Hydrology

1. Define hydrology and Engineering Hydrology?

Hydrology :

Hydrology deals with the waters of the earth, their distribution and circulation, their physical and chemical properties and their interaction with the environment including interaction with living things and in particulare human beings.

Engineering Hydrology :

Engineering hydrology includes those segments of the field pertinet to design and operation of engineering projects fore the control and use of water

2. Define Geologic cycle and Hydrologic cycle

Geologic Cycle :

The process responsible for formation and change of earth materials are reffered to as the geologic cycle which is actually a group of subcycle : (i) Tectonic (ii) hydrologic (iii) rock and (iv) biochemical .

Hydrologic Cycle :

The hydrologic cycle is a continious process of by which water is transported from the oceans to the atmosphere to the land and back to the sea.

water circulates in the hydrosphere through the paths constituting the hydrologic cycle.

3. Process in Hydrologic cycle.

Evaporation:

water evaporates from ocean and the land to become the part of the atmosphere.

Factors: (I) solar radiation

(II) moisture content

(III) wind speed

(IV) humidity

(V) temperature

Evapotranspiration:

Evaporation from land surface is accompained by transpiration by plants. Transpiration is a side effect of the plant needing to open its stomata in order to obtain CO_2 gas from air or photosynthesis.

Precipitation:

Water vapor is transported and lifted in the atmosphere until it condenses and precipitates on the land or the oceans as rain, snow, hail, sleet etc.

Interception by vegetation and depression storage:

A part of precipitated water may be intercepted by vegetation or temporarily retained in the soil in surface depression near where it falls and is ultimately returned to the atmosphere by evaporation and transpiration by plants. It is called initial loss.

Infiltration and percolation:

A portion of water that reaches the ground enters the earth's surface through infiltration.

Some part of it then ~~percolates~~ penetrates further into the ground to reach the ground water table. It is called percolation.

Subsurface flow and base flow:

A part of infiltrated water flows laterally through the unsaturated soil and the process is subsurface flow.

Lateral movement of the ground water in the saturated zone is known as base flow.

Surface runoff:

Surface runoff is that portion of ~~pere~~ precipitated water that flows over the ~~water~~ soil surface. Overland flow is a type of surface runoff having a thin layer of sheet flow. (min three layer)

Snow melt:

Snow packs in warmer climates often melt when spring arrives and melted water flows overland as snow melt.

4. What is initial loss?

A part of precipated water may be intercepted by vegetation or temporarily retained in the soil in surface depression near where it falls and is ultimately returned to the atmosphere by evaporation and transpiration by plants. It is called initial loss.

5. What are the three most abundant source of water?

(i) Oceans (96.5%)

(ii) Polar ice (1.7%)

(iii) ground water (1.69%)

6. What are the most abundant source of fresh water?

polar ice (68.6%)

ground water 30.1%

7. What is Residence time?

The residence time T_R is the average duration for a water molecule to pass through a subsystem of the hydrologic cycle. It is calculated by

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dividing the volume of water is in storage by the flow rate.

$\therefore T_r = S/Q$

8. Calculate residence time for atmospheric moisture and what is it's significance?

$S = 12900\ km^3$

$Q = \dfrac{45800 + 119000}{\text{precipitation part}}$ or $\dfrac{505000 + 72000}{\text{Evaporation part}}$

$= 577000\ km^3/year$

$\therefore T_r = \dfrac{12900}{577000} = 0.022\ yr = 8.2$ days.

It indicates that it takes 8.2 days to come into the atmosphere for a water molecule. Thats why weather prediction become difficult. Weathe can't be forecast automatically more than a few days ahead.

9. Calculate Tr for river storage and what is it's significance?

$T_r = \dfrac{2120}{44700}$

$= 0.074\ yr = 17.3$ days

Significance: If the water of river get polluted, then sources of that water can be controlled to minimize pollution and for increasing water quality.

10. T_r for ground water.

$$T_r = \frac{10530000 + 12870000}{2200}$$

$$= 10636.36 \text{ years}$$

Significance: Source control can't be the solution of removal of pollution. It takes long time to clean ground water if it is contaminated.

