and the condition of the catchment regarding humidity is also favourable for an appreciable runoff.

Stream Gauging

05.02

Q. Define stream gauging. What are the methods of stream gauging.

Stream gauging: The most satisfactory determination of the runoff from a catchment is by measuring the discharge of the stream draining it, which is termed as stream gauging.

Methods of stream gauging:

i) Venturi flumes or standing wave flumes for small channels

ii) Weirs or anicuts

iii) Slope-area method

iv) contracted area methods

v) Sluiceways, spillways and power conduits

vi) Salt-concentration method

vii) Area-velocity methods

09,08

Q. What are the factors that influence the selection of a site for a stream gauging station?

Factors that influence the selection of a site:

i) The section should be straight and uniform for a length of about 10 to 20 times the width of the stream.

ii) The bed and banks of the stream should be firm and stable so as to ensure consistency of area-discharge relationship.

iii) The bed and banks should be free from vegetal growth, boulders or other obstructions like bridge piers etc.

iv) There should be no larger overflow section at flood stage. The best cross-section is one with V-shape.

v) The stream gauging station should be easily accessible

vi) To ensure consistency between stage and discharge, there should be a good control section far downstream of the gauging site.

09, 08, 06, 05, 02

Q. Explain how a current meter rating curve is prepared?

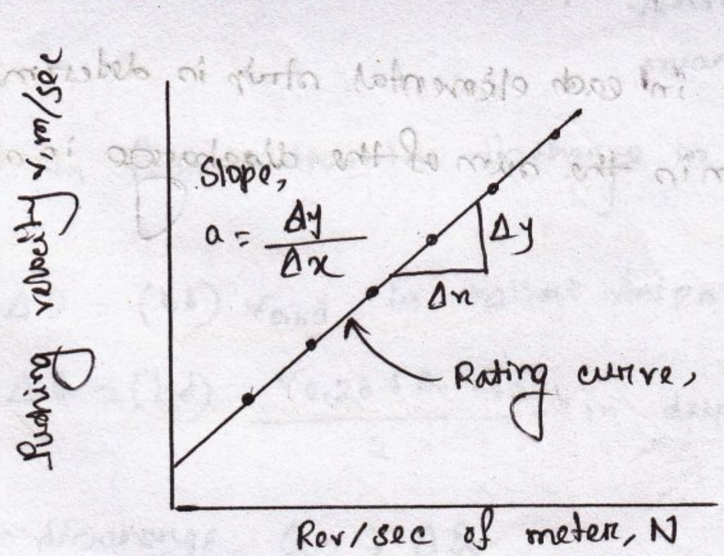
Preparation of current meter rating curve:

The relationship between the revolutions per second (N, rps) of the meter and the velocity of flow past the meter (v, m/sec) has to be first established or if the rating equation is given by the maker it has to be verified. This process of calibration of the meter is called 'rating of the current meter'. The rating equation is of the form,

$$v = aN + b$$

where a and b are constants (determined from rating of the current meter)

A current meter rating curve is drawn as 'pushing velocity' vs 'rps' which plots a straight line and the constants a and b are determined as shown in fig.



$v = \frac{\text{distance towed, m}}{\text{time, sec}}$

= speed of motor

Fig: current Meter Rating curve

Q. Short note on : Stage- Discharge- Rating curve

Stage- Discharge- Rating curve :

Once the rating equation of the current meter is known, actual stream gauging can be done from bridges, cradle, boat or launch. The cross section of the stream at the gauging site is divided into elemental strips of equal width b and the current meter is lowered to a depth of 0.6 d below water surface in shallow depths and to depths of 0.2 d and 0.8 d in deep waters, at the centre of each strip. The mean depth (d) at the centre of each strip is determined by sounding. The velocities at the appropriate depths are determined from

$$v = aN + b$$

It may be noted that the mean velocity is taken as that at 0.6 d below water surface in shallow water (One point method) and as the average of the velocities at 0.2 d and 0.8 d below the water surface (two point method).

The discharge in each elemental strip is determined and the discharge in the stream is the sum of the discharge in all the elemental strips.

Q. How can you determine the discharge in elemental strip.

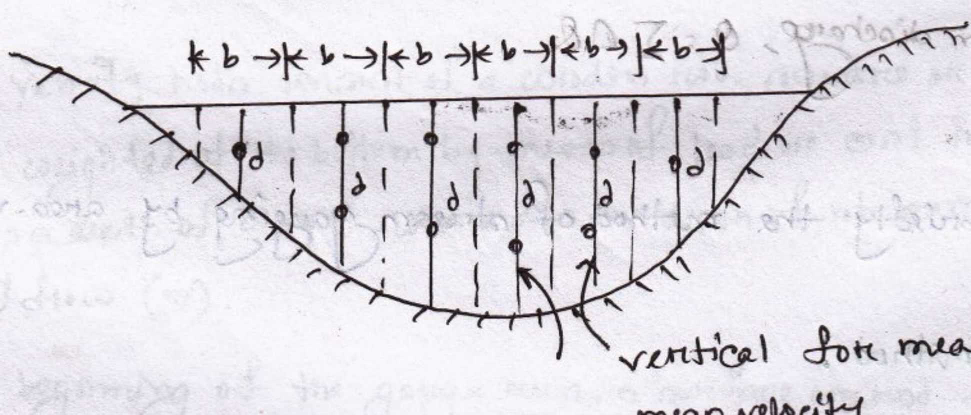
There are two methods of determining the discharge in each elemental strip:

i) Mid-section Method

ii) Mean-section method

I) Mid-section Method:

In this method the vertical in which the velocity measurements are made is taken as the middle of the strip and the water depth in the vertical is taken as the mean depth of the strip.



If b is the width of strip then the discharge in the elemental strip is given by

$$\Delta Q = (bd)\, v_{0.6d} \quad \text{in shallow strips}$$

$$\Delta Q = (bd)\, \frac{v_{0.2d} + v_{0.8d}}{2} \quad \text{in deep water strips}$$

Stream discharge, $Q = \sum \Delta Q$

ii) Mean-section method:

In this method the elemental strip is taken between two verticals and the mean depth is taken as the average of the depths in the two verticals. The width of the strip is distance b between the two verticals. The velocity in the strip is taken as the average of the mean velocity determined in the two verticals (by one points or two points method). The discharge in the elemental strip is given by.

$$Q = b\left(\frac{d_1+d_2}{2}\right)\left(\frac{v_1+v_2}{2}\right)$$

v_1, v_2 determined as $v_{0.6d}$ in shallow strip

and $\frac{v_{0.2d}+v_{0.8d}}{2}$ in deep water strip

$\therefore$ Stream discharge, $Q = \Sigma \Delta Q$

03

Q. Explain briefly the method of stream gauging by area-velocity method.

Area-velocity method:

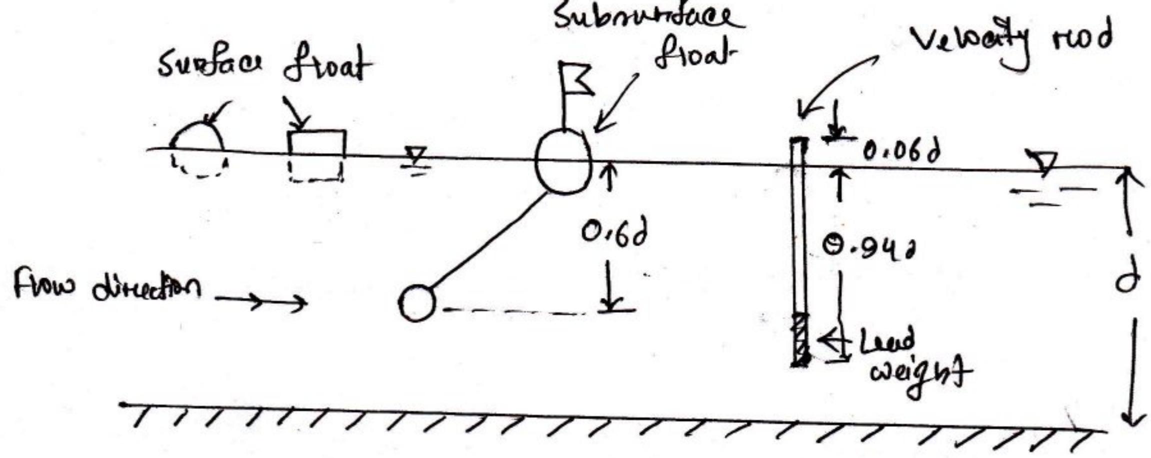
$$Q = Av$$

The area of cross section of flow may be determined by sounding and plotting the profile. The mean velocity of flow (v) may be determined by making velocity measurements.

The methods of velocity measurements are as follows:

Surface floats:

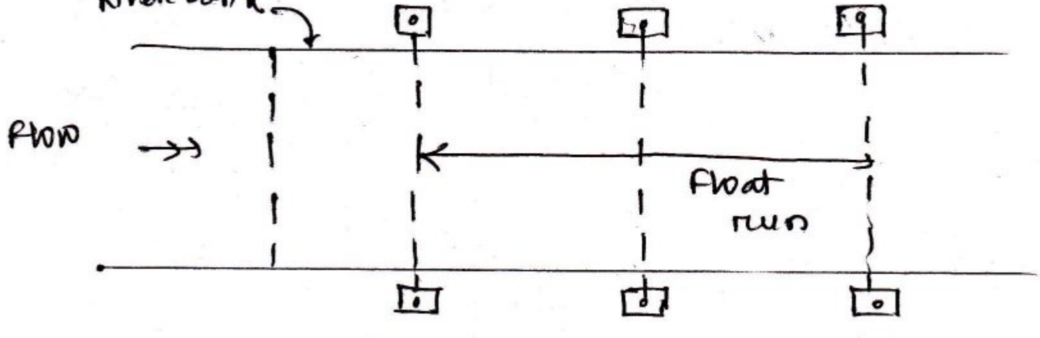
Surface floats consist of wooden dics 7-15 cm diameter time (t) taken by float to travel a certain distance (L) is measured and the surface velocity v_s and mean velocity V are calculated as $v_s = \frac{L}{t}$ and $V \approx 0.85\, v_s$. The reach of the river for float measurements should be straight and uniform.



Velocity rods:

velocity rods consist of a wooden rod, square or round in section. It is weighted at the bottom by means of lead or cast iron rings to immerse it to a depth of 0.94 d, where d is the depth of stream, to give the mean velocity of flow (V).

At the beginning of the gauge run, a surface or rod float is released at the centre of a compartment. The time taken for the float to reach the end of the gauge run is noted, knowing the length of the gauge run, the velocity of flow is determined.



(10)

CE-307

Ground water

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Q: Define groundwater.

Groundwater:

In general, the term groundwater or subsurface water refers to the water that occurs below the surface of earth.

The water in the phreatic zone which moves freely under the force of gravity is called the groundwater.

Total water resources in planet
(1.37×10^8 M ha-m)

- 97.2% salt water
- 2.8% fresh water
  - 2.2% surface water
  - 0.6% ground water

01,08

Q. Write down the advantages of ground water over the surface water.

Advantages of groundwater over the surface water:

i) Groundwater is clean, colourless and almost free from turbidities.

ii) Ground water is free from pathogenic organism which causes diseases.

iii) Groundwater is rich in several minerals which are beneficial to health.

iv) For most cases ground water needs no treatment.

v) Groundwater have uniform temperature in almost all the year.

vi) Amount of ground water is much more than that of surface water. More than 97% fresh water of Earth is stored as ground water.

vii) Groundwater is available for irrigation in dry seasons when surface water is not available.

viii) Ground water storage is free from atomic attack.

03,05,09

Q. Define aquifer. Describe different types of aquifer with neat sketches.

Aquifer:

Formations which contain groundwater and at the same time which are sufficiently permeable to transmit and yield water in usuable quantities are called the aquifers. The amount of water contained by the aquifer depends on the porosity.

Types of aquifer:

i) Unconfined aquifer
ii) confined aquifer

i). Unconfined aquifer:

An aquifer having water table in it is called an unconfined aquifer. In unconfined aquifer the water table serves as the upper surface of zone of saturation. It is also known as free aquifer, pheratic aquifer, water table aquifer or nonartesian aquifer.

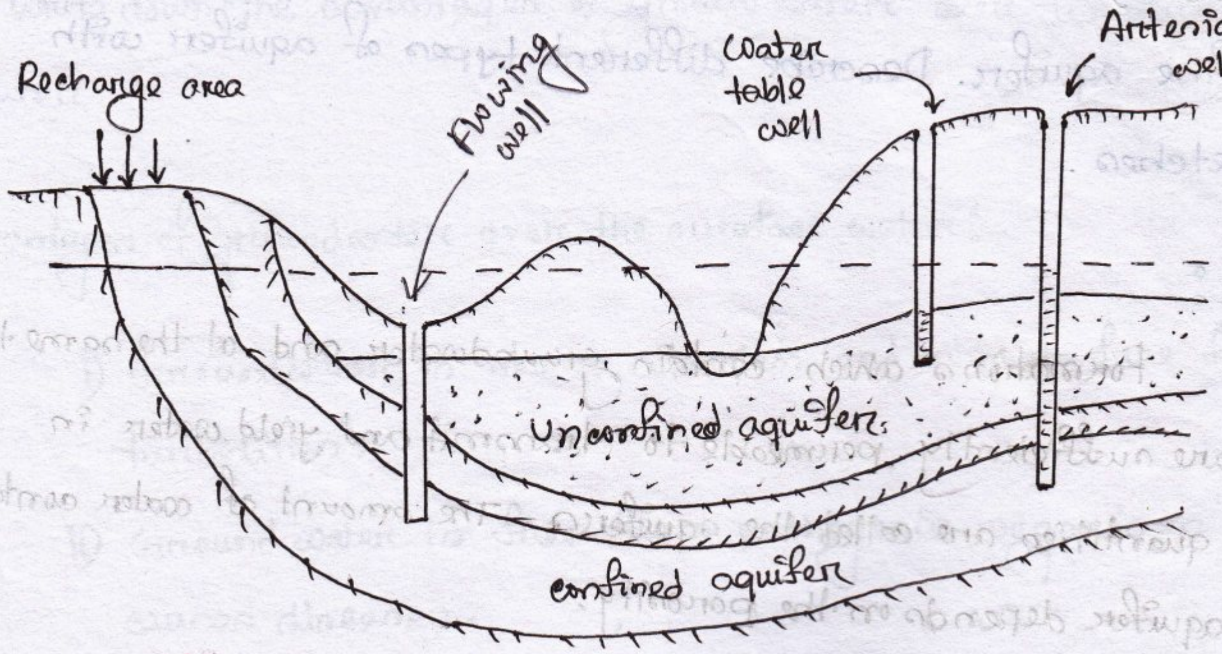


Fig: Groundwater in confined and unconfined aquifer

ii) Confined aquifer:

When an aquifer is sandwiched between two layers of much less permeable material then it is called a confined aquifer. It is also known as a pressure aquifer or an artesian aquifer. Confined aquifers are completely filled with water and they do not have a free water table.

Q. Define artesian well, flowing well, water table well.

Artesian well:

If the piezometric level at the place of the well is above the upper confining layer the static water level in the well will be above the aquifer. Such a well is called an artesian well.

Flowing well:

If the piezometric surface at the place of the well is above the ground level, the confined aquifer will yield a free-flowing well known as flowing well.

Water table well:

A well penetrating into an unconfined aquifer is called a water table well.

Q. Define aquiclude, aquitard, aquifuge, leaky aquifer

Aquiclude:

A geological formation which is saturated and which may contain large amount of water because of its high porosity but can not transmit water as it is relatively impermeable is called an aqie aquiclude. A clay layer is an example of an aquiclude.

Aquitard:

It is a saturated geological formation which is poorly permeable and hence it does not yield water freely to wells. Sandy clay is an example of aquitard.

Aquifuge:

An impervious geological formation which neither contains nor transmits water is known as aquifuge. Solid granite rock is an example of aquifuge.

Leaky aquifer:

An aquifer bound by one or two aquitards is called a leaky aquifer or a semi-confined aquifer.

Q. Define perched groundwater.

Perched groundwater:

When a groundwater body is separated from the main groundwater by a relatively impermeable stratum of small areal extent and by the zone of aeration above the main body of groundwater, it is called perched groundwater.

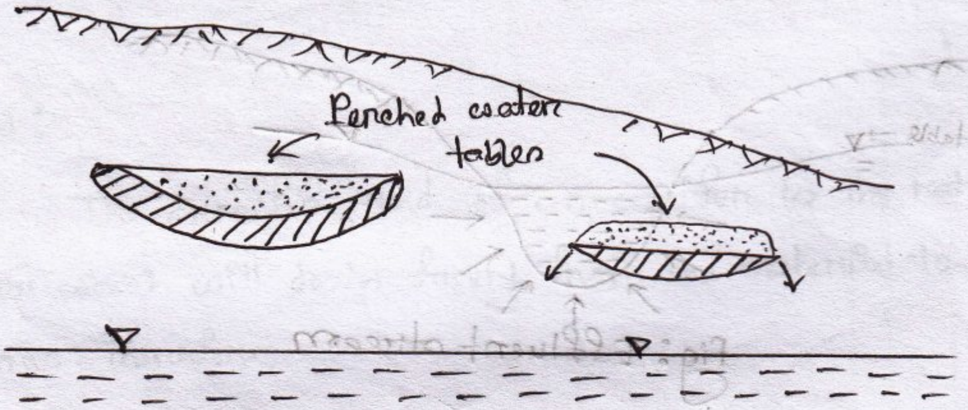
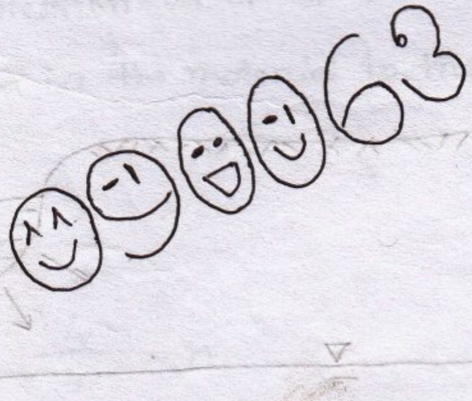


Fig: Perched water table



Q. Define influent and effluent streams.

Effluent streams: If the water table of an unconfined aquifer intersects a surface stream, then aquifer contributes water to the stream. Such, a stream is called an effluent stream

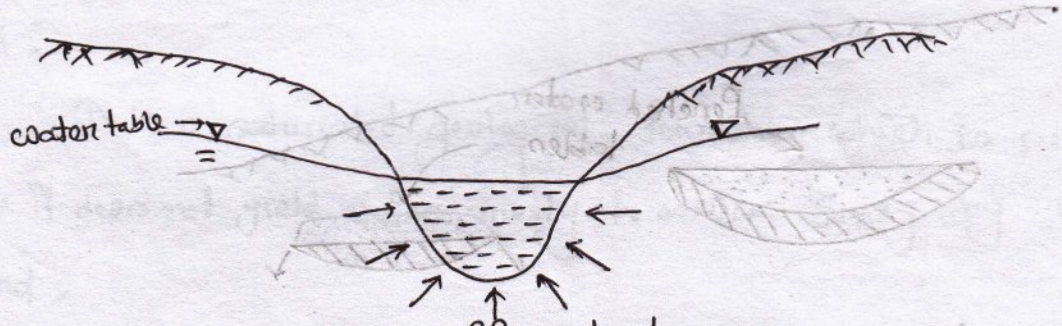


Fig: Effluent stream

Influent streams: If a surface stream runs well above the water table, water flows from the stream to the aquifer. Such a stream is called an influent stream.

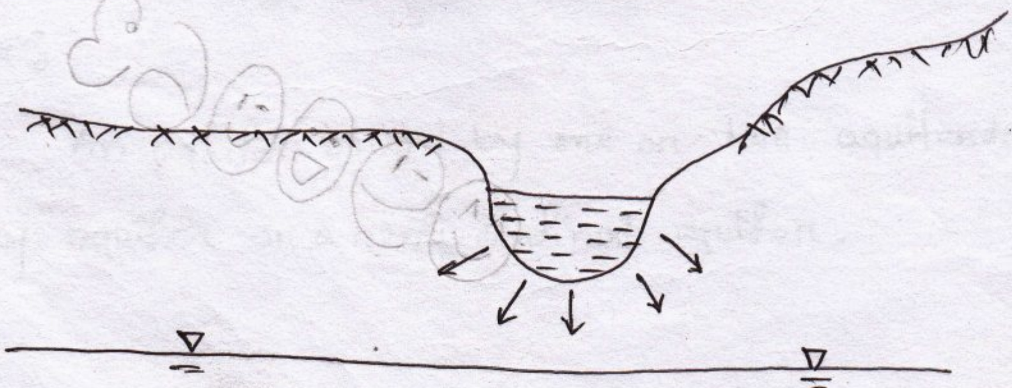


Fig: Influent stream

Q. Define : Porosity, Specific yield, Specific retention, Storage co-efficient, Permeability, Transmissivity

Porosity :

The ratio of volume of pore space, V_v to the volume of the formation V is called the porosity. It is denoted by n.

$$n = \frac{V_v}{V}$$

Specific yield :

The specific yield of an aquifer is the ratio of the volume of water which will drain freely from the material to the volume of the formation. Therefore,

$$S_y = \frac{w_y}{V}$$

where, w_y is the volume of water drained

Specific retention :

The specific retention S_r is ~~to~~ defined as the ratio of the volume of water retained w_r in the material to the total volume of the material.

$$S_r = \frac{w_r}{V}$$

$$S_r + S_y = \frac{w_r}{V} + \frac{w_y}{V} = \frac{V_v}{V} = n$$

$$\therefore n = S_r + S_y$$

Storage co-efficient :/ Storativity :

The storage coefficient S is defined as the volume of water that an aquifer releases from or takes into storage per unit surface area of the aquifer per unit drop of water table in the case of an unconfined aquifer and per unit drop of piezometric surface in the case of a confined aquifer. It is also known as storativity.

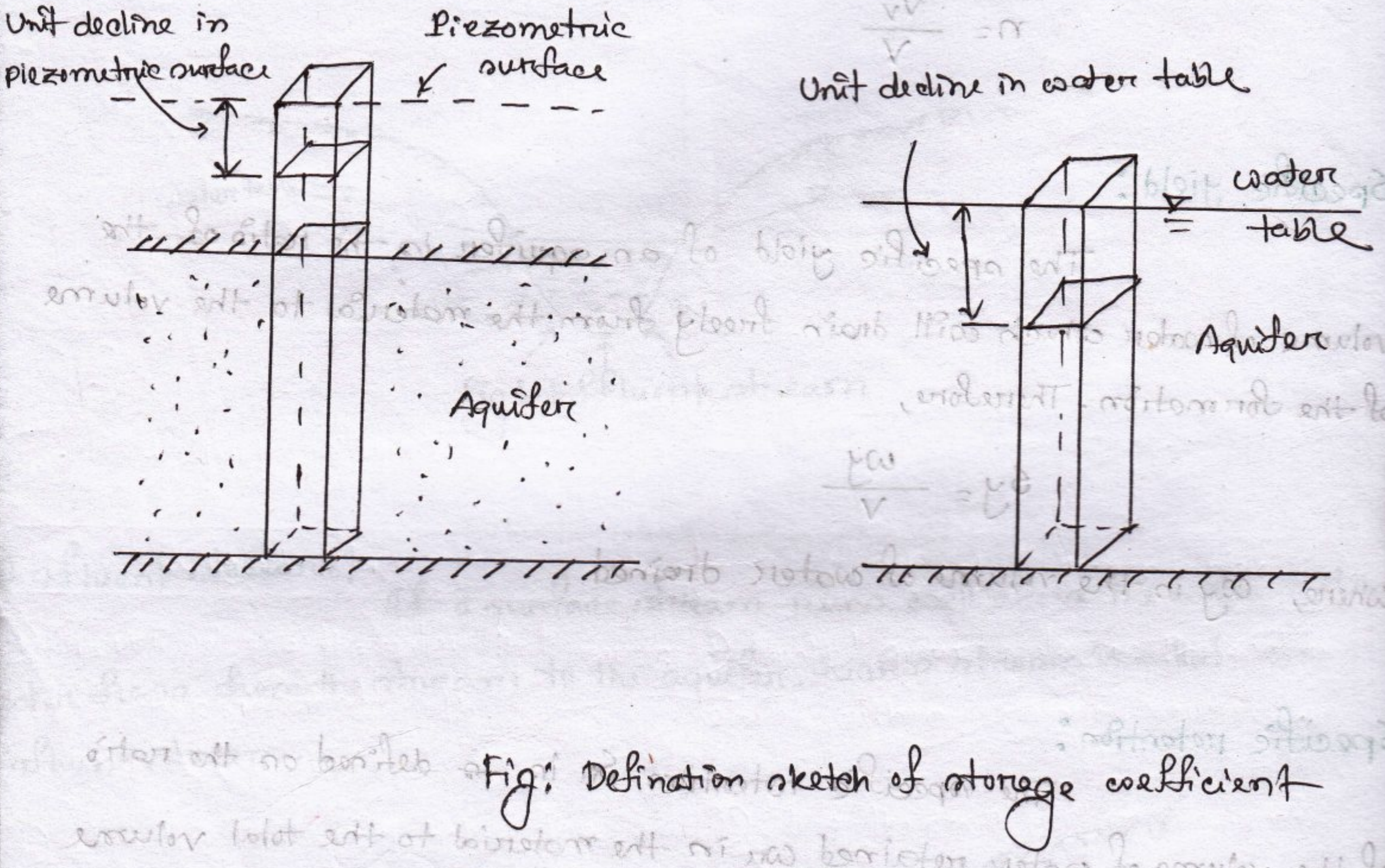


Fig: Defination sketch of storage coefficient

The storage co-efficient of a confined aquifer is 0.00005 to 0.005.

The storge " " unconfined " is 0.05 to 0.3

Permeability:

Permeability is defined as the property of a porous material which permits the passage or seepage of water through its interconnecting voids.

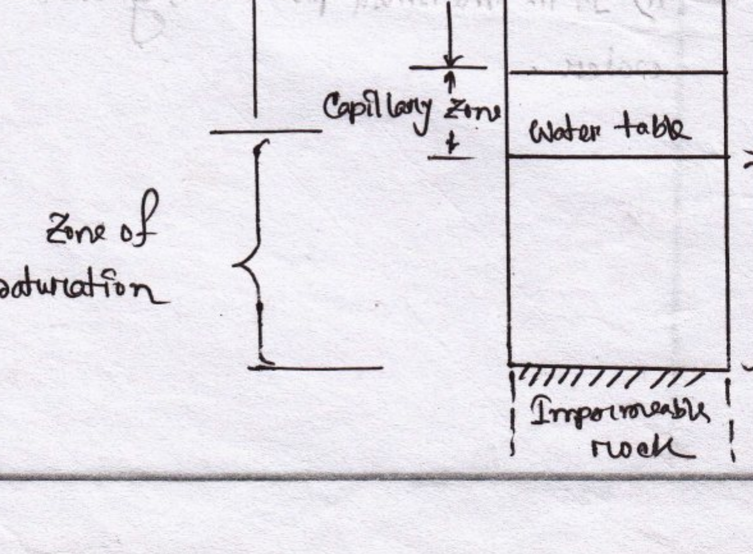
Transmissivity:

The transmissivity of an aquifer is also known as transmissibility. It is the product of the hydraulic conductivity K and the thickness of the aquifer b and is expressed in units of m^2/day

$$T = Kb$$

06, 05, 04

Q. Sketch a figure showing the ~~variation~~ divisions of subsurface water.



08

Q. Distinguish between specific yield & storage co-efficient.:

Specific yield	Storage co-efficient
i) Specific yield refers to unconfined aquifer.	i) Storage co-efficient refers to confined aquifer and unconfined aquifer.
ii) Specific yield, $S_y = \frac{W_y}{V} \times 100$	ii) Storage coefficient, $S = \gamma_w n b \left(\frac{1}{K_w} + \frac{1}{nE_s}\right)$

08

Q. Distinguish between groundwater & perched groundwater.

Ground water	Perched groundwater
i) Ground water is the water that occurs below the surface of earth.	i) Perched ground water is the water stored within a perched aquifer.
ii) It is the total water below the surface of earth.	ii) It is the small portion of ground water.

Q. What are the assumption of steady radial flow into a well/ground water movement.

Assumptions:

i) The flow is horizontal and uniformly distributed in a vertical section.

ii) The velocity of flow is proportional to the tangent of the hydraulic gradient instead of sine of the hydraulic gradient.

The above two assumptions are called **Dupuit-Forchheimer** assumptions.

iii) The well is pumped at a constant rate.

iv) The well fully penetrates the aquifer.

v) The aquifer is homogeneous, isotropic, horizontal and of infinite horizontal extent.

vi) Water is released from storage in the aquifer in immediate response to a drop in water table or piezometric surface.

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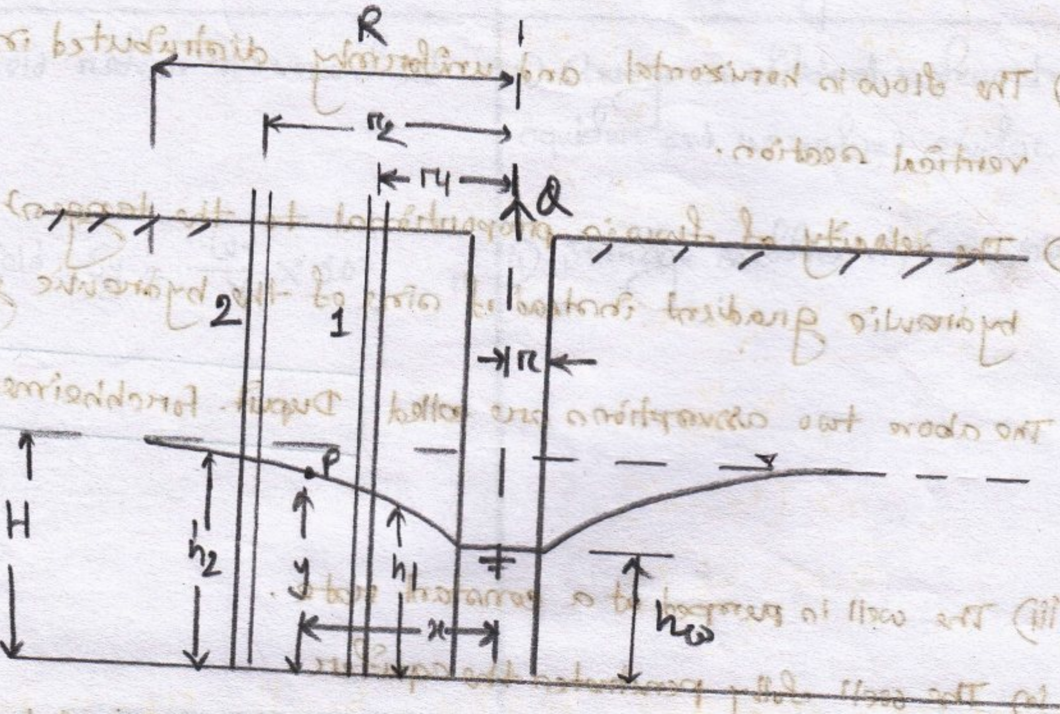
07

Q. Derive the equation for discharge from unconfined aquifer by Dupuit's theory.



Let, us consider the well is pumped at constant rate Q for a long period and the water levels in the observation wells have stabilized i.e equilibrium is obtained.

1, 2 = Observation wells

R = Radius of influence

r = well radius

h_w = water level in main well

considering a point 'P' as shown in figure,

By Darcy's law

$$Q = KiA$$

i = hydraulic gradient = $\frac{dy}{dx}$

A = Area = $2\pi xy$

K = co-efficient of permeability

$$Q = k \cdot \frac{dy}{dx} (2\pi x y)$$

$$\Rightarrow Q \cdot \frac{dx}{x} = 2\pi k y \, dy$$

$$\Rightarrow Q \cdot \int_{r_1}^{r_2} \frac{dx}{x} = 2\pi k \int_{h_1}^{h_2} y \, dy$$

$$\Rightarrow Q \ln \frac{r_2}{r_1} = 2\pi k \cdot \frac{1}{2} (h_2^2 - h_1^2)$$

$$\Rightarrow Q = \frac{\pi k (h_2^2 - h_1^2)}{\ln \frac{r_2}{r_1}}$$

$$= \frac{\pi k (h_2^2 - h_1^2)}{2.303 \log \frac{r_2}{r_1}}$$

Now, In case of zero drawdown, $h_1 = h_w$, $h_2 = H$, $r_1 = r_w$, $r_2 = R$

$$Q = \frac{\pi k (H^2 - h_w^2)}{\ln \frac{R}{r_w}}$$

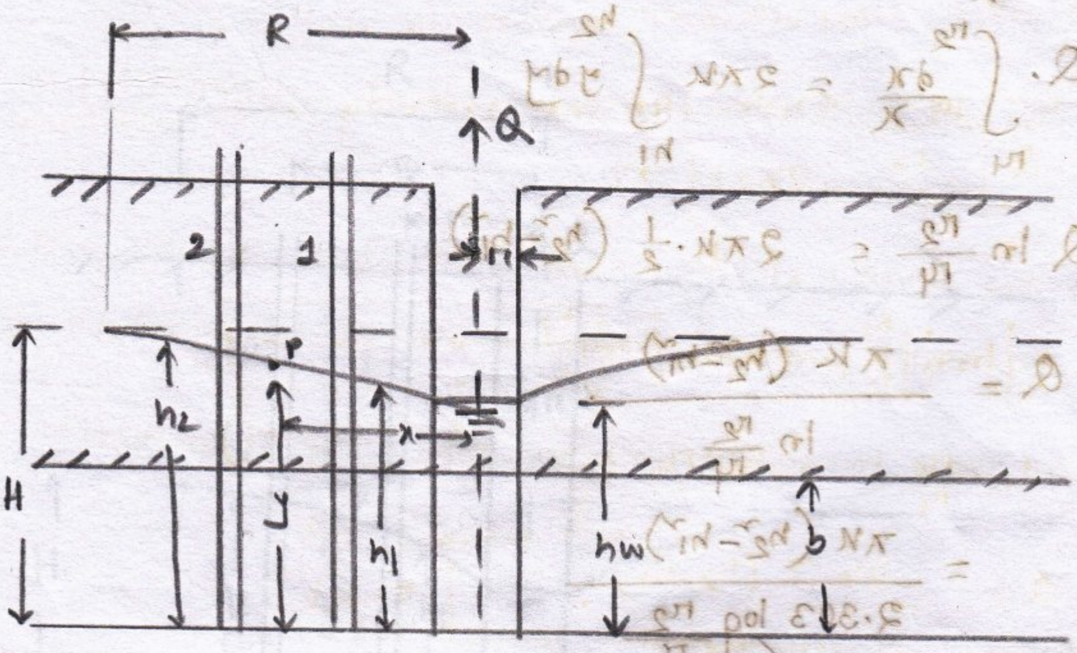
$$K(H^2 - h_w^2) = 2K \times \frac{(H + h_w)}{2} \times (H - h_w)$$

$$= 2 T S_w$$

$$Q = \frac{2\pi T S_w}{\ln \left(\frac{R}{r_w}\right)}$$

06

Q. Derive an expression for steady state discharge of well fully penetrating into a confined aquifer.



Let us consider the well is pumped at constant rate Q for a long time and the water level in the observation wells above have stabilized i.e equilibrium is obtained.

1, 2 = observation wells
R = radius of influence
b = thickness of confined layer
r = well radius
h_w = water level in main well

Considering a point 'P' as shown in fig

By Darcy's law,

$$Q = kiA$$

i = hydraulic gradient = $\frac{dy}{dx}$

Area, $A = 2\pi x b$

k = coefficient of permeability

$$Q = k \cdot \frac{dy}{dx} \cdot 2\pi x b$$

$$\Rightarrow Q \cdot \frac{dx}{x} = 2\pi k b \, dy$$

Integrating,

$$Q \int_{r_1}^{r_2} \frac{dx}{x} = 2\pi k b \int_{h_1}^{h_2} dy$$

$$\Rightarrow Q \left[\ln x\right]_{r_1}^{r_2} = 2\pi k b \cdot \left[y\right]_{h_1}^{h_2}$$

$$\Rightarrow Q \ln \frac{r_2}{r_1} = 2\pi k b (h_2 - h_1)$$

$$\Rightarrow Q = \frac{2\pi T (h_2 - h_1)}{\ln \frac{r_2}{r_1}} \qquad [T = kb]$$

$$= \frac{2\pi T (h_2 - h_1)}{2.303 \log \frac{r_2}{r_1}}$$

Now, for zero drawdown, $h_1 = h_w$, $h_2 = H$, $r_1 = r_w$, $r_2 = R$

$$Q = \frac{2\pi T (H - h_w)}{2.303 \log \frac{R}{r_w}}$$

$$= \frac{2.72 T (H - h_w)}{\log \left(\frac{R}{r_w}\right)}$$

Q. Define laminar flow, turbulent flow, Steady flow, Unsteady flow

Laminar flow:

Flow is said to be laminar when the paths taken by the individual particles do not cross one another. Laminar flow occurs in viscous fluids.

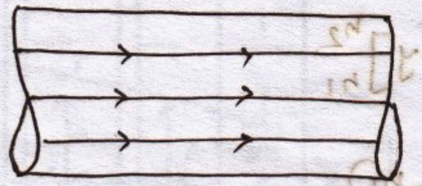


Fig: Laminar flow

Turbulent flow:

Flow is said to be turbulent when its pathlines are irregular curves crossing one another. The path are neither parallel nor fixed.

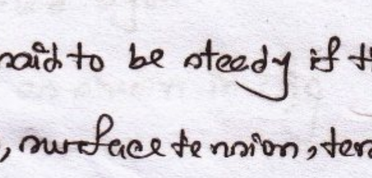


Fig: Turbulent flow

Steady flow:

Flow is said to be steady if the flow parameters like viscosity, density, velocity, pressure, surface tension, temperature etc at a particular position in space do not change with time.

$$\frac{\delta p}{\delta t} = 0$$

Unsteady flow:

Flow is said to be unsteady if the flow parameters at any particular position in space change with time.

$$\frac{\delta P}{\delta t} \neq 0$$

Q. What are the assumptions of unsteady radial flow to a well in a confined aquifer.

Assumption (Theis, 1935):

i) The aquifer is confined

ii) The well diameter is very small so that the storage within the well can be neglected.

iii) The ~~water~~ aquifer is dewatered instantaneously as the piezometric head drops,

Q. write down the Theis equation for the unsteady radial flow into a well in a confined aquifer. Explain each term in the equation.

Theis equation is given as –

$$s = \frac{Q}{4\pi T}\int_{u}^{\infty}\frac{e^{-u}}{u}\,du$$

where,

s = The drawdown in m

Q = The constant pumping rate from the well in m^3/s

T = The transmissivity of the aquifer in m^2/s

and $u = \frac{r^2 S}{4Tt}$

where, S is the storage co-efficient of the aquifer.

If a time unit of day is preferred t, T and Q should be expressed in days, m^2/day and m^3/day.

Q. Describe the Theis method of determining the aquifer parameters using the pumping test data.

In Theis equation we know,

$$u = \frac{r^2 S}{4Tt}$$

$$\Rightarrow \frac{r^2}{t} = \left(\frac{4T}{S}\right) u \quad \ldots\ldots (i)$$

In terms of well function we know,

$$s = \left(\frac{Q}{4\pi T}\right) W(u) \quad \ldots\ldots (ii)$$

comparing these two equations it can be seen that the relation between $W(u)$ and u must be similar to that between s and $\frac{r^2}{t}$.

Procedure:

i) A curve is plotted on a transparent logarithmic paper between drawdown s and the values of $\frac{r^2}{t}$, This curve is known as the data curve.

ii) Another curve is prepared on a logarithmic paper between the values of u and $W(u)$, which is called the type curve. The scale for one log cycle adopted for both these curves must be same.

iii) The data curve is now superimposed on the type curve such that the axes of both curves are parallel and it is then adjusted until some portion of the data curve coincides with the type curve. This procedure is called the matching.

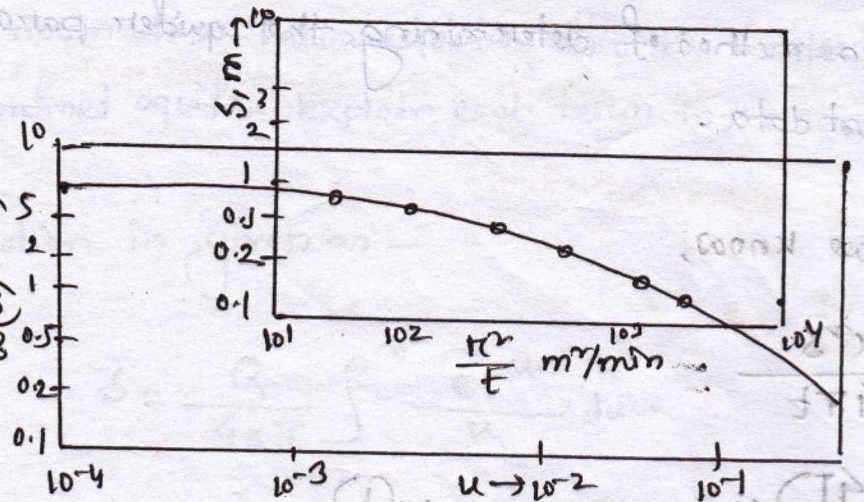


Fig: Theis method of solution for S and T

iv) The coordinates of any convenient point on the matched portion namely u, $W(u)$, $\frac{r^2}{t}$ and s are determined.

v) Then the values of T and S can be obtained by substituting those coordinate values in equation (ii) and (i).

Q. Explain with a neat sketch, the Cooper and Jacob method of determining the aquifer parameters.

Cooper and Jacob method:

Let, s_1 and s_2 be the drawdowns in an observation well near the pumping well at two different times t_1 and t_2 where both of them are large. Then we have,

$$s_1 = \frac{Q}{4\pi T} W(u_1)$$

where, $u_1 = \frac{r^2 S}{4 T t_1}$

and,
$$s_2 = \frac{Q}{4\pi T} W(u_2)$$

where, $u_2 = \frac{r^2 S}{4 T t_2}$

Therefore,
$$\Delta s = s_2 - s_1$$
$$= \frac{Q}{4\pi T}\left[W(u_2) - W(u_1)\right]$$

Since u_1 and u_2 are small,

$$\Delta s = \frac{Q}{4\pi T}\left[-0.5772 - \ln u_2 - (-0.5772 - \ln u_1)\right]$$
$$= \frac{Q}{4\pi T}(\ln u_1 - \ln u_2)$$
$$= \frac{Q}{4\pi T}\ln\left(\frac{u_1}{u_2}\right)$$
$$= \frac{Q}{4\pi T}\ln\left(\frac{t_2}{t_1}\right)$$
$$\Rightarrow T = \frac{Q}{4\pi \Delta s}\ln\left(\frac{t_2}{t_1}\right) \quad \ldots \ldots (i)$$

Changing this to decimal logarithm,

$$T = \frac{2.303\, Q}{4\pi \Delta s}\log\left(\frac{t_2}{t_1}\right) \quad \ldots \ldots (ii)$$

The drawdown s is plotted on a arithmetic scale against time t on a logarithmic scale as shown in fig. This time-drawdown curve will tend to be a straight line for large values of t. If Δs is taken as the drawdown difference for one log cycle on time, i.e $t_2 = 10\, t_1$

T is easily evaluated from $T = \frac{2.303\, Q}{4\pi \Delta s} \quad \ldots (iii)$

To evaluate S, the following procedure is adopted.

$$s = \frac{Q}{4\pi T} \omega(u)$$

when, s is zero, $\omega(u)$ must be equal to zero.

$$0 = \omega(u)$$
$$= -0.5772 - \ln u$$

which yields $u = 0.56146$. The straight line portion of the curve is extended back to intersect the x axis to give t_0.