Formula (Precipitation)

- Specific humidity, $q_v = \frac{m_v}{m_a} = \frac{\rho_v}{\rho_a}$ $\left[\begin{array}{l} \rho_v = \text{density of water vapore} \\ \rho_a = \text{" " moist air} \end{array} \right.$

  - Specific humidity, $q_v = 0.622 \frac{e}{p}$

- vapour pressure, $e = \rho_v R_v T$
  - dry air pressure, $P_d = \rho_d R_d T$
  - Total air pressure, $P = P_d + e$

    $= \rho_a R_a T$

- Saturated vapour pressure, $e_s = 611 \exp\left(\frac{17.27\,T}{237.3 + T}\right)$ (pa)

  - specific humidity for saturated air column, $q_v = 0.622 \frac{e_s}{p}$

- Relative humadity $R_h = \frac{e}{e_s} = \frac{\text{actual vapour pressure}}{\text{saturated vapour pressure}}$

- Gas constant, $R_a = R_d(1 + 0.608\,q_v)$
  - $R_d = 287$ J/kg-K
  - For dry air, $q_v = 0$
  - q_v -এর value দেওয়া না থাকলে, $R_a = R_d$

- Air density, $\rho_a = \frac{p}{R_a T}$

- For standard temperature and pressure,

  $p = 101.3$ ka , $T = 25^\circ c$

  $\rho_a = 1.20$ kg-m^3

- $P_2 = P_1 \left(\frac{T_2}{T_1}\right)^{g/\alpha R_a}$
- Temperature variation between altitudes z_1 and z_2 is,

$$T_2 = T_1 - \alpha(z_2 - z_1)$$

- incremental mass of precipitable water,

$$\Delta m_p = \bar{q}_v \bar{\rho}_a A \Delta z$$

Example 3.2.1

At a climate station, air pressure is measured as 100 kpa, air temperature as 20°c and wet-bulb or dew point temperature as 16°c. Calculate —

- The corresponding vapor pressure
- relative humidity
- specific humidity
- Air density.

Solve:

The saturated vapor pressure at 20°c,

$$e_s = 611 \exp\left(\frac{17.27T}{237.3+T}\right)$$

$$= 611 \exp\left(\frac{17.27\times 20}{237.7+20}\right) = 2339 \text{ pa}$$

dew-point temperature, $T_d = 16°c$

∴ The corresponding vapour pressure = saturated vapour pressure at dew-point

$$= 611 \exp\left(\frac{17.27\, T_d}{237.7+T_d}\right)$$

$$= 611 \exp\left(\frac{17.27\times 16}{237.7+16}\right)$$

$$= 1819 \text{ pa}$$

Relative humidity, $R_h = \frac{e}{e_s} = \frac{1819}{2339} \times 100 = 78\%$

Specific humidity, $q_v = 0.622 \frac{e}{p}$

$$= 0.622 \times \left(\frac{1819}{100\times 10^3}\right) = 0.0113 \text{ kg water/kg moist air}$$

air density, $\rho_a = \frac{p}{R_a T}$

$R_a = R_d(1 + 0.608 q_v) = 287(1 + 0.608 \times 0.0113) = 289 \, J/kg\text{-}K$

$T = (20 + 273) K = 293 K$

$\therefore \rho_a = \frac{p}{R_a T} = \frac{100 \times 10^3}{289 \times 293} = 1.18 \, kg/m^3$

Example 3.2.2

Calculate the precipitable water in a saturated air column 10 km high above $1 m^2$ of ground surface. The surface pressure is 101.3 kpa. The saturated air temperature is 30°c and the lapse rate is 6.5°c/km.

Solve:

let's take the increment of elevation = 2 km

$\Delta m_p = \bar{q}_v \bar{\rho}_a A \Delta z$; $\bar{q}_v = \frac{q_{v_1} + q_{v_2}}{2}$, $\bar{\rho}_a = \frac{\rho_{a_1} + \rho_{a_2}}{2}$, $q_v = 0.622 \frac{e}{p}$

For the 1st interval (From ground to 2 km)

$e_1 = 611 \exp\left(\frac{17.27 T}{237.3 + T}\right) = 611 \exp\left(\frac{17.27 \times 30}{237.3 + 30}\right) = 4.24 \, kpa$

$T_1 = 30°c$, $T_2 = 30 - 2 \times 6.5 = 17°c$

$e_2 = 611 \exp\left(\frac{17.27 T}{237.3 + T}\right) = 611 \exp\left(\frac{17.27 \times 17}{237.3 + 17}\right) = 1.94 \, kpa$