Hence at, $s = 0$,

$$u = 0.56146 = \frac{r^2 S}{4Tt_0}$$

$$\therefore S = \frac{2.246\, T t_0}{r^2} \quad \text{(iv)}$$

Equation (iii) and (iv) are used to evaluate T and S after obtaining Δs and t_0 from the time-drawdown curve.

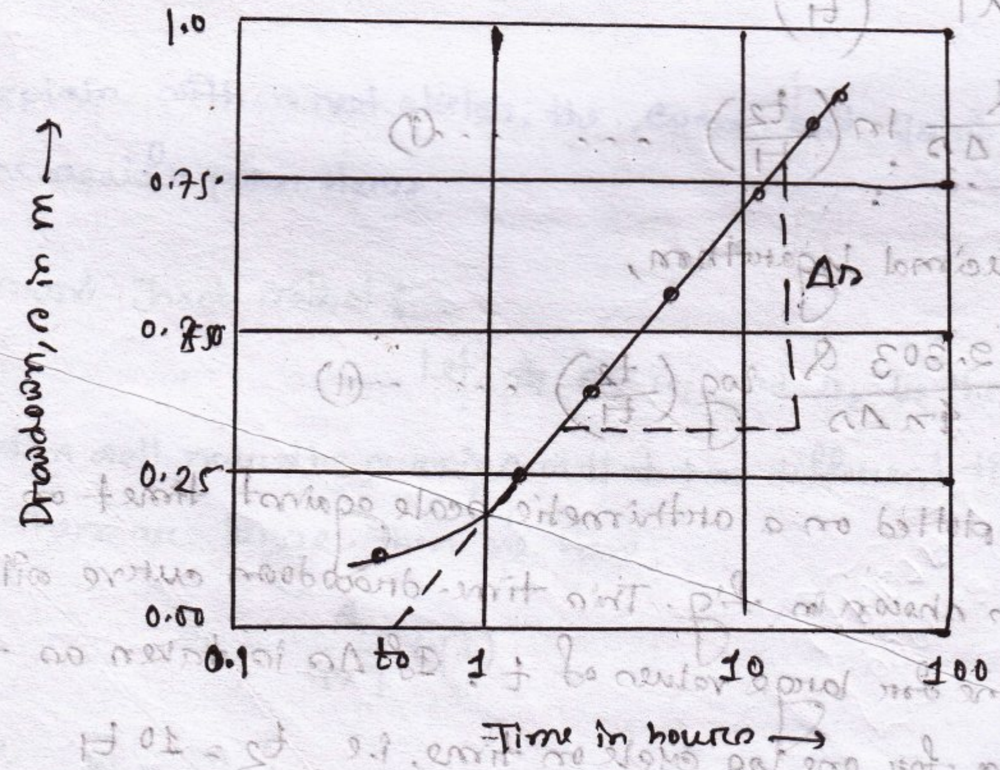


Fig: Time-drawdown plot for Cooper-Jacob method

Q. Explain the chow's method of determining the aquifer parameters using the pumping test data.

Chow's method :

we know,

$$s = \frac{Q}{4\pi T} \, \omega(u) \quad \cdots \text{(i)}$$

and

$$\frac{r^2}{t} = \left(\frac{4T}{S}\right) u \quad \cdots \text{(ii)}$$

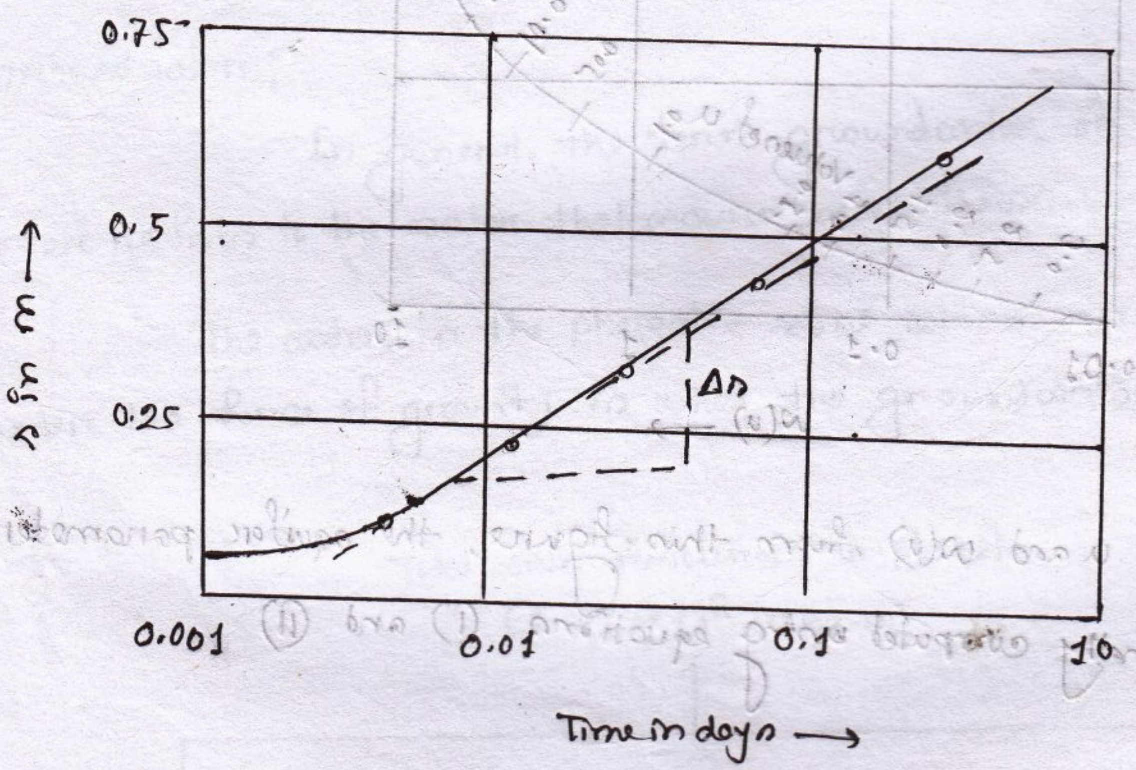


Fig: Determination of T and S by Chow's method

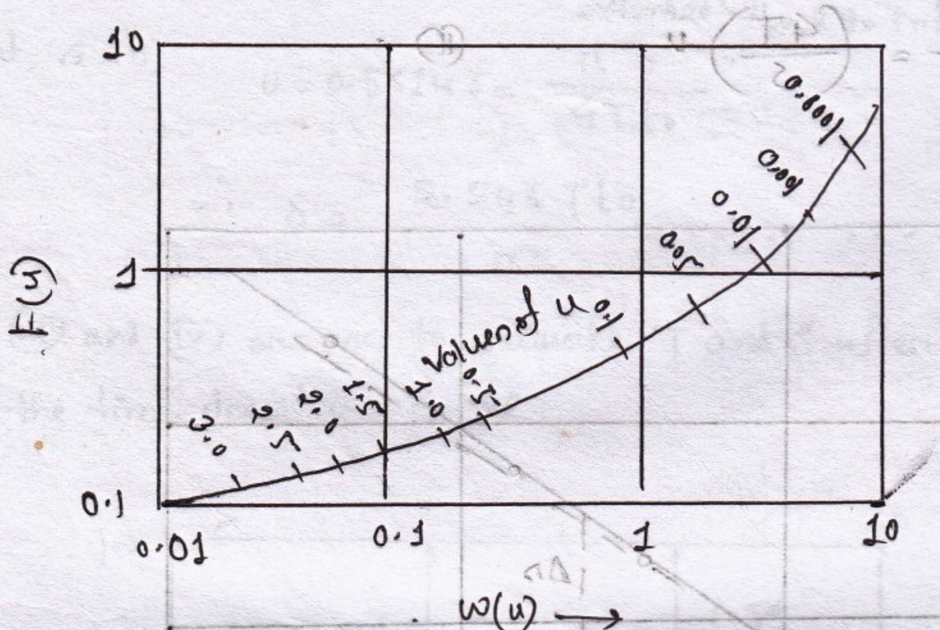
On the plotted curve an arbitrary point with co-ordinates t and s is choosen. At this chosen point a tangent is drawn to the drawdown curve and the drawdown difference Δs in m per log cycle is determined.

Then the value of the new function F(u) is computed from,

$$F(u) = \frac{s}{\Delta s} \quad \ldots \quad \ldots \text{(iii)}$$

Since, the relation between F(u), W(u) and u is given by

$$F(u) = \frac{W(u)\, e^{u}}{2.3}$$



After knowing u and W(u) from this figure, the aquifer parameters T and S are finally computed using equations (i) and (ii)

Water well Design

Q. what is water well design.

water well design:

A water well design involves selection of proper dimensions like the diameter of the well and that of the casing, length and location of the screen including slot size, shape and percentage open area, design of gravel pack, selection of screen material etc.

Q. what are the advantages & disadvantages of open well?

Open wells - Advantages:

i) Storage capacity of water is available in the well itself.

ii) Does not required sophisticated equipment and skilled personnel for construction.

iii) can be easily operated by installing a centrifugal pump at different settings for low and high water levels,

Disadvantages:

i) Large space is required for the well.

ii) construction is slow and laborious

iii) Susceptibility to dry up in years of drought
iv) uncertainty of tapping water of good quality.

Q. what are the advantages & disadvantages of tube wells / bore wells.

Bore wells - Advantages:

i) Do not require much space
ii) Can be constructed quickly
iii) Generally good quality of water is tapped
iv) Economical when deep-seated aquifers are encountered

Disadvantages:

i) Requires costly and complicated drilling equipment and machinary.

ii) Required skilled workers and great ~~care~~ care to drill and complete the tube wells.

iii) Installation of costly turbine or submersible pumps is required.

Q. what are the factors affecting design of well:

Factors affecting design of well:

i) Topography
ii) Geological formation of the underlying strata
iii) Quantity of water required
iv) Depth of water table
v) Rainfall
vi) Climate

CD GRQT

Q. Explain the criteria of designed for i) Artificially gravel-packed wells ii) Naturally developed wells.

i) Criteria for artificially gravel packed wells:

If the slot size selected becomes smaller than 0.75 mm, then it calls for an artificial gravel pack. Artificial gravel pack is required when the aquifer material is homogenious with a uniformity coefficient less than 3 and effective grain size less than 0.25 mm. The pack-aquifer ratio i.e the ratio of the 30 or 50% size of the gravel pack material to the 30 or 50% size of the formation material is kept at 4:1 if the formation is fine and uniform and 6:1 if the formation is coarse and non-uniform. The gravel pack material should have a uniformity coefficient less than 2.5

ii) Criteria for naturally developed wells:

In the case of naturally developed wells the slot size is taken as 40 to 70% of the size of the formation material.

Q. Discuss the design of well screen.

Design of well screen:

The design of the well screen consists of the length of the screen, its location, percentage open area, size and shape of the slots and selection of the screen material.

☐ Screen length:

Factor: i) Thickness of the aquifer

ii) Available drawdown

In homogenious artesian aquifer about 70 to 80% of the aquifer thickness is screened. In the case of non-homogenious artesian aquifer it is best to screen the most permiable strata.

☐ Slot size:

Factor: i) Gradation

ii) Size of the formation material

In the case of naturally developed wells the slot size is taken as 40 to 70% of the size of the formation material. If the slot size selected on the basis becomes smaller than 0.75 mm, then it calls for an artifical gravel pack. The gravel-pack material should have a uniformity coefficient less than 2.5.

Gravel pack size:

Gravel pack = 4 to 6 times the D_{30} of aquifer material

Slot size of strainer = 10% size (D_{10}) of gravel pack material

Maxm grain size of pack material < 10 mm

Size of pea gravel = 4 to 8 mm

Screen diameter:

~~Factor: Presence of mineral content, presence of bacterial slimes and strength requirements~~

~~The screen material should be resistant to incrustation and corrosion and should have strength to withstand the column load and collapse pressure.~~

Screen diameter:

Screen diameter is determined so that the entrance velocities near the well screen will not exceed 3 to 6 cm/sec to prevent incrustation and corrosion.

Selection of screen:

Factor: Presence of mineral content, quality of the ground water, diameter and depth of the well, strength requirements

The screen materials should be resistant to incrustation and corrosion and should have strength to withstand the column load and collapse pressure.

Some of the commonly used types of screens are –

i) continuous - slot type
ii) Louver-type
iii) Slotted pipe screen
iv) V-shape continuous slot

CE-307

Hydrographs

AHSAN
090063

08, 06, 05, 03

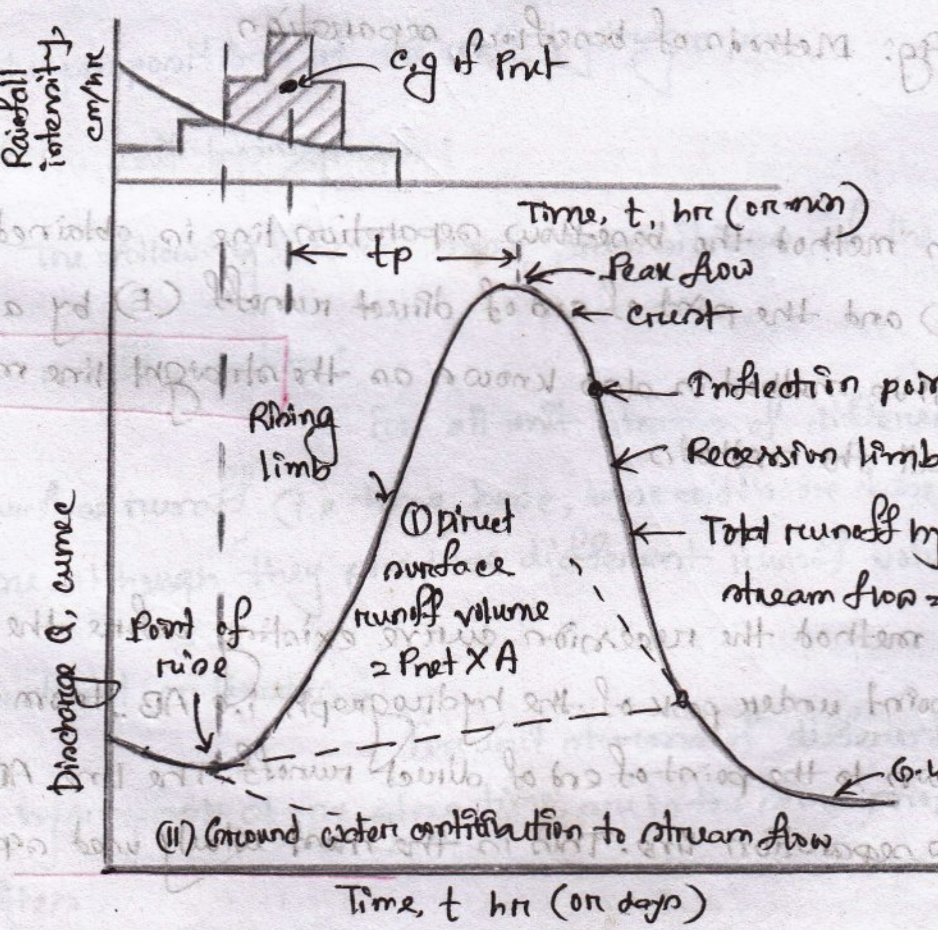
Q. Define Hydrograph.

Hydrograph:

A hydrograph is a graph showing discharge (i.e. stream flow at the concentration point) versus time.

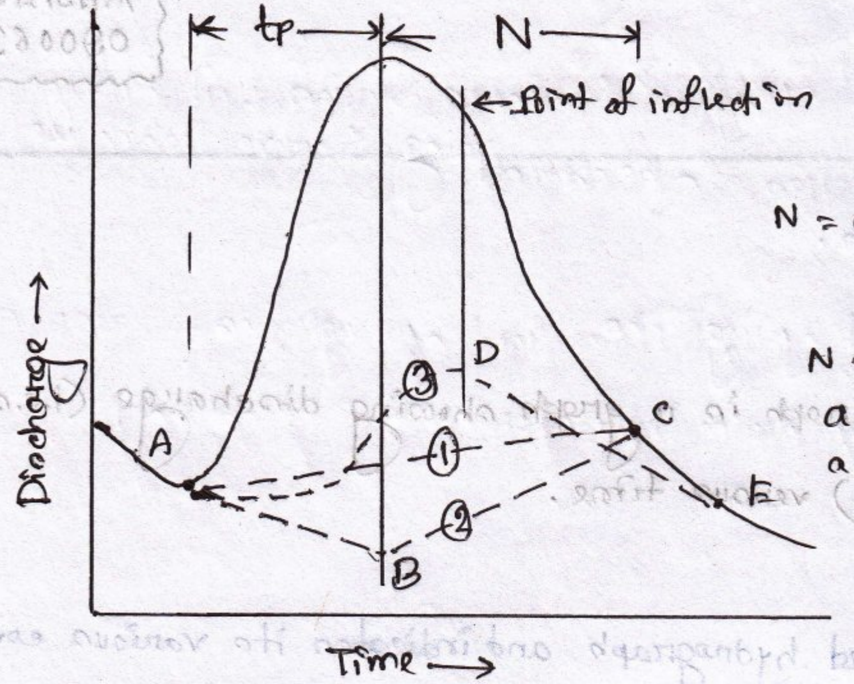
08, 06, 05, 03

Q. Draw a single peaked hydrograph and indicates its various components.



05,07

Q. Describe with the help of a neat sketch any three methods of seperation of base flow from the hydrograph of runoff.



$N = 0.827 A^{0.2}$ Days

or

$N = a t_p$

$a = 2$ to 4 for small basin

$a > 4$ for large basin

Fig: Methods of baseflow separation

Method 1 :

In this method the baseflow separation line is obtained by joining the point of rise (A) and the point of end of direct runoff (E) by a simple straight line AC. This method is also known as the straight line method. This is the simplest of all the methods.

Method 2 :

In this method the recession curve existing before the point of rise is extended to a point under peak of the hydrograph i.e AB. From this point a straight line is drawn to the point of end of direct runoff. The line ABC then represents the baseflow separation line. This is the most widely used separation procedure.

Method 3:

In this method the baseflow curve on the recession side of the hydrograph is extrapolated backwards to the time of point of inflection on the recession limb and then it is connected to the point of rise by a smooth curve. ADE represents the baseflow separation line of this method.

Q. Define unit hydrograph.

Unit hydrograph:

The unit hydrograph is defined as the hydrograph of storm runoff resulting from an isolated rainfall of some unit duration occurring uniformly over the entire area of the catchment produce a unit volume (i.e. 1 cm) of runoff.

08
Q. What are the propositions of the unit hydrograph.

Propositions of the unit hydrograph:

The following are the basic propositions of the unit hydrograph:

I) Same runoff duration:

For all unit storms of different intensities, the period of surface runoff (i.e time base, base width or base period) is approximately the same, although they produce different runoff volumes.

II) Proportional ordinates:

For unit storms of different intensities, the ordinates of the hydrograph at any given time, are in the same proportion as the rainfall intensities.

iii) Principle of superposition :

If there is a continuous storm or isolated storms of uniform intensity net rain, they may be divided into unit storms and hydrographs of runoff for each storm obtained and the ordinates added with the appropriate time lag to get the combined hydrograph.

iv) Same distribution percentage :

If the total period of surface runoff (i.e time base or base width) is divided into equal time intervals the percentage of surface runoff that occurs during each of these periods will be same for all unit storms of different ~~itensi~~ intensities.

08, 06, 05, 03

Q. What are the limitations of unit hydrograph.

Limitations of unit hydrograph :

i) The derivation of unit hydrograph assumes that, rainfall is uniformly distributed throughout the watershed and its duration, but it is never satisfied.

ii) There is also an assumption, that rainfall intensity is constant for the duration of excess rainfall. In practice it is also not satisfied in the field.

iii) Unit hydrograph can not be derived from a storm, which takes place in snow form i.e it is applicable only for rainfall.

iv) Unit hydrograph of one-day storm can not be derived, particularly where infiltration rate is greater than rainfall intensity.

v) For the area less than 25 km², it is not applicable.

vi) This method of estimating the runoff, requires a lot of observed rainfall data, for which it is essential to install the raingauge in large numbers, thus involves additional investment of money.

Q. What are the assumptions of unit hydrograph.

Assumptions of unit hydrograph:

i) The effective rainfall is uniformly distributed throughout the watershed area.

ii) The time base of hydrograph resulting from direct runoff caused by effective rainfall is constant.

iii) The effective rainfall is uniformly distributed, within its duration.

iv) The ordinates of direct runoff hydrograph of common time base are directly proportional to the direct runoff volume.

v) For a given watershed, the hydrograph for a specified rainfall duration reflects all physical characteristics of the watershed.

Q. Discuss the steps of derivation of unit hydrograph.

Derivation of unit hydrograph:

The following steps are followed for deriving the unit hydrograph by using runoff hydrograph.

Step (1): Using the past record of several storms, an isolated storm should be selected which has some unit period of heavy rainfall.

Step (2): With the help of runoff data obtained from selected storm the hydrograph should be developed.

Step (3): Base flow should be separated.

Step (4): The ordinate of direct runoff should be found.

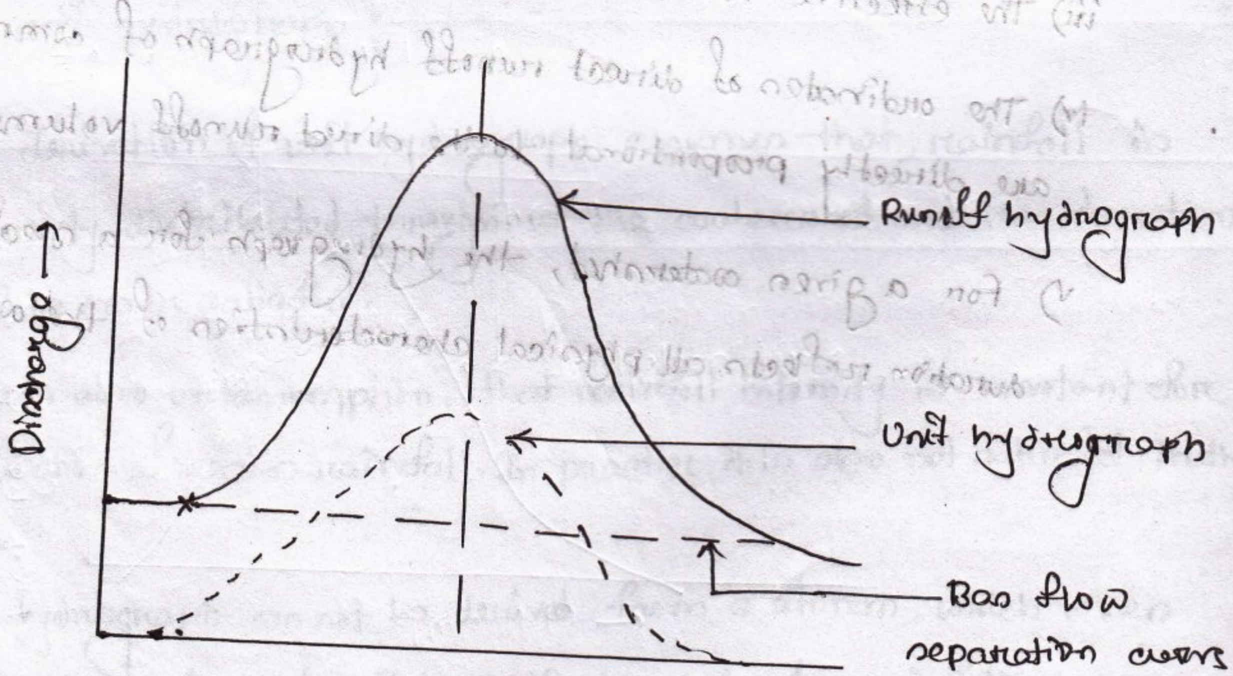


Fig: Derivation of unit hydrograph

Step (5): Total depth of effective rainfall should be calculated. It may be obtained by using the following equation,

$$\text{Effective rainfall depth (cm)} = \frac{(\Sigma O) \cdot t}{A}$$

where, ΣO = Sum of all direct runoff ordinates of the hydrograph (m^3/s)

t = Time interval between successive ordinates (h)

A = catchment area (km^2)

Step(6): The ordinates of unit hydrograph should be determined using the following relation,

$$\text{Ordinate of U.H} = \frac{\text{Ordinate of direct runoff}}{\text{Effective rainfall depth (cm)}}$$

Step (7): All obtained ordinates of unit hydrograph versus corresponding time should be plotted. The obtained hydrograph is the unit hydrograph, which has unit area below the curve.

04

Q. what is an instantaneous unit hydrograph.

Instantaneous unit hydrograph (IUH):

The instantaneous unit hydrograph is a hydrograph of runoff resulting from the instantaneous application of 1 cm net rain on the drainage basin. The IUH was first proposed by Clark in 1945. The IUH can be developed either directly from the observed data or by adopting conceptual models.

03,05,08

Q. What do you mean by 6-h unit hydrograph? Discuss with diagram.

6-h unit hydrograph:

6-h unit hydrograph means the hydrograph of surface runoff resulting from an isolated rainfall of 6 hour unit duration occuring uniformly over the entire basin and producing a unit volume of runoff (i.e 1cm depth).

Let us consider a storm of 6 hour unit duration which occures uniformly over the basin and produces 1cm of net rain. If we plot discharge with respect to time from begining of direct runoff, we will obtain a unit hydrograph which is a 6-h unit hydrograph.

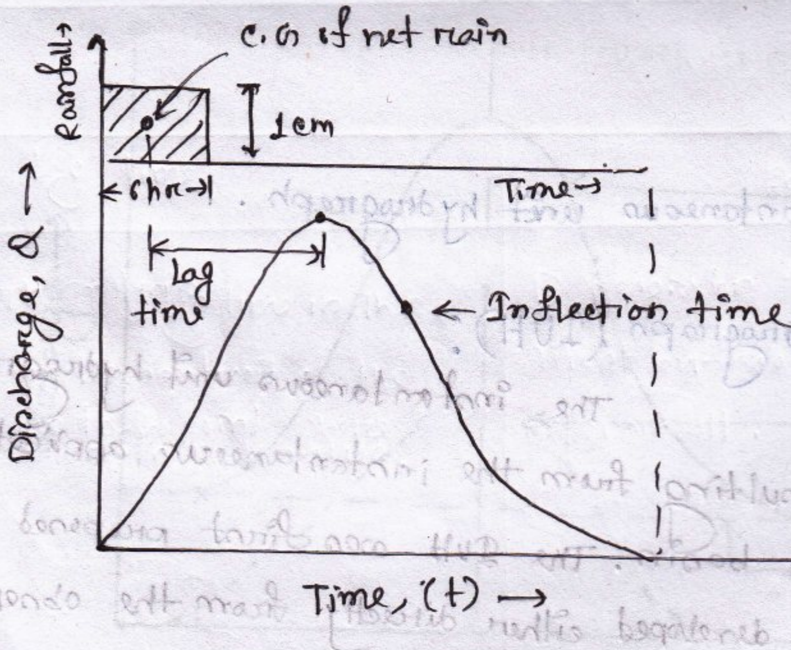


Fig: 6h unit hydrograph

03

Q. State the significance of the inflection point on the recession side of hydrograph.

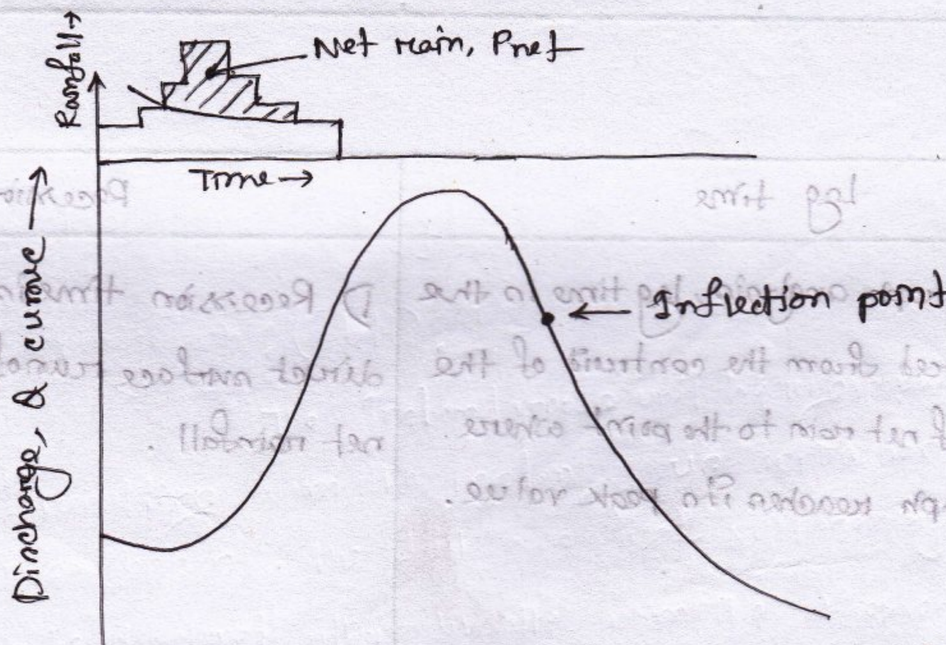
Inflection point is a point on the recession limb where there is a change in slope. Significance of this point is:

i) Inflection point indicates the end of surface inflow to the channel

ii) It represents the condition of maximum storage.

iii) It is the point after which gradual withdrawl of catchment storage is started.

iv) It is the point after which the hydrograph is independent of storm characteristics and dependent only on basin characteristics.



Q. Distinguish between:

i) Hydrograph & hyetograph

ii) Lag time & recession time

Hydrograph	Hyetograph
i) A hydrograph is a graphical plot showing the variation of discharge with respect to time.	i) A hyetograph is a graphical plot or bar diagram showing the variation of intensity of rainfall with respect to time

Lag time	Recession time
i) In hydrograph analysis, lag time is the time measured from the centroid of the hyetograph of net rain to the point where the hydrograph reaches its peak value.	i) Recession time is the duration of direct surface runoff after the end of net rainfall.

Q. what are the application of unit hydrograph.

Applications of unit hydrograph:

i) from a unit hydrograph of known duration, unit hydrograph of any desired duration can be obtained using S-curve technique or by superposition.

ii) from the unit hydrographs, flood hydrographs corresponding to a single storm or multiple storms can be obtained.

(5)

Thu

CE-307

Water Losses

মো: আহসান হাবীব
0200৬৫

09,06

Q-1: Enumerate the various water losses. 3.00

Water Losses:

i) Interception loss - due to surface vegetation i.e held by plant leaves.

ii) Evaporation: (a) from water surface i.e reservoirs, lakes, ponds river channels etc.

(b) from soil surface, appreciably when the ground water table is very near the soil surface.

iii) Transpiration - from plant leaves.

iv) Evapotranspiration or consumptive use - from irrigated or cropped land.

v) Infiltration - into the soil at the ground surface.

vi) Watershed leakage - ground water movement from one basin to another or into the sea.

Q-2: What are the factors affecting evaporation rate.

Factors affecting evaporation rate:

The various factors, which affect the evaporation, are listed below:

i) Surface area of the water body
ii) Depth of water in the reservoir
iii) Nature of the rainfall
iv) Humidity
v) Wind velocity
vi) Temperature of water and atmosphere
vii) Salinity of water.

SDN HWTS

Q-3: What are the methods of estimating lake evaporation.

Methods of estimating lake evaporation:

Evaporation from water surfaces can be determined from the following methods:

i) The storage equation $P + I \pm O_g = E + O \pm S$

where, P = Precipitation, I = Surface inflow

O = surface outflow, O_g = subsurface inflow or outflow

E = evaporation

S = change in surface water storage

ii) Auxiliary pans like land pans, floating pans, colarado sunken pans etc.

iii) Evaporation formula like that of Dalton's law.

$$E = K(e_w - e_a)$$

iv) Humidity and wind velocity gradients.

v) The energy budget

vi) The water budget

vii) combination of aerodynamic and energy balance equations - Penman's equation.

07

Q-4: write short note on Pan Coefficient.

Pan coefficient:

Pan evaporation data have to be corrected to obtain the actual evaporation from water surfaces of lakes and reservoirs i.e by multiplying by a co-efficient called pan coefficient and is denoted as -

$$\text{Pan coefficient} = \frac{\text{Lake evaporation}}{\text{Pan evaporation}}$$

The experimental values for pan coefficient range from 0.67 to 0.82 with an average of 0.7.

08

Q-5: Recommend measures to reduce reservoir evaporation.

Measures to reduce lake/reservoir evaporation:

i) Storage reservoirs of more depth and less surface area.

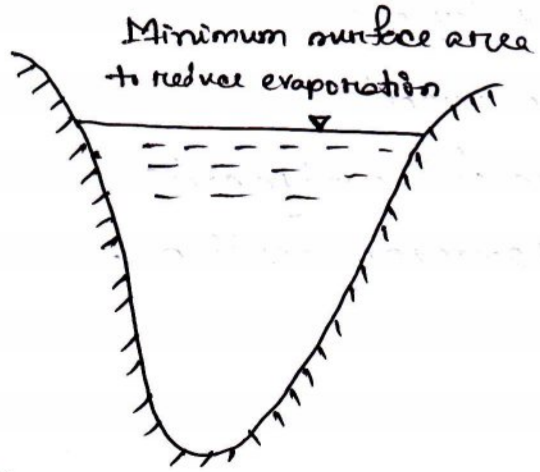


Fig: Reservoir in a Deep Gorge

ii) By growing tall trees like Causerina on the windward side of the reservoirs.

iii) By spraying certain chemicals or fatty acids and formation of films.

iv) By allowing flow of water temperature is reduced and evaporation is reduced.

v) By removing the water loving weeds and plants like Phreatophytes from the periphery of the reservoir.

vi) By straightening the stream-channels the exposed area of the water surface is reduced and hence evaporation is reduced.

vii) By providing mechanical coverings like thin polythene sheets to small agricultural ponds and lakes.

viii) By developing underground reservoirs.

ix) If the reservoir is surrounded by huge trees and forest, the evaporation loss will be less due to cooler environment.

Q-6: Write short note on soil evaporation and evaporation opportunity.

Soil evaporation: The evaporation from a wet soil surface immediately after rain or escape of water molecules with more resistance when the water table lies within a metre from the ground is called soil evaporation.

This expressed as a percentage of evaporation from free water surface is called evaporation opportunity

$$\text{Evaporation opportunity} = \frac{\text{Actual evaporation from the land at a given time}}{\text{Evaporation from an equivalent water surface}} \times 100$$

02

Q-7: Explain the difference between evaporation, transpiration and evapotranspiration.

Evaporation	Transpiration	Evapotranspiration
i) Conservation of water from its liquid phase to vapour phase is called evaporation.	i) The process by which the living plants leave water from their leaves is called transpiration.	i) Combined process in which both evaporation and transpiration take place is called evapotranspiration.
ii) It is caused by temperature effect.	ii) It is caused due to respiration process of plants.	ii) It takes place by the combination of repiration and temperature effect.
iii) Expressed as a depth.	iii) Expressed as a ratio called transpiration ratio.	iii) Expressed as depth over the area

Q-8: Define: Transpiration, Transpiration ratio, evapo-transpiration.

Transpiration:

Transpiration is the process by which the water vapour escapes from the living plant leaves and enters the atmosphere.

Transpiration ratio:

Transpiration ratio is the ratio of the weight of water absorbed, conveyed (বহন করার) through and transpired from a plant during the growing season to the weight of the dry matter produced exclusive of roots.

$$\text{Transpiration ratio} = \frac{\text{weight of water transpired}}{\text{weight of dry matter produced}}$$

Evapotranspiration:

Evapotranspiration or consumptive use is the total water lost from a cropped land due to evaporation from the soil and transpiration by the plants or used by the plants in building up of plant tissue.

Q-9: What are the factors affecting evapotranspiration.

Factors affecting evapotranspiration:

i) climatological factors like percentage sunshine hours, wind speed, mean monthly temperature and humidity.

ii) crop factors like the type of crop and the percentage growing season.

CCT

iii) The moisture level in the soil.

00, 01, 02, 04, 06, 07, 08

Q. Define infiltration. Describe the factors affecting infiltration rate.

Infiltration: (R-74)

Water entering the ~~surface~~ soil at the ground surface is called infiltration. It is counted as a form of hydrologic loss.

Factors affecting infiltration rate: (S-124)

a) Rainfall factors:

i) Rainfall intensity

ii) Rainfall duration

iii) Forms of precipitation

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b) Soil factors:

i) Soil type

ii) Soil surface slope

iii) Soil moisture

iv) cultivation practice

c) Surface cover factor:

i) Vegitation type

ii) Agricultural crops

iii) Litter

iv) Snow cover

d) climate factor:

i) Atmospheric temperature

ii) Soil temperature

iii) Seasonal variation

e) Other factors:

i) Water quality

ii) Salinity and contamination of water.

00, 02, 05, 06, 07

Q. Draw a typical infiltration curve and give its equation.

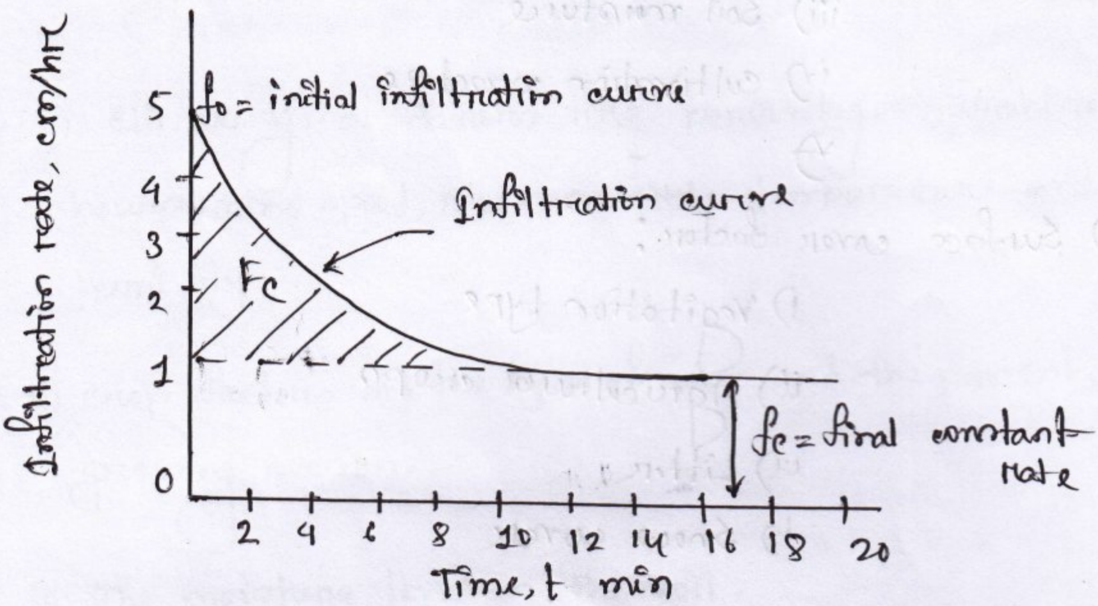


fig: Infiltration curve (Horton)

The infiltration rate (f) at any time t is given by Horton's equation,

$$f = f_c + (f_o - f_c)e^{-kt}$$

$$K = \frac{f_o - f_c}{F_c}$$

where, f_o = initial rate of infiltration capacity

f_c = final constant rate of infiltration at saturation

K = constant depending upon soil and vegetation

e = base of the Napierian logarithm

F_c = shaded area in fig

t = time from beginning of the storm

06

Q. Explain any method of determining infiltration capacity of soil surface. (R-76)

Methods of Determining Infiltration:

i) Infiltrometers

ii) Observation in pits and ponds

iii) Placing a catch basin below a laboratory sample

iv) Artificial rain simulators

v) Hydrograph analysis etc

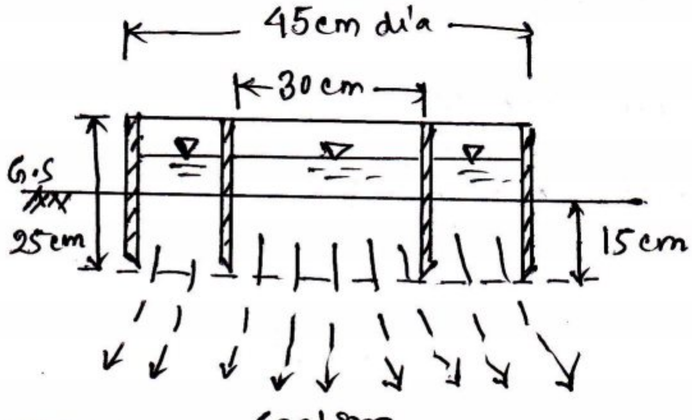
PIA HO

I) Double-ring infiltrometer:

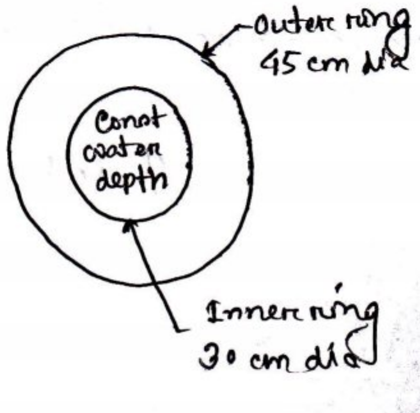
i) A double ring infiltrometer is penetrated into the soil to a depth of 15 cm with a hammer.

ii) The disturbed soil, if any, adjacent to the sides is tamped.

iii) Point gauges are fixed in the centre of the rings and in the annular space between the two ring



Section



Plan

(iv) Water is poured into the ring to a desire depth.

(v) To maintain constant depth, water is added continously and water requirement for regular time intervals is recorded upto a period of at least 6 hours.

(vi) The results are plotted as infiltration rate cm/hr versus time. in minutes.

Infiltration capacity is determined from this curve.

Q. Explain infiltration indices.

Infiltration indices: There are three types of infiltration indices.

i) ϕ-index
ii) W- index
iii) fare-index

07

i) ϕ index:

The ϕ index is defined as that rate of rainfall above which the rainfall volume equals the runoff volume.

$$\phi\text{-index} = \frac{\text{basin recharge}}{\text{duration of rainfall}}$$

rainfall = runoff

ii) W-index:

The W-index is the average infiltration rate during the time rainfall intensity exceeds the infiltration capacity rate.

$$W\text{-index} = \frac{F_p}{t_R} = \frac{P-Q-S}{t_R}$$

where, P = total rainfall

Q = surface runoff

S = effective surface retention

t_R = duration of storm during which $i > f_p$

F_p = total infiltration

iii) f_{ave}-index:

In this method an average infiltration loss is assumed throughout the storm, for the period $i > f$.

Q. Write short note on: watershed leakage, water balance.

07

Watershed leakage:

The rain water after infiltering into the ground may percolate through water through the water bearing strata may flow into the adjacent basin or directly into the sea if the water bearing strata outcrops into the sea. This is called watershed leakage.

Water balance :

The input items into a basin are essentially precipitation (P) and subsurface inflow (Gi) while the water losses are evaporation (E), evapotranspiration (Et) and subsurface outflow (Go). The balance goes to recharge ground water (GR), increase the soil moisture (SMA) and as surface runoff (streamflow, R).

The water balance equation can be written as,

$$P + G_i = E + E_t + G_o + SMA + G_R + R$$

FLOOD ESTIMATION & CONTROL

Q. Define SPF, MPF, Design flood.

SPF :

SPF means Standard Project Flood. This is the estimate of the flood likely to occure from the most severe combination of the meteorological and hydrological conditions which are reasonably characteristics of the drainage basin being considered, but excluding extremely rare combination.