$P_1 = 101.3 \, kpa$, $P_2 = P_1 \left(\frac{T_2}{T_1}\right)^{g/\alpha R_a} = 101.3 \times \left(\frac{290}{303}\right)^{\frac{9.81}{0.0065 \times 287}} = 80.4 \, kPa$

$\bar{q}_v = 0.622 \times \left(\frac{e_1/P_1 + e_2/P_2}{2}\right) = 0.622 \times \left(\frac{\frac{4.24}{101.3} + \frac{1.94}{80.4}}{2}\right) = 0.0205 \, kg/kg$

Now, $\rho_{a_1} = \frac{P_1}{R_a T_1} = \frac{101.3 \times 1000}{287 \times 303} = 1.16 \, kg/m^3$

$\rho_{a_2} = \frac{P_2}{R_a T_2} = \frac{80.4 \times 10^3}{287 \times 290} = 0.97 \, kg/m^3$

$\bar{\rho}_a = \frac{\rho_{a_1} + \rho_{a_2}}{2} = 1.07 \, kg/m^3$

$\Delta m_p = \bar{q}_v \bar{\rho}_a A \Delta z = 0.0205 \times 1.07 \times 1 \times 2000 = 43.87 \, kg$

Elevation Temperature (°C) Temperature (K) Air pressure Density ρ_a Vapour pressure e Specific humidity q_v Average $\bar{q}_v$ Average pressure

Elevation	Temperature °C	Temperature (K)	Air pressure P	Density ρ_a	vapour pressure e	Specific humidity q_v	Average $\bar{q}_v$	Average ~~pressure~~ ρ_a	Δm
0	30	303	101·3	1·16	4·24	0·026			
2	17	290	80·4	0·97	1·94	0·015	0·0205	1·065	43·7
4	4	277	63·2	0·79	0·81	0·008	0·0115	0·88	20·2
6	−9	264	49·1	0·65	0·31	0·0039	0·006	0·72	8·64
8	−22	251	37·6	0·52	0·10	0·0017	0·0028	0·585	3·3
10	−35	238	28·5	0·42	0·03	0·0007	0·0012	0·47	1·1
									76·94

≃ 77 mm

2010-11 $\boxed{13\text{-}2}$

1 (e) For $10°c$ in first 1 km of saturated atmospheric column

$T_1 = 10°c$, $T_2 = 10 - 6.5 = 3.5°c = 276.5^k$

$P_1 = 101.3$ kPa,

$\alpha = \frac{6.5}{1000} = 0.0065$

$P_2 = P_1\left(\frac{T_2}{T_1}\right)^{g/\alpha R_a} = 101.3 \times \left(\frac{276.5}{283}\right)^{\frac{9.81}{0.0065 \times 287}} = 89.65$ kPa

$e_1 = .611 \exp\left(\frac{17.27 T_1}{237.3 + T_1}\right) = .611 \exp\left(\frac{17.27 \times 10}{237.3 + 10}\right) = 1.23$ kpa

$e_2 = .611 \exp\left(\frac{17.27\ T_2}{237.3 + T_2}\right) = .611 \exp\left(\frac{17.27 \times 3.5}{237.3 + 3.5}\right) = 0.785$ kpa

$\bar{q}_v = 0.622\left(\frac{q_{v_1} + q_{v_2}}{2}\right) = \frac{0.622}{2} \times \left(\frac{e_1}{P_1} + \frac{e_2}{P_2}\right)$

$= \frac{0.622}{2} \times \left(\frac{1.23}{101.3} + \frac{0.785}{89.65}\right) = 0.0065$ kg/kg

$\bar{\rho}_a = \frac{1}{2}\left(\frac{P_1}{R_a T_1} + \frac{P_2}{R_a T_2}\right)$

$= \frac{1}{2 \times 287} \times \left(\frac{101.3 \times 10^3}{283} + \frac{89.65 \times 10^3}{276.5}\right) = 1.19$ kg/m^3