MPF :

MPF means Maximum Probable Flood. It includes the extremely rare and catastrophic floods and is usually confined to spillway design of very high dams. The SPF is usually around 80% of the MPF for the basin.

Design flood :

It is the flood adopted for the design of hydraulic structures like spillways, bridge openings, flood banks etc.

Q. How can you determine peak flood in a river.

Estimation of peak flood:

The maximum flood discharge (peak flood) in a river may be determined by the following methods:

i) Physical indications of past floods - flood marks and local enquiry

ii) Empirical formulae and curves

iii) Concentration time method

iv) Overland flow hydrograph

v) Rational method

vi) Unit hydrograph

vii) Flood frequency studies

FORCE

DESIGN FLOOD

09

Q. Write down the procedure to estimate the design flood for any return period using Gumbel's distribution.

The procedure to estimate the design flood for any return period using Gumbel's distribution is as given below:

Step-1: From the given data on flood peaks for n years, the mean $\bar{x}$ and standard deviation S_x are computed from

$$\bar{x} = \frac{x_1 + x_2 + \cdots + x_n}{n}$$

$$S_x = \sqrt{\frac{1}{(n-1)} \sum_{i=1}^{n} (x_i - \bar{x})^2}$$

Step-2: for the known size sample size n, the values of $\bar{y}_n$ and σ_n are obtained from table.

Step-3: For the given return period T_r, the reduced variate y_T is found from

$$y_T = -\ln\left[\ln\left(\frac{T_r}{T_r - 1}\right)\right]$$

Step-4: With the values of $\bar{y}_n$ and σ_n obtained by in step 2 and y_T obtained in step 3, the frequency factor K_T is calculated using

$$K_T = \frac{y_T - \bar{y}_n}{\sigma_n}$$

Step-5: With values of $\bar{x}$ and S_x obtained in step 1 and K_T obtained in step 4, the magnitude of the flood x_T is computed using

$$x_T = \bar{x} + K_T \cdot S_x$$

07

Q. What do you understand by frequency factor? How is it determined for Gumbel's distribution.

Frequency factor:

The magnitude of the flood,

$$x_T = \bar{x} + K_T \cdot S_x$$

where, $\bar{x}$ = mean S_x = standard deviation

K_T = frequency factor

Frequency factor K_T is given by,

$$K_T = \frac{y_T - \bar{y}_n}{\sigma_n}$$

The frequency factor K_T depends on the type of distribution and the return period.

Determination of K_T for Gumbel's distribution:

[আগের Question এর step-4 পর্যন্ত লিখতে হবে]

Q. Distinguish between annual series and partial series.

Annual series	Partial series
i) If the extreme floods are of primary concern, wherein the flood magnitudes with an exceedence probability of 0.5 or less are estimated, annual series is used.	i) When estimates of very frequent events with return periods of less than 5 years are required, the partial series is preferable.
ii) In the annual series the largest flood observed in each water year only is taken	ii) In the partial series all flood events above a selected base value are included.

↓ Annual series

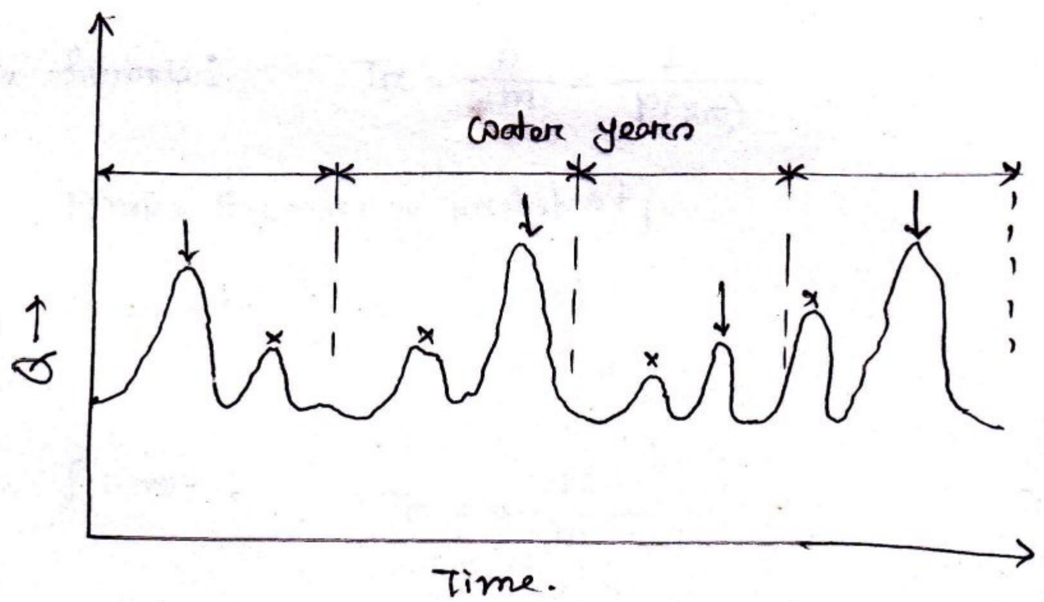


Fig: composition of annual and partial series

Probability and Statistics

08.06

Q. What do you mean by return period? Give some of the formulas which are used to determine the return period.

Return period:

Return period indicates the average number of years within which a given event will be equalled or exceeded. It is usually denoted by Tr. It is also known as recurrence interval, or simply the frequency.

Formula:

California formula: $T_r = \frac{n}{m} = \frac{1}{P(x_m)}$

$P(x_m)$ = Exceedence probability

Hazen's formula: $T_r = \frac{2n}{2m-1}$

Weibul's formula: $T_r = \frac{n+1}{m}$

07

Q. Distinguish between return period and exceedence probability.

Return period	Exceedence probability
i) It indicates the average number of years within which a given event will be equalled or exceeded.	i) It is opposite of return period.
ii) It is denoted by T_r.	ii) It is denoted by $P(x_m)$
iii) $T_r = \frac{n}{m}$	iii) $P(x_m) = \frac{m}{n}$

Flood Routing

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09

Q. Define flood routing? What are the uses of flood routing?

Flood routing:

Flood routing may be defined as the procedure whereby the shape of a flood hydrograph at a particular location on the stream is determined from the known or assumed flood hydrograph at some other location upstream.

Uses of flood routing:

i) It is establishing the height of a flood peak at a downstream location in short term flood forecasting.

ii) It is estimating the protection that would result from construction of a reservoir.

iii) It is used for determining required levee heights for flood protection

iv) It is used for determining the adequacy of spillways

v) Predicting the behaviour of a river after a change in channel conditions

vi) It is used for the derivation of synthetic unit graphs.

07

Q. Distinguish between channel routing & reservoir routing.

Channel routing	Reservoir routing
i) It analyses the effect of storage of a specified channel reach on the flood hydrograph.	I) It analyses the effect of reservoir storage on the flood hydrograph.
ii) This gives an information about flood occurrence in the river/stream.	II) For this purpose information such as: storage vs elevation curve, outflow vs elevation curve, inflow hydrograph are required
iii) Some channel routing method are: a) Muskingum method b) Muskingum crust segment method, c) Graphical method	(4) Some reservoir routing methods are; I.S.D method, Modified puls method, Trial and error method, graphical method

07

Q. Distinguish between prism storage & wedge storage.

Prism storage	Wedge storage
i) The prism storage is formed by a volume of constant cross section along the length of the prismatic channel.	i) wedge storage may be taken as a fraction of the volume of the prism corresponding to (I - Q). I = Inflow, Q = outflow.
ii) Prism storage depends on the outflow alone.	ii) wedge storage depends on the difference (I-Q).
iii) Prism storage = KQ	iii) wedge storage = K.x (I-Q)

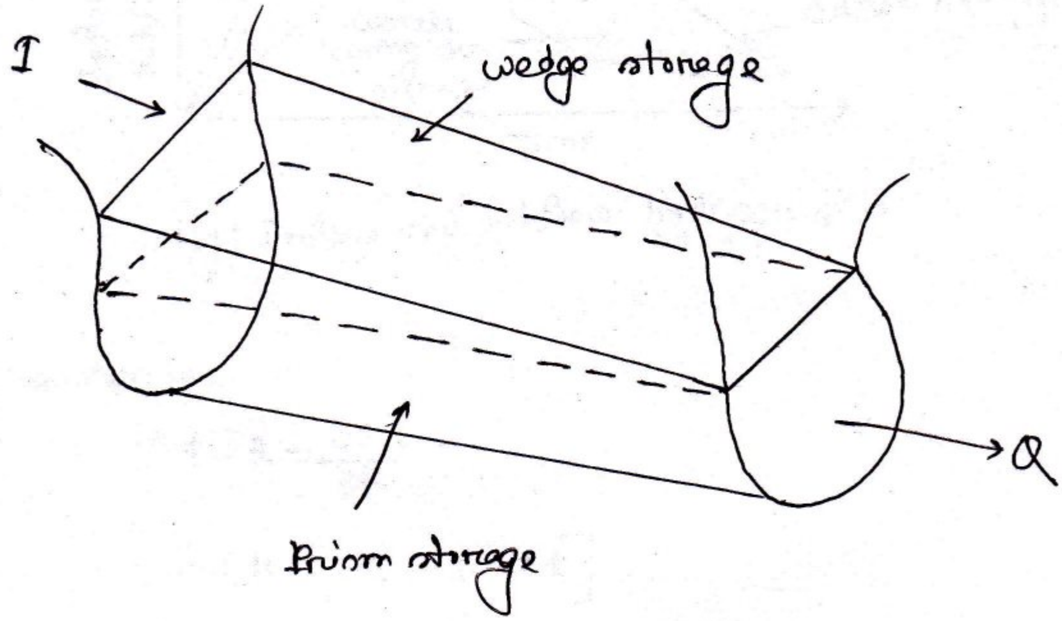


Fig: Prism and wedge storage in a channel reach

07

Q. Distinguish between hydraulic routing and hydrologic routing.

Q. Explain the method of determining the Muskingum parameters K and x of a reach from a pair of observed inflow and outflow hydrograph.

When a pair of observed inflow and outflow hydrographs is available for a reach, the values of K and x of the reach can be determined using these graphs. When these two graphs are plotted it will be seen that both will cross on the recession side of the inflow hydrograph.

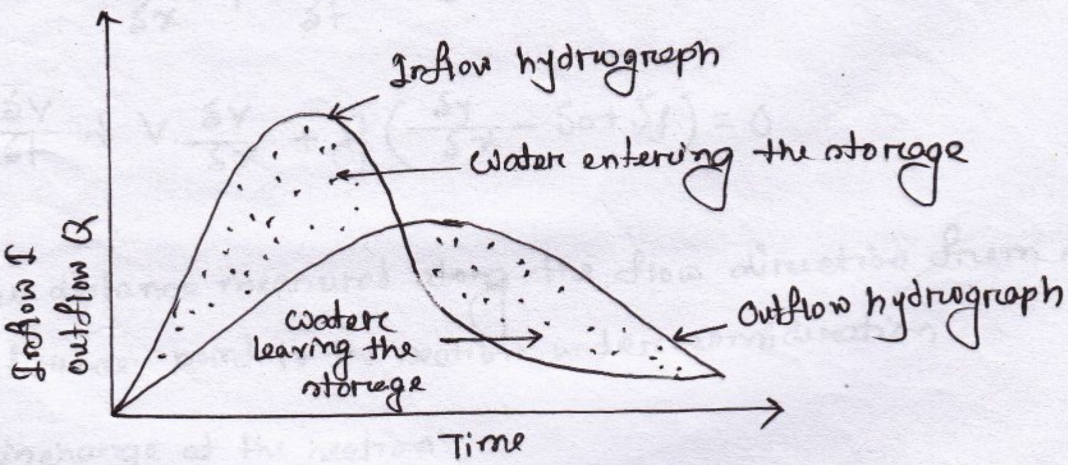


fig: Inflow and outflow hydrographs

The routing equation is,

$$I - Q = \frac{dS}{dt}$$

$$S = K\left[xI + (1-x)Q\right]$$

$$\Rightarrow \frac{dS}{dt} = K\left[x \cdot \frac{dI}{dt} + (1-x)\frac{dQ}{dt}\right]$$

$$\Rightarrow I - Q = K\left[x \cdot \frac{dI}{dt} + (1-x)\frac{dQ}{dt}\right] \quad \cdots \cdots (i)$$

When the two hydrographs are crossing $I = Q$ and $I - Q = 0$

$$x = \frac{\frac{dQ}{dt}}{\frac{dQ}{dt} - \frac{dI}{dt}} \quad \cdots \cdots \cdots (ii)$$

finding out the slopes of inflow and outflow hydrographs at the point of crossing and substituting them in eqn (ii) we can determine the value of x. Then, the slopes of the hydrographs are found out at any other time, and hence the slopes along with the known values of x are substituted in eqn (i) to determine the value of k.

Q. Write down the two basic differential equations of hydraulic routing method and explain each term.

When there is no lateral inflow into the channel reach, the unsteady flow in the channel is described by the following two equations which are known as Saint-Venant equations.

$$\frac{\delta Q}{\delta x} + \frac{\delta A}{\delta t} = 0$$

$$\frac{\delta V}{\delta t} + V.\frac{\delta V}{\delta x} + g\left(\frac{\delta y}{\delta x} - S_o + S_f\right) = 0$$

where, x = the distance measured along the flow direction from some reference point to the section under consideration

Q = discharge at the section

A = area of the flow at the section

t = the time variable

V = the average velocity of flow for the section

y = the depth of flow at the section

g = acceleration due to gravity

S_o = channel bed slope

S_f = slope of the energy line

(12) CE-307 মো: আহসান হাবীব 0১00৬৬

Introduction: Precipitation:

Raghunath: 2.3(a), 2.4, 2.8, 2.1,

Reddi: 5.13, 5.12, 5.15

Suresh: 3.9, 3.8

Formula-01:

$$P_x = \frac{1}{m}\left[\frac{N_x}{N_a}P_a + \frac{N_x}{N_b}P_b + \frac{N_x}{N_c}P_c\right]$$

m = surrounding stations

*** $\frac{N_D - N_A}{N_D} \times 100$ এটা যদি < 10% হয় তাহলে arithmatic average method হবে
$P = \frac{P_A + P_B + P_C}{3}$

Q-2.1: (Raghunath 25)

Rain gauge station D was inoperative for part of a month during which a storm occured. The storm rainfall recorded in the three surrounding stations A, B and C were 8.5, 6.7 and 9.0 cm. If the a.a.r. for the stations are 75, 84, 70 and 90 cm respectively, estimate the storm rainfall at station D.

Solution:

$$\frac{N_D - N_A}{N_D} \times 100 = \frac{90-75}{90} \times 100 = 16.67 > 10\%$$

$$\frac{N_D - N_B}{N_D} \times 100 = \frac{90-84}{90} \times 100 = 6.67 < 10\%$$

$$\frac{N_D - N_C}{N_D} \times 100 = \frac{90-70}{90} \times 100 = 22.22 > 10\%$$

Here, $m = 3$

$P_A = 8.5$ cm $P_B = 6.7$ m $P_C = 9$ cm

$N_A = 75$ cm $N_B = 84$ cm $N_C = 70$ cm $N_D = 90$ cm

$$P_D = \frac{1}{m}\left[\frac{N_D}{N_A} \times P_A + \frac{N_D}{N_B} \times P_B + \frac{N_D}{N_c} \times P_c\right]$$

$$= \frac{1}{3}\left[\frac{90}{75} \times 8.5 + \frac{90}{84} \times 6.7 + \frac{90}{70} \times 9\right]$$

$$= \frac{1}{3}(10.2 + 7.18 + 11.57)$$

$$= 9.65 \text{ cm (Ans)}.$$

Ex-5.12 (Reddi):

Raingauge station X did not function for a part of month during which a storm occurred. The storm produced rainfalls of 84, 70 and 96 mm at these surrounding stations A, B and C respectively. The normal annual rainfalls at the station X, A, B and C are respectively 770, 882, 736 and 944 mm. Estimate the missing storm rainfall at station X.

Solution:

$P_A = 84$ mm $P_B = 70$ mm $P_C = 96$ mm

$N_A = 882$ $N_B = 736$ $N_C = 944$ mm $N_X = 770$

** যে কোন একটা 10% এর চেয়ে বেশী হলে এই নিচের formula use করতে হবে

$$\frac{N_A - N_X}{N_X} \times 100 = \frac{882-770}{770} \times 100 = 14.55\% > 10\%$$

$$\frac{N_X - N_B}{N_X} \times 100 = \frac{770-736}{770} \times 100 = 4.42\% < 10\%$$

$$\frac{N_C - N_X}{N_X} \times 100 = \frac{944-770}{770} \times 100 = 22.08\% > 10\%$$

$$P_X = \frac{1}{m}\left[\frac{N_X}{N_A} \times P_A + \frac{N_X}{N_B} \times P_B + \frac{N_X}{N_C} \times P_C\right]$$

$$= \frac{1}{3}\left[\frac{770}{882} \times 84 + \frac{770}{736} \times 70 + \frac{770}{944} \times 96\right]$$

$$= \frac{1}{3}(73.33 + 73.23 + 78.31)$$

$$= 74.96 \simeq 75 \text{ mm}.$$

(Ans).

Formula - 02:

* Standard deviation, $\sigma = \sqrt{\dfrac{\sum_{n=1}^{n}(x_i - \bar{x})^2}{n-1}}$ → অথবা n হবে?

* co-efficient of variation, $C_v = \dfrac{\sigma}{\bar{x}}$

* $\bar{x} = \dfrac{\sum x_i}{n}$

* Optimum number of raingauges, $N = \left(\dfrac{C_v}{\varepsilon}\right)^2$

  ε = percentage of error

02, 08

Similar to Ex-2.4 (Raghunath):

A watershed has a network of five raingauges. Annual rainfall recorded by these gauges in given for a year. Calculate optimum number of raingauges for a 10% error in estimate of mean annual rainfall.

Raingauge:	1	2	3	4	5
Annual rainfall (cm):	50	82	73	64	105

Solution :

Raingauge	Annual rainfall (cm) x_i	$\bar{x} = \frac{\sum x_i}{n}$	$(x_i - \bar{x})$	$(x_i - \bar{x})^2$
1	50		-24.8	615.04
2	82		7.2	51.84
3	73	$\bar{x} = 74.8$	-1.8	3.24
4	64		-10.8	116.64
5	105		30.2	912.04
n=5	374			$\sum(x_i-\bar{x})^2 = 1698.8$

$$\sigma = \sqrt{\frac{\sum_{n=1} (x_i-\bar{x})^2}{n-1}} = \sqrt{\frac{1698.8}{5-1}} = 20.61 \text{ cm}$$

co-efficient of variation, $C_v = \frac{\sigma}{\bar{x}} = \frac{20.61}{74.8} \times 100 = 27.55\%$

$\therefore$ Optimum numbers of raingauge, $N = \left(\frac{C_v}{\varepsilon}\right)^2$

$$= \left(\frac{27.55}{10}\right)^2$$

$$= 7.59$$

$$\simeq 8. \text{ (Ans).}$$

01

Q. Problem-04:

In a certain river basin, there are six raingauge stations, annual rainfall having 42.4, 53.6, 67.8, 78.5, 82.7 and 95.5 cm respectively. Determine optimum number of raingauge stations to limit the error to 10% and indicate how you distribute them.

Solution:

Station	Annual rainfall (cm) x_i	$\bar{x} = \frac{\sum x_i}{n}$	$(x_i - \bar{x})$	$(x_i - \bar{x})^2$
1.	42.4		-27.68	766.18
2.	53.6		-16.48	271.59
3.	67.8		-2.28	5.20
4.	78.5	$\bar{x} = 70.08$	8.42	70.90
5.	82.7		12.62	159.26
6.	95.5		25.42	646.18
n=6	$\sum x_i = 420.5$			$\Sigma = 1919.31$

$$\sigma = \sqrt{\frac{\sum (x_i - \bar{x})^2}{n-1}} = \sqrt{\frac{1919.31}{6-1}} = 19.59 \text{ cm}$$

$$C_v = \frac{\sigma}{\bar{x}} = \frac{19.59}{70.08} \times 100 = 27.95\%$$

∴ optimum number of raingauge, $N = \left(\frac{C_v}{\epsilon}\right)^2$

$$= \left(\frac{27.95}{10}\right)^2 = 7.81$$

$$\simeq 8 \quad \text{(Ans)}$$

Here, Existing no of raingauge = 6

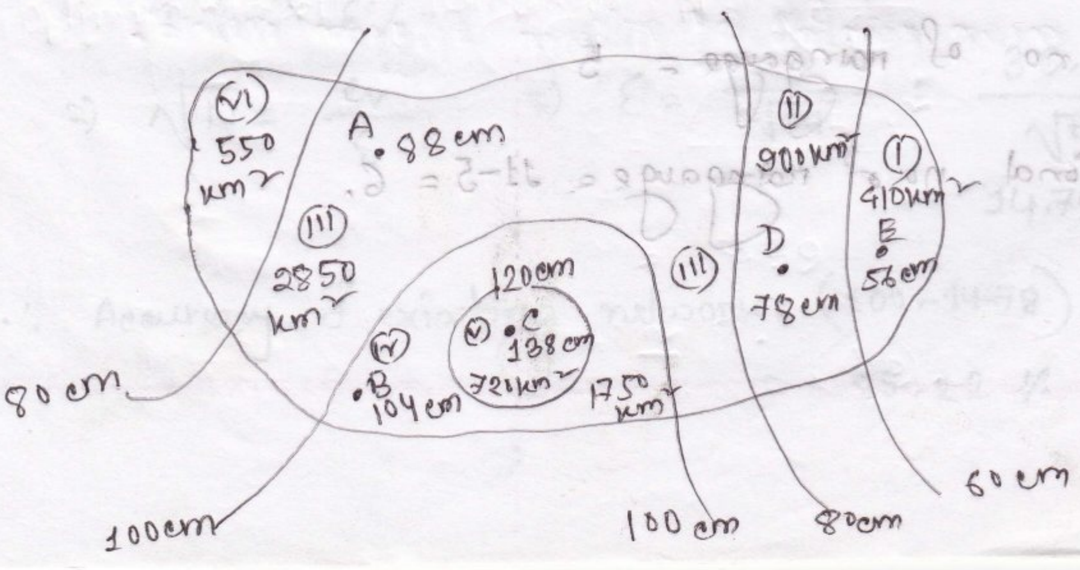
∴ Additional no of " $= 8 - 6 = 2$

These two additional raingauges are distributed according to the proportion of areas of different zones formed in a isohyetal map of the river basin.

07

Problem - 05 :

For a basin, annual rainfall data and isohyets are given. Determine optimum number of raingauges stations to limit the error in the mean rainfall to 10%. Also distribute the additional gauges if any what in percentage accuracy of existing network ?



Station	Rainfall (cm) x_i	$\bar{x} = \frac{\sum x_i}{n}$	$(x_i - \bar{x})$	$(x_i - \bar{x})^2$
A	88		-4.8	23.04
B	104		11.2	125.44
C	138	$\bar{x} = 92.8$	45.2	2043.04
D	78		-14.8	219.04
E	56		-36.8	1354.24
n=5	$\Sigma = 464$			$\Sigma = 3764.8$

$$\sigma = \sqrt{\frac{\sum_{n=1}^{5} (x_i - \bar{x})^2}{n-1}} = \sqrt{\frac{3764.8}{5-1}} = 30.68 \text{ cm}$$

$$C_v = \frac{\sigma}{\bar{x}} = \frac{30.68}{92.8} \times 100 = 33.06\%$$

$$N = \left(\frac{C_v}{\varepsilon}\right)^2 = \left(\frac{33.06}{10}\right)^2 = 10.93 \approx 11 \text{ (Ans)}$$

Existing no of raingauge = 5

∴ Additional no of raingauge = 11 − 5 = 6.

Distribution of additional raingauges:

Zone	Area km^2	Area as decimal of total area	N X Area as decimal	Rounded as	Existing Raingauge	Additional raingauge
(i)	410	$\frac{410}{7180} = 0.06$	0.66	1	1	0
(ii)	910	0.13	1.43	1	1	0
(iii)	2850	0.40	4.4	4	1	3
(iv)	1750	0.24	2.64	3	1	2
(v)	720	0.10	1.1	1	1	0
(vi)	550	0.08	0.88	1	0	1

$\Sigma = 7180$

Accuracy of existing network:

Existing no of raingauge, N = 5

$C_V = 33.06\%$

$$N = \left(\frac{C_V}{\varepsilon}\right)^2$$

$$\Rightarrow \sqrt{N} = \frac{C_V}{\varepsilon} \quad \Rightarrow \varepsilon = \frac{C_V}{\sqrt{N}} = \frac{33.06}{\sqrt{5}}$$

$$= 14.78\%$$

$\therefore$ Accuracy of existing network $= (100 - 14.78)\%$

$= 85.22\%$ (Ans).

Formula-13 : Thissen Polygon method

* Mean precipitation = $\frac{\Sigma PA}{\Sigma A}$

05

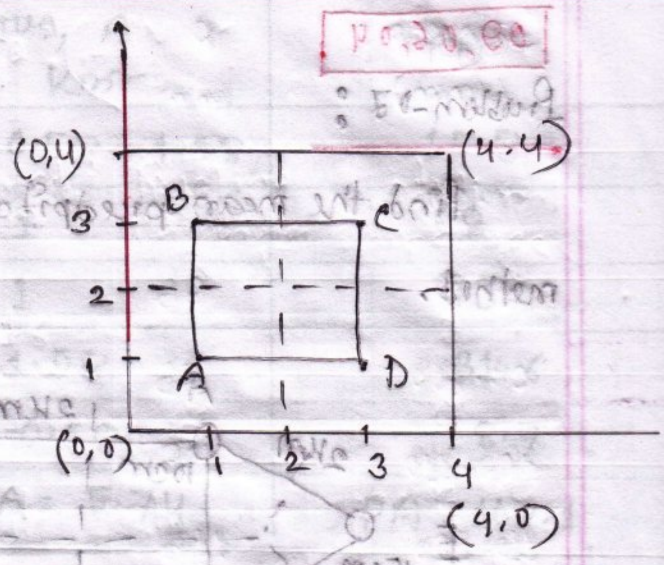
Problem - 06 :

Consider a rectangular area whose (x,y) co-ordinates are (0,0), (4,0), (0,4) and (4,4). The area is 4 km wide and 4 km long. The area has 4 raingauges. The location of the gauges and rainfall data are;

Raingauge	(x,y)	Rainfall (cm)
A	(1,1)	5
B	(1,3)	10
C	(3,3)	8
D	(3,1)	12

Determine mean rainfall by Thissen Polygon method.

Solution :



Area of outer square = 4×4 = 16 km²

Area of inner " = 2×2 = 4 km²

∴ Area of each corner square

$= \frac{1}{4}(16-4)$

$= 3$ km²

Station	Area, A km²	Rainfall P (cm)	PA km²-cm
A	3	5	15
B	3	10	30
C	3	8	24
D	3	12	36
	ΣA = 12		ΣPA = 105

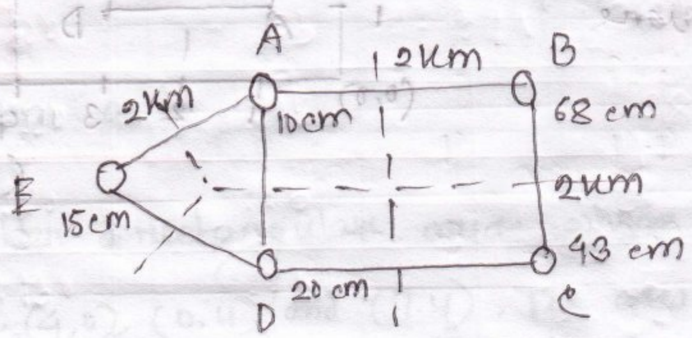
∴ Mean rainfall $= \frac{\Sigma PA}{\Sigma A} = \frac{105}{12}$

$= 8.75$ cm (Ans).

09.06.04

Problem-07:

Find the mean precipitation by Thissen Polygon method.



Solution:

Area of outer square = $2 \times 2 = 4 \text{ km}^2$

" of each inner " = $\frac{1}{4} \times 4 = 1 \text{ km}^2$

" of triangle = $\frac{\sqrt{3}}{4}(2)^2 = 1.73 \text{ km}^2$

$\frac{1}{3}$ area of " = $\frac{1}{3} \times 1.73 = 0.58 \text{ km}^2$

Station	Precipitation, P (cm)	Area, A km²	PA (mm)
A	10	1+0.58 = 1.58	15.8
B	68	1	68
C	43	1	43
D	20	1.58	31.6
E	15	0.58	8.7
		$\Sigma A = 5.74$	$\Sigma PA = 167.1$

$\therefore$ Mean precipitation $= \frac{\Sigma PA}{\Sigma A} = \frac{167.1}{5.74} = 29.11$ cm

(Ans).

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Problem-08 :

The analysis of storm yielded the following information regarding isohyets. Calculate the average depth of rainfall.

Isohyets interval (mm) :	70-80	80-90	90-100	100-110	110-120	120-130
Area (km²)	10	85	113	98	136	67

Isohyets (mm)	P (mm)	A km^2	PA
70-80	75	10	750
80-90	85	85	7225
90-100	95	113	10735
100-110	105	98	10290
110-120	115	136	15640
120-130	125	67	8375
		$\Sigma A = 509$	$\Sigma PA = 53015$

$\therefore$ Average depth of rainfall $= \frac{\Sigma PA}{\Sigma A}$

$= \frac{53015}{509}$

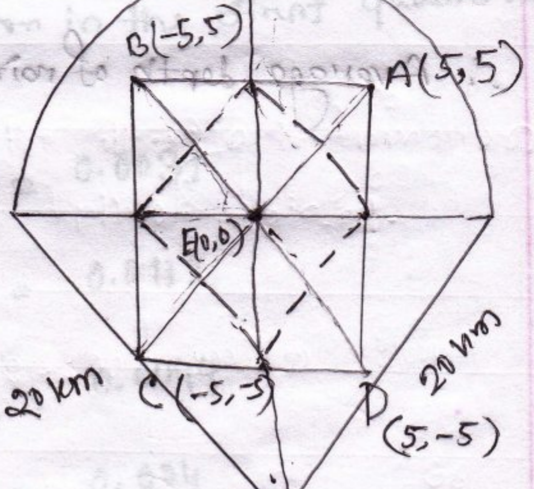
$= 104.16$ mm. (Ans)

03

Problem-09 : (Reddi)

A semicircle of diameter 20 km with an equilateral triangle of side 20 km below its diameter is a close approximation to a river basin. Five stations A, B, C, D and E are located with respect to a co-ordinate axis system whose x-axis and origin are diameter of circle and centre of circle are (5, 5), (−5, 5), (−5, −5), (5, −5) and (0, 0) in km respectively. Rainfall records of these stations are 85, 92, 77, 80 and 105 mm respectively. Determine average depth of rainfall by Theissen polygon method.

Solution:



Area of semi-circle $= \frac{\pi D^2}{8}$

$= \frac{\pi \times (20)^2}{8}$

$= 157.08\ km^2$

Area of equilateral triangle $= \frac{\sqrt{3}}{4}(20)^2$

$= 173.21\ km^2$

Area of square ABCD $= 10 \times 10 = 100\ km^2$

Area of inner square $= (2 \times 5 \cos 45)^2 = 50\ km^2$

Area of corner triangle $= \frac{1}{4}(100 - 50) = 12.5\ km^2$

Station	P (mm)	Area, A (km²)	PA
A	85	$12.5+\left(\frac{157.08}{2}-\frac{100}{4}\right)=66.04$	5613.4
B	92	66.04	6075.68
C	77	$12.5+\left(\frac{173.21}{2}-\frac{100}{4}\right)=74.11$	5706.47
D	80	74.11	5928.8
E	105	50	5250
		$\Sigma A = 330.3$	$\Sigma = 28574.35$

$\therefore$ Average depth of rainfall $= \frac{28574.35}{330.3}$

$= 86.51$ mm. (Ans).

$$P_x = \frac{\left[\frac{1}{r_1^2}\times P_1 + \frac{1}{r_2^2}\times P_2 + \frac{1}{r_3^2}\times P_3 + \frac{1}{r_4^2}\times P_4\right]}{\frac{1}{r_1^2}+\frac{1}{r_2^2}+\frac{1}{r_3^2}+\frac{1}{r_4^2}}$$

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Example – 5.13:

Station x failed to report the rainfall recorded during a storm. With respect to east-west and north-south axes set up at station X, the coordinates of 4 surrounding gauges which are the nearest to station X in the respective quadrants are (10,15), (-8,5), (-12,-9) and (5,-15) km respectively. Determine the missing rainfall at X, if the storm rainfalls at the four surrounding gauges are 73, 89, 68 and 57 mm respectively.

Solution:

$P_1 = 73mm$ $\quad P_2 = 89mm$ $\quad P_3 = 68mm$ $\quad P_4 = 57 mm$

Let, r_1 be the distance between the station in the first quadrant and the station X, then,

$r_1^2 = 10^2 + 15^2 = 325$ $\quad \frac{1}{r_1^2} = 0.0031$

$r_2^2 = (-8)^2 + 5^2 = 89$ $\quad \frac{1}{r_2^2} = 0.0112$

$r_3^2 = (-12)^2 + (-9)^2 = 225$ $\quad \frac{1}{r_3^2} = 0.0044$

$r_4^2 = (5)^2 + (-15)^2 = 250$ $\quad \frac{1}{r_4^2} = 0.004$

$$P_x = \frac{\frac{1}{r_1^2}\times P_1 + \frac{1}{r_2^2}\times P_2 + \frac{1}{r_3^2}\times P_3 + \frac{1}{r_4^2}\times P_4}{\frac{1}{r_1^2}+\frac{1}{r_2^2}+\frac{1}{r_3^2}+\frac{1}{r_4^2}}$$

$$= \frac{0.0031\times 73 + 0.0112\times 89 + 0.0044\times 68 + 0.004\times 57}{0.0031 + 0.0112 + 0.0044 + 0.004}$$

$$= 77.11 \text{ mm (Ans).}$$

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Ex-4.2: A basin has an area of 26560 km², perimeter 965 km and length of the thalweg 230 km. Determine: (i) form factor (ii) compactness coefficient (iii) elongation ratio and (iv) circularity ratio.

Solution:

i) Form factor, $F_f = \frac{A}{L_b^2} = \frac{26560}{(230)^2} = 0.502$

An inverted factor will give 2 (Co-efficient of shape of the basin)

ii)

$\pi R^2 = 26560 \quad \therefore R = 91.95$ km

$C_c = \frac{P_b}{2\pi R} = \frac{965}{2\pi \times 91.95} = 1.67$

iii) $E_r = \frac{2R}{L_b} = \frac{2\times 91.95}{230} = 0.8$

iv)

$2\pi R' = 965 \quad \therefore R' = 153.58$ km

$C_r = \frac{A}{\pi R'^2} = \frac{26560}{\pi \times (153.58)^2}$

$= 0.358$ (Ans).

Ex-- : The areas between different contour elevations for the Noyyil River basin, Coimbatore (South India) are given below. Determine the mean and median elevation for the basin.

Contour elevations m	<225	225-300	300-375	375-450	450-525	525-600	>600
Area between contours Km^2	181	723	1144	814	216	46	140

Solution:

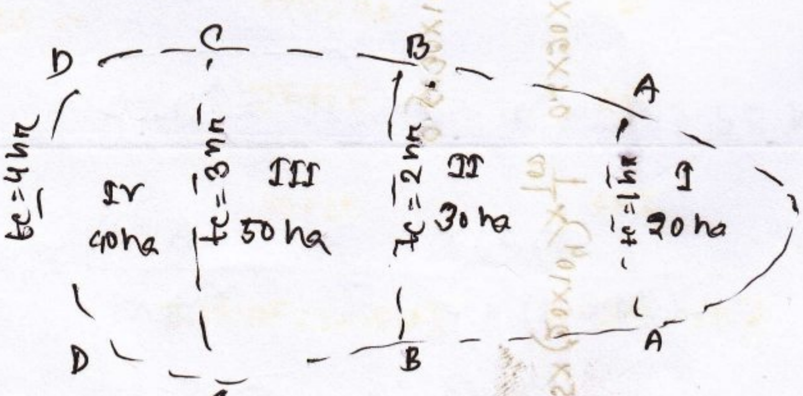
computation of mean elevation of basin:

contour elevation m	Mean elevation between contours Z_1, m	Area between contours, a_1 km^2	Product $a_1 \times Z_1$	Mean elevation m
<225	Say, 200	181	36200	
225-300	262.5	723	189787.5	
300-375	337.5	1144	386100	
375-450	412.5	814	335775	$Z_0 = \frac{1170037.5}{3264}$
450-525	487.5	216	105300	$= 358.47$
525-600	562.5	46	25875	
>600	Say, 650	140	91000	
		$\Sigma a_1 = 3264$	$\Sigma a_1 Z_1 = 1170037.5$	

Computation of median elevation of basin:

contour elevations m	Area between contours, a_i km^2	Percent of total area %	% of total area over given lower limit
<225	181	$\frac{181 \times 100}{3264} = 5.5$	100.0
225-300	723	22.1	94.5
300-375	1144	35.1	72.4
375-450	814	25.0	37.3
450-525	216	6.6	12.3
525-600	46	1.4	5.7
>600	140	4.3	4.3
	A = 3264		

Ex-4.3: A 4hour-rain of average intensity 1 cm/hr falls over the fern leaf type catchment as shown in fig. The time of concentration from the lines AA, BB, CC and DD are 1, 2, 3 and 4 hours respectively.



to the site O where the discharge measurements are made. The values of the runoff coefficient C are 0.5, 0.6 and 0.7 for the 1st, 2nd and 3rd hours of rainfall respectively and attains a constant value of 0.8 after

3 hours. Determine the discharge at site O.

Solution:

Sub area contributing runoff, hr	Time from beginning of storm, hr						
	1	2	3	4	5	6	7
I	20	20	20	20			
II		30	30	30	30		
III			50	50	50	50	
IV				40	40	40	40
Discharge at O from sub areas $Q=\sum CAP$	$0.5\times(20\times10^4)\times\frac{1}{100}$	$0.6\times20\times10^4\times\frac{1}{100}$ $0.5\times30\times10^4\times\frac{1}{100}$	$0.7\times20\times10^4\times\frac{1}{100}$ $0.6\times30\times10^4\times\frac{1}{100}$ $0.5\times50\times10^4\times\frac{1}{100}$	$0.8\times20\times10^4\times\frac{1}{100}$ $0.7\times30\times10^4\times\frac{1}{100}$ $0.6\times50\times10^4\times\frac{1}{100}$ $0.5\times40\times10^4\times\frac{1}{100}$	$0.8\times30\times10^4\times\frac{1}{100}$ $0.7\times50\times10^4\times\frac{1}{100}$ $0.6\times40\times10^4\times\frac{1}{100}$	$0.8\times50\times10^4\times\frac{1}{100}$ $0.7\times40\times10^4\times\frac{1}{100}$	$0.8\times40\times10^4\times\frac{1}{100}$
Discharge at O, Q, m^3/hr	1000	2700	5700	8700	8300	6800	3200

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Stream Gauging

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Formula:

* $\frac{Q_a}{Q_o} = \left(\frac{\Delta h_a}{\Delta h_o}\right)^n$

* $Q = k\,(h-h_o)^n$

* Two point method, $V_m = \frac{0.2d + 0.8d}{2}$

* Three point method, $V_m = \frac{0.2d + 0.6d + 0.8d}{3}$

* $v = aN + b$

* Volume of runoff = basin area X depth of runoff

* $10000\ m^3 = 0.01$ million $\cdot\ m^3$

  $10000\ m^3 = 1$ ha-m

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Example - 6.3 :

The following data were obtained by stream gauging of a river:

Main gauge staff reading (m)	:	12	12
Auxiliary " " (m)	:	11.65	11.02
Discharge (cumec)	:	9.50	15.20

what should be the discharge when the main gauge reads 12 m and the auxiliary gauge reads 11.37 m ?

Solution :

$\Delta h_o = 12 - 11.65 = 0.35$ m

$\Delta h_a = 12 - 11.02 = 0.98$ m

$Q_o = 9.50 \quad Q_a = 15.20$

we know,

$$\left(\frac{Q_a}{Q_o}\right) = \left(\frac{\Delta h_a}{\Delta h_o}\right)^n$$

$$\Rightarrow \frac{15.20}{9.50} = \left(\frac{0.98}{0.35}\right)^n$$

$$\Rightarrow 1.6 = (2.8)^n$$

$$\Rightarrow \log 1.6 = n \log 2.8 \qquad n = 0.456$$

Again, $\Delta h_a = 12 - 11.37 = 0.63$ m $\quad Q_a = ?$

$$\frac{Q_a}{Q_o} = \left(\frac{\Delta h_a}{\Delta h_o}\right)^n \Rightarrow \frac{Q_a}{9.50} = \left(\frac{0.63}{0.35}\right)^{0.456}$$

$$\Rightarrow Q_a = 12.42 \text{ cumec.}$$ (Ans).

Suresh - 7.4 :

Find the mean stream flow velocity for a = 0.4 and b = 0.06 using data :

Stream depth :	0.2d	0.6d	0.8d
Revolution :	40	15	30
Time (sec) :	58	50	54

Solution :

We know,

$$V = aN + b$$

$$V_{0.2d} = 0.4 \times \frac{40}{58} + 0.06 = 0.34 \text{ m/sec}$$

$$V_{0.6d} = 0.4 \times \frac{15}{50} + 0.06 = 0.18 \text{ m/sec}$$

$$V_{0.8d} = 0.4 \times \frac{30}{54} + 0.06 = 0.28 \text{ m/sec}$$

$$\therefore V_{mean} = \frac{1}{3}\left(V_{0.2d} + V_{0.6d} + V_{0.8d}\right)$$

$$= \frac{1}{3}\left(0.34 + 0.18 + 0.28\right)$$

$$= 0.27 \text{ m/sec.}$$

(Ans).

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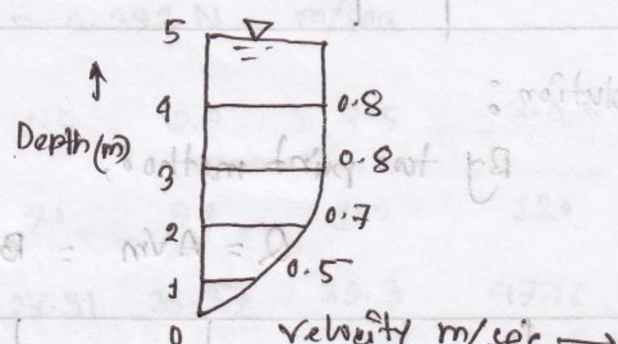
Ex-3 (b) : (Raghunath - 303):

Following velocities are recorded in a stream with a current meter;

Depth above bed (m) :	0	1	2	3	4
velocity (m/sec) :	0	0.5	0.7	0.8	0.8

Find the discharge per unit width of stream near the point of measurement for a depth of flow of 5 m.

Solution:



Depth of flow, $d = 5\,m$

Now,

From bed $0.2d = 0.2 \times 5 = 1\,m$

$0.8d = 0.8 \times 5 = 4\,m$

from water surface, $0.2d = 5 - 1 = 4\,m$

$0.8d = 5 - 4 = 1\,m$

velocity of 0.2d from water surface

$$V_{0.2d} = V_{4m} = 0.8\ m/sec$$

velocity of 0.8d from water surface,

$$V_{0.8d} = V_{1m} = 0.5\ m/sec$$

Average velocity, $\bar{V} = \frac{V_{0.2d} + V_{0.8d}}{2} = \frac{0.8 + 0.5}{2} = 0.65\ m/sec$

$Q = AV = B \times d \times 0.65 = B \times 5 \times 0.65 = 3.25\,B$

$\therefore$ Discharge per unit width, $q = \frac{Q}{B} = 3.25$ cumec. (Ans).

08

Problem-04 : (Suresh – EX-7.5)

compute the value of stream flow rate using two point method.

Depth from one end (m)		0	1	2	3	4	5	6	7
Depth (m)		0	1.4	3.3	5.0	9.0	5.4	3.8	1.8
Velocity at m/sec	0.2d	0	0.4	0.6	0.84	0.90	0.80	0.62	0.54
	0.6d	0	0.25	0.35	0.60	0.70	0.65	0.50	0.36
	0.8d	0	0.20	0.30	0.50	0.62	0.55	0.40	0.30

Solution:

By two point method,

$$Q = AV_m = Bd\,V_m \qquad V_m = \frac{0.2d + 0.8d}{2}$$

Distance (m)	0	1	2	3	4	5	6	7
Width, b (m)	0	1-0 = 1	2-1 = 1	3-2 = 1	1	1	1	1
Depth, d (m)	0	1.4	3.3	5.0	9.0	5.4	3.8	1.8
$V_m = \frac{0.2d+0.8d}{2}$	0	$\frac{0.4+0.2}{2} = 0.3$	0.45	0.67	0.76	0.68	0.51	0.42
Q = bd Vm cumec	0	0.42	1.49	3.35	6.84	3.67	1.94	0.76

∴ Total flow rate = 0.42 + 1.49 + 3.35 + 6.84 + 3.67 + 1.94 + 0.76

= 18.47 cumec. (Ans).

01

Problem - 05:

Compute the velocity of flow using a 12.5 cm diameter cup-type price meter. The meter is kept at 0.6 times the depth of flow below water surface. Recorded measurements are -

Depth (m) :	0	0.5	1.0	1.5	2.0	2.5	3.0
Revolution (N/S) :	0	30	60	70	90	100	120

Solution:

$V = \pi DN = \pi \times 12.5 \times N = 39.27 N \text{ cm/sec}$

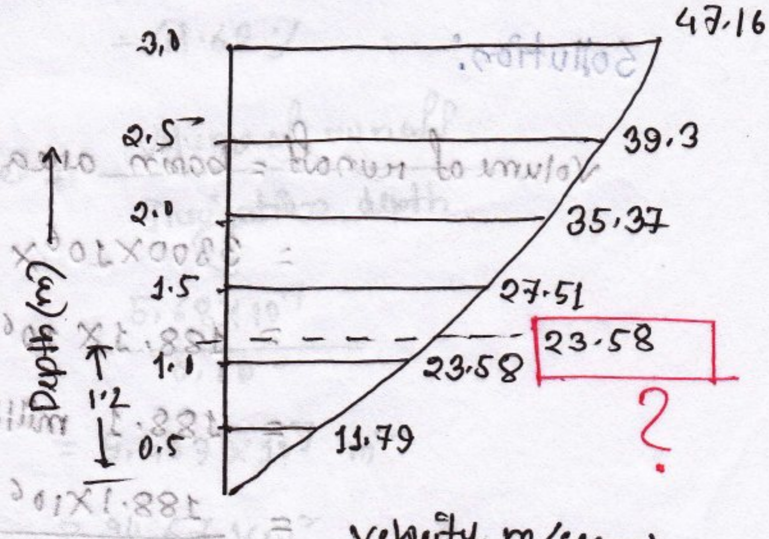
$= 0.393 N \text{ m/sec}$

Depth (m) :	0	0.5	1.0	1.5	2.0	2.5	3.0
N (rps) :	0	30	60	70	90	100	120
V (m/sec) :	0	11.79	23.58	27.51	35.37	39.3	47.16

Depth of cup-type meter from top surface $= 0.6d = 0.6 \times 3$

$= 1.8 \text{ m}$

from bed level height of meter $= 3 - 1.8 = 1.2 \text{ m}$



$V_{1.2m} = 23.58 + \frac{27.51 - 23.58}{5} \times 2$

$= 25.152 \text{ m/sec.}$

(Ans).

Ex-7.2 : (Suresh)

The stream flow velocity measurement was conducted using curely type current meter. If current meter makes 50 rps then what would be the stream flow velocity. Assume the value of a and b as 0.3 and 0.05 respectively.

Solution:

$N = 50$ rps $\quad a = 0.3 \quad b = 0.05$

$V = aN + b = 0.3 \times 50 + 0.05$

$= 15.05$ m/sec. (Ans)

Ex-6.7 : (Reddi)

What volume is represented by 57 mm of runoff depth from a basin of area 3300 km²? Give the answer in m³, cumec-days, ha-m and million cubic meters.

Sollution:

Volume of runoff = basin area × depth of runoff

$= 3300 \times 10^6 \times 57 \times 10^{-3} =$

$= 188.1 \times 10^6$ m³

$= 188.1$ million m³ [10000 m³ = 0.01 million m³]

$= \frac{188.1 \times 10^6}{10000} = 18810$ ha-m [10000 m³ = 1 ha-m]

$= \frac{188.1 \times 10^6}{86400} = 2177.08$ cumec days [1 day = 86400 sec]

08

EX - 6.8 : (Reddi)

A drainage basin has an area of 210 km², The average depth of rainfall received by it during a monsoon period is computed as 65 cm, while the runoff measured at its outlet during the same period is estimated to be 5.68 X 10⁷ m³. Compute the depth of runoff. What percentage of rainfall has become runoff ? If all this runoff volume is stored and used to irrigate a crop which requires 60 cm of water. How many hectares can be irrigated?

Solution:

$$\text{Depth of runoff} = \frac{\text{Volume of runoff}}{\text{Basin area}}$$

$$= \frac{5.68 \times 10^7}{210 \times 10^6} = 0.2705 \text{ m} = 27.05 \text{ cm}$$

$$\text{\% of rainfall that became runoff} = \frac{27.05}{65} \times 100$$

$$= 41.62\ \%$$

$$\text{Area of crop that can be irrigated} = \frac{\text{Volume of runoff}}{\text{Irrigation depth}}$$

$$= \frac{5.68 \times 10^7}{0.60}$$

$$= 9.467 \times 10^7 \text{ m}^2$$

$$= 94.67 \text{ km}^2$$

$$= 9467 \text{ hectares.}$$

(Ans),

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Ground Water

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* For confined aquifer or artesian aquifer,

$$Q = \frac{2.72\, T (s_1 - s_2)}{\log \frac{r_2}{r_1}}$$

$h_1 = H - s_1$ $\quad$ H = static head $\quad$ $T = Kb = KH$ → Transmissibility

$h_2 = H - s_2$

T: $m^3/min/m$ $\quad$ K: m/min

* For unconfined aquifer,

$$Q = \frac{\pi K (h_2^2 - h_1^2)}{\ln \frac{r_2}{r_1}} \quad m^3/min$$

$1\ m^3/d = 60 \times 24 \times 1000$ lpd

* Specific capacity $= \frac{Q}{s_w}$ $\quad$ $m^3/min/m$

* Porosity, $n = S_y + S_r$

* change in ground water storage = Area of aquifer × drop in g.w.t × S_y $\quad$ m^3

* Storage coefficient, $S = \gamma_w b (\alpha + n\beta)$

$\gamma_w = 9810\ N/m^3$ $\quad$ $\alpha = \frac{1}{E_s}$ $\quad$ E_s = Bulk modulus of elasticity

$\beta = \frac{1}{K_w}$ $\quad$ $K_w = 2.1\ GN/m^2 = 2.1 \times 10^9\ N/m^2$

* $S_w = \frac{\gamma_w n b}{K_w}$ $\quad$ $S_w (\%) = \frac{S_w}{S} \times 100$

08 | 07

01. A 30 cm well fully penetrates a confined aquifer 30 m deep. After a long period of pumping at a rate of 1200 lpm, the drawdown in the wells at 20 and 45 m from the pumping well are found to be 2.2 and 1.8 m, respectively. Determine the transmissibility of the aquifer. what is the drawdown in the pumped well? (R-139)

Solution:

$$Q = \frac{2.72 T (S_1 - S_2)}{\log \frac{r_2}{r_1}}$$

$$\Rightarrow 1.2 = \frac{2.72 T (2.2 - 1.8)}{\log \frac{45}{20}}$$

$[1 m^3/min = 24 \times 60 \times 1000 \text{ lpd}]$

$\therefore T = 0.388 \ m^3/min/m$

$= 5.58 \times 10^5$ lpd/m

$= 558 \ m^2/day$. (A

Now, $r_1 = r = \frac{d}{2} = \frac{0.3}{2} = 0.15$ m

$$Q = \frac{2.72 T (S - S_2)}{\log \frac{r_2}{r}}$$

$$\Rightarrow 1.2 = \frac{2.72 \times 0.388 \times (S - 1.8)}{\log \frac{45}{0.15}}$$

$\therefore S = 4.62$ m.

(Ans).

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02. A 20 cm diameter well penetrates fully a confined aquifer of thickness 25 m when the well is pumped at a rate of 200 lit/min, the steady state draw down in two observation wells located at 10 m and 100 m distance from pumping well are found to be 3.5 m and 0.05 m respectively. Calculate permeability and transmissibity.

Solution:

$Q = 200$ lit/min $= 0.2\ m^3/min$ $\quad b = 25 m$

$r_2 = 100 m \quad r_1 = 10 m \quad S_1 = 3.5 m \quad S_2 = 0.05 m$

$$Q = \frac{2.72\, Kb\,(S_1 - S_2)}{\log \frac{r_2}{r_1}}$$

$$\Rightarrow 0.2 = \frac{2.72\, K \times 25 \times (3.5 - 0.05)}{\log \frac{100}{10}}$$

$\therefore K = 8.53 \times 10^{-4}$ m/min $= 1.22$ m/day.

$T = Kb = 1.22 \times 25 = 30.5\ m^3/day/m$.

(Ans).

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03. A well with a radius of 0.5m completely penetrates an unconfined aquifer of thickness 50 m and $k = 30$ m/day. The well is pumped so that the water level in the well ~~is pumped so that the water level in the~~ well remains at 40 m above the bottom. Assuming that pumping has essentially no effect on water table at $r = 500$ m. What is the steady state discharge. (Reddi - 293)

Solution:

$r_w = 0.5$ m $\quad H = 50$ m $\quad k = 30$ m/day

$h_w = 40$ m $\quad R = 500$ m

$$Q = \frac{\pi k (H^2 - h_w^2)}{\ln \frac{R}{r_w}}$$

$$= \frac{\pi \times 30 \times \{(50)^2 - (40)^2\}}{\ln \frac{500}{0.5}}$$

$= 12279.42$ m³/day

$= 0.1421$ m³/sec

$= 142.12$ lit/sec. (Ans).

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04. A 30 cm well penetrates 50m below the static water table. After a long period of pumping at a rate of 1800 lpm. The draw downs in the wells 15 and 45m from the pumped well were 1.7 and 0.8 m respectively. Determine the transmissibility of the aquifer. What is the draw down in the pumped well? (R-139)

Solution:

$H = 50m$ $\quad Q = 1800$ lpm $= 1.8\ m^3/min$

$r_2 = 45m$ $\quad r_1 = 15m$ $\quad s_2 = \sout{1.7m}$ 0.8m $\quad s_1 = \sout{0.8m}$ 1.7 m

$h_1 = H - s_1 = 50 - 1.7 = 48.3m$

$h_2 = H - s_2 = 50 - 0.8 = 49.2m$

$T = ?$ $\quad s = ?$

$$Q = \frac{\pi k (h_2^2 - h_1^2)}{\ln \frac{r_2}{r_1}}$$

$$\Rightarrow 1.8 = \frac{\pi k \{(49.2)^2 - (48.3)^2\}}{\ln \frac{45}{15}}$$

$\therefore k = 7.17 \times 10^{-3}\ m/min = 1.196 \times 10^{-4}\ m/sec$

$T = kH = 1.196 \times 10^{-4} \times 50 = 5.98 \times 10^{-3}\ m^3/sec/m$

(Ans.

$r_1 = r = \frac{d}{2} = \frac{0.3}{2} = 0.15\ m$

$$Q = \frac{\pi K (h_2^2 - h_1^2)}{\ln \frac{r_2}{r}}$$

$$\Rightarrow 1.8 = \frac{\pi \times 1.196 \times 10^{-4} \times \{(49.2)^2 - h_1^2\} \times 7.17 \times 10^{-3}}{\ln \frac{45}{0.15}}$$

$\Rightarrow h_1 = 44.33\ m$

$h_1 = H - S$

$\Rightarrow S = H - h_1 = 50 - 44.33 = 5.67\ m$. (Ans).

04

05. A 20 cm well penetrates 30m below static water level. After long pumping at a rate of 1800 lpm, drawdown of two observation wells 12m and 36m from pumped well are 1.2 and 0.5m. Determine -

i) Transmissibility

ii) Drawdown of pumped well for $R = 300\ m$

iii) Specific capacity of well.

Solution: $H = 30\ m$ $\quad Q = 1800\ lpm = 1.8\ m^3/min$

$r_1 = 12m$ $\quad r_2 = 36m$ $\quad S_1 = 1.2m$ $\quad S_2 = 0.5m$

$h_1 = H - S_1 = 30 - 1.2 = 28.8m$

$h_2 = H - S_2 = 30 - 0.5 = 29.5\ m$

$$Q = \frac{\pi k (h_2^2 - h_1^2)}{\ln \frac{r_2}{r_1}}$$

$$\Rightarrow 1.8 = \frac{\pi \times k \{(29.5)^2 - (28.8)^2\}}{\ln \frac{36}{12}}$$

$\therefore k = 0.0154 \ m/min = 22.21 \ m/day$

$T = kH = 0.0154 \times 30 = 0.462 \ m^3/min/m$

ii) $R = 300 \ m$, $r = \frac{d}{2} = \frac{0.2}{2} = 0.1 \ m$

$$Q = \frac{\pi k (h_2^2 - h_1^2)}{\ln \frac{R}{r}}$$

$$\Rightarrow 1.8 = \frac{\pi \times 0.0154 \times \{(29.5)^2 - h_1^2\}}{\ln \frac{300}{0.1}}$$

$h_1 = 23.92 \ m$

$S_1 = H - h_1 = 30 - 23.92 = 6.08 \ m$

iii) Specific capacity $= \frac{Q}{S_1} = \frac{1.8}{6.08}$

$= 0.3 \ m^3/min/m$.

(Ans).

03 | 05

06. In an area of 100 ha, the water table dropped by 4.5 m. If the porosity is 30% and the specific retention is 10%, determine (i) the specific yield of the aquifer (ii) change in ground water storage. (R-84)

Solution:

$A = 100\ ha \quad n = 30\% \quad S_r = 10\%$

(i)

$n = S_y + S_r$

$\Rightarrow S_y = n - S_r = 30 - 10 = 20\% = 0.2$

(ii) change in ground water storage = Area of aquifer × drop in g.w.t × S_y

$= 100 \times 4.5 \times 0.2$

$= 90$ ha-m

$= 90 \times 10^4\ m^3$. (Ans).

03

07. A artesian aquifer 25m thick has a porosity of 17% and bulk modulus of compression 2400 kg/cm². Estimate the storage coefficient. What fraction of this is attributable to the expansibility of water? Bulk modulus of elasticity of water 2.14×10^4 kg/cm². (R-86)

Solution:

$b = 25m \quad n = 17\% = 0.17$

$E_s = 2400\ kg/cm^2 = 2400 \times 10^4\ kg/m^2$

$K_w = 2.14 \times 10^4\ kg/cm^2 = 2.14 \times 10^8\ kg/m^2$

$\gamma_w = 1000\ kg/m^3$

$$S = \gamma_w b (\alpha + n\beta)$$

$$= \gamma_w b \left(\frac{1}{E_s} + n \cdot \frac{1}{K_w} \right)$$

$$= 1000 \times 25 \times \left(\frac{1}{2400 \times 10^4} + \frac{0.17}{2.14 \times 10^8} \right)$$

$$= 25000 \times (4.17 \times 10^{-8} + 7.94 \times 10^{-10})$$

$$= 1.06 \times 10^{-3}$$

$$S_w = \frac{\gamma_w n b}{K_w} = \frac{1000 \times 0.17 \times 25}{2.14 \times 108} = 1.986 \times 10^{-5}$$

$$S_w (\%) = \frac{S_w}{S} \times 100$$

$$= \frac{1.986 \times 10^{-5}}{1.06 \times 10^{-3}} \times 100$$

$$= 1.87\ \% \text{ of } S.$$

(Ans).

06

08. In a certain place in, the average thickness of the confined aquifer is 30 m and extends over an area of 800 km^2. The piezometric surface fluctuates annually from 19 m to 9 m above the top of the aquifer. Assuming a storage coefficient of 0.0008, what ground water storage can be expected annually?

Assuming an average well yield of 30 m^3/hr and about 200 days of pumping in a year, how many wells can be drilled in the area? (R-87)

Solution:

Change in ground water storage = Area of aquifer × drop of piezometric surface × S

$= 800 \times 10^6 \times (19-9) \times 0.0008$

$= 6.4 \times 10^6\ m^3$

$= 6.4\ Mm^3$

Annual draft $= 200 \times 24 \times 30 = 144000\ m^3$

∴ Number of wells that can be drilled in the area $= \frac{6.4 \times 10^6}{144000}$

$= 44.5$

$\simeq 44$ (say) wells

(Ans)

09. An aquifer has an average thickness of 60 m and an aerial extent of 100 ha. Estimate the available groundwater storage if,

(a) the aquifer is unconfined and the fluctuation in GWT is observed as 15 m.

(b) the aquifer is confined, and the piezometric head is lowered by 50 m, which drains half the thickness of the aquifer.

Assume, a storage co-efficient of 2×10^{-4} and a specific yield of 16%. (R-87)

Solution:

(a) Change in ground water storage = Area of aquifer × change in g.w.t × Sy

$= 100 \times 15 \times 0.16$

$= 240$ ha-m

(b) Change in ground water storage = Aaq $[\Delta piezo \times S + \Delta.GWT \times Sy]$

$= 100 \times [20 \times 2\times10^{-4} + 30 \times 0.16]$

$= 480.4$ ha.m.

(Ans).

2.04 $\times 10^{-8}$

10.

$$\Delta b = \Delta p \left(\frac{S}{\gamma_w} - n b \beta \right)$$

Δb = land subsidence (m)

Δp = reduction in artesian pressure (N/m^2)

10. Estimate the probable land subsidence when the piezometric head drops by 70 m in an artesian aquifer 30 m thick, having a porosity of 30% and storage co-efficient 2×10^{-4}.

Solution: ~~$\Delta p = 70m$~~ $b = 30m$ $n = 30\% = 0.3$ $S = 2 \times 10^{-4}$

$\Delta H = 70m$ $k_w = 2.1 \times 10^9$

$$\Delta b = \Delta p \left(\frac{S}{\gamma_w} - n b \beta \right)$$

$$= \gamma_w \Delta H \left(\frac{S}{\gamma_w} - n b \beta \right)$$

$$= 9810 \times 70 \times \left(\frac{2 \times 10^{-4}}{9810} - 0.3 \times 30 \times \frac{1}{2.1 \times 10^9} \right)$$

$= 0.011$ m

$= 11$ mm

(Ans).

Actual velocity, $V_a = \frac{Q}{A_{act}} = \frac{Q}{nA} = \frac{V}{n}$

$V = Ki = K.\frac{h}{L}$

$V_a = \frac{x}{t}$

04

11. It was observed in a field test that 3 hr 20 min was required for a tracer to travel from one well to another 20 m apart, and the difference in their water surface elevations was 0.5 m. Samples of the aquifer between the wells indicated a porosity of 15%. Determine the permeability of the aquifer, seepage velocity, and the Reynold's number for the flow, assuming an average grain size of 1 mm and ν water at 27°C = 0.008 Stoke.

Solution:

$$V_a = \frac{x}{t} = \frac{20}{3.33} = 6 \text{ m/hr}$$

Seepage velocity, $V = Ki = K.\frac{h}{L} = \frac{0.5K}{20} = \frac{K}{40}$

$$V_a = \frac{V}{n} = \frac{K}{40n}$$

$$\Rightarrow 6 = \frac{K}{40 \times 0.15} \quad \therefore K = 36 \text{ m/hr} = 864 \text{ m/day}$$

$$V = \frac{K}{40} = \frac{36}{40} = 0.9 \text{ m/hr} = 0.025 \text{ cm/sec}$$

$$Re = \frac{Vd_m}{\nu} = \frac{0.025}{100} \times \frac{1}{1000} \times \frac{1}{0.008 \times 10^{-4}} = 0.3 \text{ (Ans)}$$

12. In a phreatic aquifer extending over 1 km² the water table was initially at 25 m below ground level. Sometime after irrigation with a depth of 20 cm of water, the water table rose to a depth of 24 m b.g.l. Later 3×10^5 m³ of water, was pumped out and the water table dropped to 26.2 m b.g.l. Determine (i) specific yield of the aquifer (ii) deficit in soil moisture (below field capacity) before irrigation.

Solution:

(i) Volume of water pumped out = Area of aquifer × drop in g.w.t × S_y

$$\Rightarrow 3 \times 10^5 = 10^6 \times (26.2 - 24) \times S_y$$

$$\therefore S_y = 0.136 = 13.6\%$$

(ii) Volume of irrigation water recharching the aquifer = Area of aquifer × rise in g.w.t × S_y

considering an area of 1 m² of aquifer,

$$1 \times y = 1 \times 1 \times 0.136$$

$$\therefore y = 0.136 \text{ m or } 136 \text{ mm}$$

Soil moisture deficit before irrigation = 200 − 136
= 64 mm (Ans).

Ex-9.10: A pumping test was carried out in a new irrigation bore well penetrating fully into a confined aquifer at a rate of 22 lit/s. The drawdown measured in an observation well located at 45.7 m from the pumping well during the test is as given below. Determine T and S of the aquifer, using cooper-Jacob method.

Time t in hours:	0.5	1.8	2.7	5.4	9.6	12.0	18	30	54
Drawdown s in m:	0.091	0.294	0.382	0.55	0.701	0.785	0.911	1.06	1.24

Solution:

Given time-drawdown data is plotted at semi-logarithmic paper,

from graph, $\Delta s = 0.68$ m

$t_0 = 0.8$

$\frac{0.084}{0.1-0.04}$

$\frac{0.084}{0.05-0.02}$

Here, $Q = 22$ lit/s $= 0.022\ m^3/s$

$r = 45.7$ m

$$T = \frac{2.303 Q}{4\pi \Delta s} = \frac{2.303 \times 0.022}{4\pi \times 0.68}$$

$$= 5.93 \times 10^{-3}\ m^3/s/m$$

$t_0 = 0.8h = 2880$ sec

$$S = \frac{2.246\, T t_0}{r^2} = \frac{2.246 \times 5.93 \times 10^{-3} \times \sout{0.8} \times 2880}{(45.7)^2}$$

$$= 0.01836.$$

(Ans).

Hydrograph

{AHSAN
090063}

Formula:

* $P_{net} = \frac{DRO\ peak}{UGD\ peak}$
* $DRO_{peak} = TRO\ peak - BF$
* $TRO_{peak} = DRO\ peak + BF$
* $P = P_{net} + Losses$
* $DRO = P_{net} \times UGD$
* $TRO = DRO + BF$
* $Duration = \frac{P_{net}}{Intensity}$
* $Runoff\ coefficient = \frac{Runoff}{Rainfall}$
* Volume of water over basin = Area of UG triangle

DRO = Direct runoff
UGD = Unit hydrograph
TRO = Total runoff
BF = Base flow.

05

Problem-01:

Compute peak of 4-hr UG. Given flood hydrograph peak was 400 cumec, Base flow = 40 cumec, average loss = 0.4 cm/hr, Average watershed rainfall = 4 cm.

Solution:

$$P_{net} = \frac{DRO\ peak}{UG\ peak}$$

$$\Rightarrow UG_{peak} = \frac{DRO_{peak}}{P_{net}}$$

$$= \frac{360}{2.4} = 150 \text{ cumec.}$$

(Ans).

$DRO_{peak} = TRO\ peak - BF$

$= 400 - 40$

$= 360$ cumec

Total loss $= 0.4 \times 4 = 1.6$ cm

P_{net} = Rainfall − loss

$= 4 - 1.6 = 2.4$ cm

00, 02, 04

Example-5.13:

The successive three hourly ordinates of a 6-hr UG for a particular basin are 0, 15, 36, 30, 17.5, 8.5, 3, 0 cumec respectively. The flood peak observed due to a 6hr storm was 150 cumec. Assuming a constant base flow of 6 cumec and an average strom loss of 6 mm/hr, determine the depth of storm rainfall and the streamflow at successive 3 hr interval.

Solution:

$P = P_{net} + \text{losses}$

$= \dfrac{DRO_{peak}}{UGO_{peak}} + \text{losses}$

$= \dfrac{144}{36} + 3.6 = 4 + 3.6$

$= 7.6$ cm

DRO peak = Flood peak − BF

= 150 − 6

= 144 cumec

Losses = 0.6 × 6 = 3.6 cm

UGO peak = 36

Given,

UGO (cumec) :	0	15	36	30	17.5	8.5	3	0
DRO = UGO × Pnet :	0	60	144	120	70	34	12	0
TRO = DRO + BF :	6	66	150	126	76	40	18	6

(Ans).

05

Problem-03:

Peak flood due to a 3-h duration storm was 270 cumec. Total rainfall depth is 5.9 cm. Loss = 0.3 cm/h, and base flow = 20 cumec. Estimate (i) peak of 3-h UH, (ii) base width of 3h UH if basin area = 567 km² and the UH is triangular.

Solution:

(i) $UGO_{peak} = \frac{DRO_{peak}}{P_{net}}$

$P_{net} = P - Losses$

$= 5.9 - 0.3 \times 3$

$= 5$

$= \frac{250}{5}$

$DRO_{peak} = TRO_{peak} - BF$

$= 270 - 20$

$= 250$ cumec

$= 50$ cumec

(Ans).

(ii) Let, Base of unit hydrograph = B

Volume of water over basin = Area of UH triangle

$\Rightarrow Area \times \frac{1}{100} = \frac{1}{2} \times B \times 50$

$\Rightarrow 567 \times 10^6 \times \frac{1}{100} = 25 B$

$\therefore B = 226800$ sec

$= 63$ hr.

(Ans).

03,08

Problem - 04 :

A steady 6h rainfall with intensity 4 cm/hr produces peak discharge 560 cumec; loss = 1 cm/hr and base flow = 20 cumec. (i) What is the peak discharge of UG and its duration? (ii) Determine peak discharge from 6h rainfall at intensity 3.5 cm/hr with a loss rate of 1.5 cm/hr & base flow of 1.5 cumec. for the same basin.

Solution:

(i) $UGO_{peak} = \frac{DRO\ peak}{P_{net}}$

$= \frac{540}{18}$

$= 30$ cumec

DRO peak = TRO peak − BF

$= 560 - 20$

$= 540$ cumec

$P_{net} = P - \text{Losses}$

$= 6 \times 4 - 6 \times 1$

$= 18$ cm

Duration $= \frac{P_{net}}{\text{Intensity}}$

$= \frac{18}{4} = 4.5$ hr. (Ans)

(ii)

DRO peak = UGO peak × P_{net}

$= 30 \times 12$

$= 360$ cumec

$P_{net} = P - \text{losses}$

$= 6 \times 3.5 - 6 \times 1.5$

$= 12$ cm

BF = 1.5 cumec

∴ TRO peak = DRO peak + BF

$= 360 + 1.5$

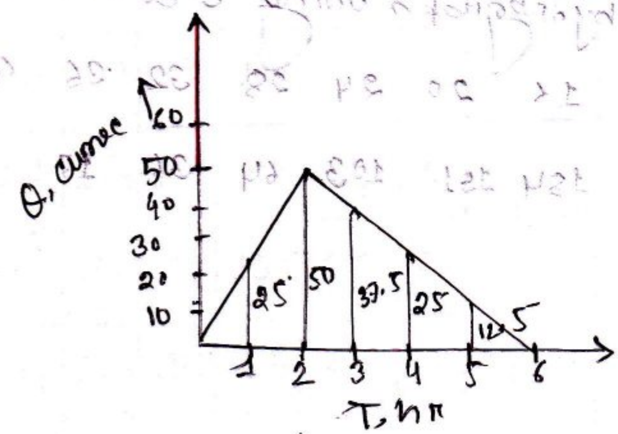
$= 361.5$ cumec (Ans).

, 05, 07

Problem - 05 : (EX-5.11)

The design storm of a watershed has a depth of 4.9 cm and 3.9 cm for the consecutive 1-hr periods. The 1-hr UG can be approximated by a triangle of base 6 hr with a peak of 50 cumec occurring after 2h from begining. Compute flood hydrograph assuming average loss rate of 9 mm/hr and a constant baseflow of 10 cumec. Calculate basin area and runoff coefficient.

Solution :



Time hr	UGO cumec	DRO = UGO × Pnet 1st storm Pnet = 4.9-0.9	2nd storm Pnet = 3.9-0.9	Total DRO cumec	BF cumec	TRO = DRO+BF cumec	Remark.
1	0	0	–	0		10	
2	25	100	0	100		110	
3	50	200	75	275		285	
4	37.5	150	150	300	10	310	← Peak flood
5	25	100	112.5	212.5		222.5	
6	12.5	50	75	125		135	
7	0	0	37.5	37.5		47.5	
8	–	–	0	0		10	

$$\text{Runoff coefficient} = \frac{\text{Runoff}}{\text{Rainfall}} = \frac{(4.9-0.9)+(3.9-0.9)}{4.9+3.9} = 0.795$$

(Ans).

Let, Basin Area = A

Volume of water over basin = Area of UG triangle

$$\Rightarrow A \times \frac{1}{100} = \frac{1}{2} \times 50 \times 60 \times 60 \times 6$$

$$\therefore A = 54 \text{ km}^2 \text{ (Ans)}$$

06

Problem-06: (Same as 5.5, 5.6)

The ordinates of a 4 hour unit hydrograph are given below. Derive the ordinates of a 8 hour unit hydrograph using S-curve method.

Time :	0	4	8	12	16	20	24	28	32	36	40	44
4th UGO curve :	0	24	82	159	184	151	103	64	36	17	6	0

Solution:

P.T.O

t (hr) (1)	4h UG cumec (2)	S curve addition curve (Unit storm after every 4 hour) (3)										4 S-curve ordinate (2)+(3)	5 Lagged S-curve (5)	6 S-curve difference (4)-(5)	(7) 8h UGO $6\times\frac{4}{8}$
0	0	–	–	–	–	–	–	–	–	–	–	0	—	0	0
4	24	0	–	–	–	–	–	–	–	–	–	24	–	24	12
8	82	24	0	–	–	–	–	–	–	–	–	106	0	106	53
12	159	82	24	0	–	–	–	–	–	–	–	265	24	241	120.5
16	184	159	82	24	0	–	–	–	–	–	–	449	106	343	171.5
20	151	184	159	82	24	0	–	–	–	–	–	600	265	335	167.5
24	103	151	184	159	82	24	0	–	–	–	–	703	449	254	127
28	64	103	151	184	159	82	24	0	–	–	–	767	600	167	83.5
32	36	64	103	151	184	159	82	24	0	–	–	803	703	100	50
36	17	36	64	103	151	184	159	82	24	0	–	820	767	53	26.5
40	6	17	36	64	103	151	184	159	82	24	0	826	803	23	11.5
44	0	6	17	36	64	103	151	184	159	82	24	826	820	6	3

Ordinate of 8-h UGO is determined in column-(7).

(Ans).

(15)

CE-307

Water Losses

AHSAN
090063

Formula:

i) Infiltration loss F_p = Rainfall (P) − Runoff (R)

ii) Runoff = $\frac{\text{Volume}}{\text{Area}}$

iii) Average infiltration rate, $f_{ave} = \frac{F_p}{t}$

iv) Yield = CAP

→ C = Runoff co-efficient

v) $K = \frac{f_0 - f_c}{F_c}$ f_0 = initial infiltration rate, f_c = final constant "

vi) Horton's equation, $f = f_c + (f_0 - f_c)e^{-Kt}$

vii) Runoff = P − Fp − E

viii) $P_{net} = \sum(i - \phi)t$

ix) $W\text{-index} = \frac{F_p}{t_R} = \frac{P - Q - S}{t_R}$ → S = effective surface retention

P = total rainfall, Q = surface runoff, t_R = duration of storm

x) $A_{ave} = \frac{1}{3}\left(A_1 + A_2 + \sqrt{A_1 A_2}\right)$ → cone formula

07

Q1. The total observed runoff volume during a storm of 6-hr duration with a uniform intensity of 15 mm/hr is 21.6 M.m³. If the area of the basin is 300 Km², find the average infiltration rate and the runoff coefficient for the basin. (EX-3.1)

Solution:

i) Infiltration loss F_p = Rainfall (P) − Runoff (R)

$$= 15 \times 6 - \frac{\text{Volume}}{\text{Area}}$$

$$= 15 \times 6 - \frac{21.6 \times 10^6}{300 \times 10^6} \times 1000$$

$$= 90 - 72$$

$$= 18 \text{ mm}$$

$$f_{ave} = \frac{F_p}{t} = \frac{18}{6} = 3 \text{ mm/hr}$$

ii) Yield = CAP

$$\Rightarrow 21.6 \times 10^6 = C \times 300 \times 10^6 \times \frac{90}{1000}$$

$\therefore C = 0.8$. (Ans).

09

02. The cumulative depth of infiltration in an experiment on a tube infiltrometer is observed to ~~flow~~ follow the equation $F = 0.165\,t^{0.65}$ where F is in cm and t is in minutes. Determine the equation for infiltration rate and the average infiltration rate. (Ex-8.6)

Solution:

$$F = 0.165\,t^{0.65}$$

$$f = \frac{\partial F}{\partial t} = 0.165 \times 0.65\,t^{-0.35} = 0.10725\,t^{-0.35} \text{ cm/minute}$$

$$f = 0.10725 \times (60 \times t)^{-0.35} = 6.435\,t^{-0.35} \text{ cm/h, where } t \text{ is in minutes}$$

$$f = 6.435 \times (60)^{-0.35} \times t^{-0.35} = 1.5353\,t^{-0.35} \text{ cm/h, where } t \text{ is in hours}$$

$$f_{av} = \frac{F}{t} = \frac{0.165\,t^{0.65}}{t} = 0.165\,t^{-0.35} \text{ cm/minute}$$

$$= 9.9\,t^{-0.35} \text{ cm/h, where } t \text{ is in minutes}$$

$$= 2.362\,t^{-0.35} \text{ cm/h, where } t \text{ is in hours.}$$

(Ans).

03. The Horton's infiltration equation for a basin is given by $f = 6 + 16e^{-2t}$ where f is in mm/h and t is in hours. What are the values of f_0, f_c and K? If a storm occurs on this basin with an intensity of more than 22 mm/h determine the depth of infiltration for the first 45 minutes and the average infiltration rate for first 75 minutes. (Ex-8.7)

Solution:

We know, ~~$f = f_c + f_0 e^{-Kt}$~~ $f = f_c + (f_0 - f_c)e^{-Kt}$

Here, $f = 6 + 16e^{-2t}$

$\therefore f_c = 6$ mm/h $\quad f_0 - f_c = 16 \quad \therefore f_0 = 22$ mm/h

$K = 2/h$

For first 45 minutes,

$$F = \int_0^{0.75} f \cdot dt = \int_0^{0.75} (6 + 16e^{-2t})\, dt$$

$$= \left[6t - \frac{16e^{-2t}}{2}\right]_0^{0.75}$$

$$= \left(6 \times 0.75 - 8 \times e^{-1.5}\right) - (0 - 8)$$

$$= 10.715 \text{ mm}$$

(Ans)

for first 75 minutes,

$$F = \int_0^{1.25} f.\,dt = \int_0^{1.25} (6+16e^{-2t})\,dt$$

$$= \left[6t - 8e^{-2t}\right]_0^{1.25}$$

$$= (6\times1.25 - 8e^{-2.5}) - (0-8)$$

$$= 14.843 \text{ mm}$$

$$f_{ave} = \frac{F}{t} = \frac{14.843}{1.25} = 11.874 \text{ mm/h. (Ans)}$$

04. For a small catchment, the infiltration rate at the beginning of rain was observed to be 90 mm/hr and decreased exponentially to a constant rate of 8 mm/hr after $2\frac{1}{2}$ hr. The total infiltration during $2\frac{1}{2}$ hr was 50 mm. Develop the Horton's equation for the infiltration rate at any time $t < 2\frac{1}{2}$ hr. (EX-3.4(a))

Solution:

$f_0 = 90$ mm/hr $\qquad f_c = 8$ mm/hr

$$K = \frac{f_0 - f_c}{F_c} = \frac{90-8}{50-8\times2.5} = 2.73 \text{ hr}^{-1}$$

$$f = f_c + (f_0 - f_c)e^{-Kt}$$

$$= 8 + (90-8)\times e^{-2.73\times t}$$

$$= 8 + 82e^{-2.73t}, \quad f \text{ in mm/hr}, \quad t \text{ in hr}$$

(Ans).

05. A 24-hour storm occurred over a catchment of 1.8 km^2 area and the total rainfall observed was 10 cm. An infiltration capacity curve prepared had the initial infiltration capacity of 1cm/hr and attained a constant value of 0.3 cm/hr after 15 hours of rainfall with a Horton's constant K = 5 hr^{-1}. An IMD pan installed in the catchment indicated a decrease of 0.6 cm in the water level (after allowing for rainfall) during 24 hours of its operation. Other losses were found to be negligible. Determine the run off from the catchment. Assume a pan co-efficient of 0.7

Solution:

$f_0 = 1$ cm/hr $\quad f_c = 0.3$ cm/hr

$$F_P = \int_0^{24} [f_c + (f_0 - f_c)e^{-Kt}]\,dt$$

$$= \int_0^{24} [0.3 + 0.7\, e^{-5t}]\,dt$$

$$= \left[0.3t + 0.7 \times \frac{e^{-5t}}{-5}\right]_0^{24}$$

$$= \left(0.3 \times 24 - \frac{0.7 \times e^{-5 \times 24}}{5}\right) - \left(0 - \frac{0.7}{5}\right)$$

$$= 7.2 - (1.02 \times 10^{-53}) + 0.14$$

$$= 7.34 \text{ cm}$$

Runoff = P − Fp − E

$= 10 - 7.34 - (0.6 \times 0.7) = 2.24$ cm

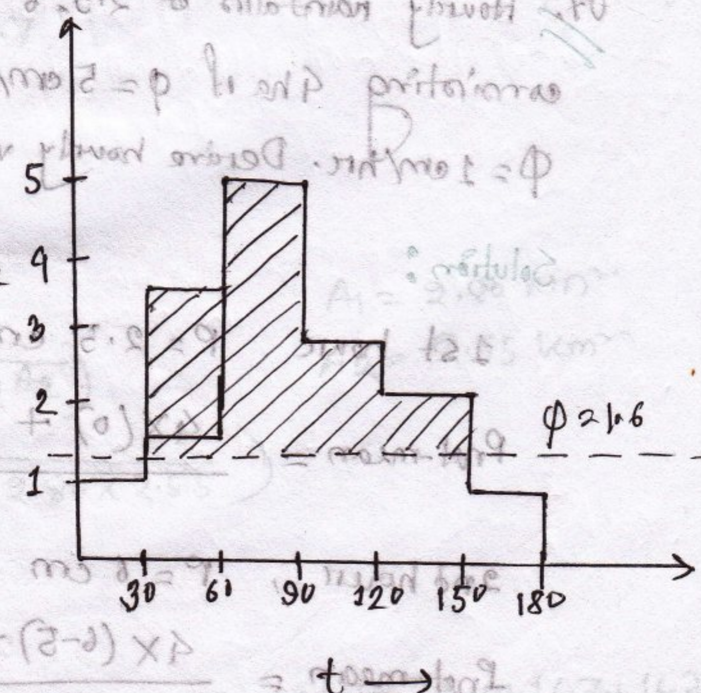
Volume of runoff from the catchment

$= \frac{2.24 \times 1.8 \times 10^6}{100} = 40320\ m^3$. (Ans)

04, 05, 06

06. The rates of rainfall for the successive 30 min period of a 3-hour storm are: 1.6, 3.6, 5.0, 2.8, 2.2, 1.0 cm/hr. The corresponding surface runoff is estimated to be 3.6 cm. Establish the ϕ index. Also determine the W-index.

Solution:



Let, ϕ lies between 2.2 to 2.8

$\sum (i - \phi) t = P_{net}$

$\Rightarrow [(3.6 - \phi) + (5.0 - \phi) + (2.8 - \phi)] \times \frac{30}{60} = 3.6$

$\Rightarrow (11.4 - 3\phi) = \frac{3.6 \times 60}{30}$

$\therefore \phi = 1.4$ cm/hr

Hence, ϕ do not lies between 2.2 to 2.8

Let, ϕ lies between 1.0 to 1.6

$$\left[(1.6-\phi)+(3.6-\phi)+(5-\phi)+(2.8-\phi)+(2.2-\phi)\right]\times\frac{30}{60}=3.6$$

$$\Rightarrow 15.2-5\phi = 3.6\times 2$$

$$\therefore \phi = 1.6 \text{ cm/hr}$$

$$P = (1.6+3.6+5+2.8+2.2+1)\times\frac{30}{60}$$

$$= 8.1 \text{ cm}$$

$$W\text{-index} = \frac{P-Q}{t_R} = \frac{8.1-3.6}{3} = 1.5 \text{ cm/hr}$$ (Ans).

07. Hourly rainfalls of 2.5, 6 and 3 cm occur over a 20-ha area consisting 4 ha of $\phi = 5$ cm/hr, 10 ha of $\phi = 3$ cm/hr and 6 ha of $\phi = 1$ cm/hr. Derive hourly values of net rain.

$$P_{net} = \frac{\Sigma PA}{\Sigma A}$$

Solution:

1st hour $P = 2.5$ cm

$$P_{net\text{-}mean} = \frac{4\times(0)+10\times(0)+6\times(2.5-1)}{20} = 0.45 \text{ cm}$$

2nd hour, $P = 6$ cm

$$P_{net\text{-}mean} = \frac{4\times(6-5)+10\times(6-3)+6\times(6-1)}{20} = 3.20 \text{ cm}$$

3rd hour, $P = 3$ cm

$$\text{Net-mean} = \frac{4\times(0) + 10\times(0) + 6\times(3-1)}{20} = 0.60 \text{ cm}$$

∴ Total net-rain for the 3-hour storm = 4.25 cm. (Ans).

08. The following are the pan evaporation data (Jan-Dec) in a certain year:

16.7, 14.3, 17.8, 25.0, 28.6, 21.4, 16.7, 16.7, 16.7, 21.4, 16.7, 16.7

The water spread area in a lake nearby in the beginning of January in that year was 2.80 km^2 and at the end of December it was measured as 2.55 km^2. Calculate the loss of water due to evaporation in that year. Assume a pan coefficient of 0.7.

Solution:

Mean water spread area of lake,

$A_1 = 2.80\ km^2$

$A_2 = 2.55\ km^2$

$$A_{ave} = \frac{1}{3}\left(A_1 + A_2 + \sqrt{A_1 A_2}\right)$$

$$= \frac{1}{3}\left(2.80 + 2.55 + \sqrt{2.80 \times 2.55}\right)$$

$$= 2.674\ km^2$$

Annual loss of water due to evaporation

$= 16.7 + 14.3 + 17.8 + 25 + 28.6 + 21.4 + 16.7 + 16.7 + 16.7 + 21.4 + 16.7 + 16.7$

$= 228.7$ cm

Annual volume of water lost due to evaporation:

$$= (2.674 \times 10^6) \times \frac{228.7}{100} \times 0.7$$

$$= 4.29 \times 10^6 \, m^3$$

$$= 4.29 \, Mm^3. \text{ (Ans)}.$$