$\Delta m_p = \bar{q}_v\, \bar{\rho}_a\, A\, \Delta z$

$= 0.0065 \times 1.19 \times 1 \times 1000 = 7.725$ kg

For $25°c$ in first 1 km saturated atmospheric column

$T_1 = 25°c$, $T_2 = 25 - 6.5 = 18.5°c = 291.5\,k$

$P_1 = 101.3$ kPa

$P_2 = P_1\left(\frac{T_2}{T_1}\right)^{g/\alpha R_a} = 101.3 \times \left(\frac{291.5}{298}\right)^{\frac{9.81}{0.0065 \times 287}} = 90.21$ kPa

$e_1 = .611 \exp\left(\frac{17.27 T_1}{237.3 + T_1}\right) = .611 \exp\left(\frac{17.27 \times 25}{237.3 + 25}\right) = 3.17$ kPa

$e_2 = .611 \exp\left(\frac{17.27\ T_2}{237.3 + T_2}\right) = .611 \exp\left(\frac{17.27 \times 18.5}{237.3 + 18.5}\right) = 2.13$ kPa

$$\bar{q}_v = \frac{0.622}{2}\left(\frac{e_1}{P_1} + \frac{e_2}{P_2}\right)$$

$$= \frac{0.622}{2} \times \left(\frac{3.17}{101.3} + \frac{2.13}{90.21}\right)$$

$$= 0.017 \text{ kg/kg}$$

$$\bar{\rho}_a = \frac{1}{2}\left(\frac{P_1}{R_a T_1} + \frac{P_2}{R_a T_2}\right)$$

$$= \cancel{\frac{1}{2\times 287} \times \left(\frac{3.17\times10^3}{298} + \frac{2.13\times10^3}{291.5}\right) =}$$

$$= \frac{1}{2\times 287} \times \left(\frac{101.3\times10^3}{298} + \frac{90.21\times10^3}{291.5}\right) = 1.13 \text{ kg/m}^3$$

$$\therefore \Delta m = \bar{\rho}_a \, \bar{q}_v \, A \Delta Z$$

$$= 1.13 \times 0.017 \times 1 \times 1000 = 19.21 \text{ kg}$$

percent increase $= \frac{19.21 - 7.725}{7.725} \times 100 = 149\%$

As, the temperature increase, so moisture carrying capacity of air increase.

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2009-10 $\boxed{\text{L-3, T-2}}$

11 (d) If atmospheric pressure at sea level is 101.3 kPa and 90% of the atmosphere by man is below an altitude of 16 km, compute the atmosphere pressure at an altitude of 16 km.

$101.3 - 101.3 \times 0.9 =$

1(e) At ground level

$R_h = 80\%$

$e_{s_1} = 2500 = 611 \exp\left(\frac{17.27 \times T}{237.3+T}\right)$

$\therefore T = 21.08°c$

$e = 0.8\, e_{s_1} = 0.8 \times 2500 = 2000\ pa = 2\ kpa$

$P_1 = 101.3\ kpa$

let assumed, $\alpha = 0.0065\ °c/m$

At 2 km elevation

$T_2 = 21.08 - 2 \times 6.5 = 8.08°c$

$e_{s_2} = 611 \exp\left(\frac{17.27 T_2}{237.3+T_2}\right) = 611 \exp\left(\frac{17.27 \times 8.08}{237.3+8.08}\right) = \cancel{1.6\ kpa}\ 1.079\ kPa$

$P_2 = P_1 \left(\frac{T_2}{T_1}\right)^{\frac{g}{\alpha R_a}}$

$= \cancel{101.3} \times \left(\frac{8.08+273}{21.08+273}\right)^{\frac{9.81}{0.0065 \times 287}} = \cancel{79.86\ kpa}$

$= 101.3 \times \left(\frac{8.08+273}{21.08+273}\right)^{\frac{9.81}{0.0065 \times 287}} = 79.86\ kpa$

~~$\bar{q}_v = 0.622\ e_1$~~

$e_2 = 0.9 \times 1.079 = 0.9711\ kpa$

$\bar{q}_v = \frac{0.622}{2} \left(e_1/P_1 + e_2/P_2\right) = \frac{0.622}{2} \times \left(\frac{2}{101.3} + \frac{0.971}{79.86}\right) = 0.00992\ kg/kg$

$\bar{\rho}_a = \frac{1}{2}\left(\frac{P_1}{R_a T_1} + \frac{P_2}{R_a T_2}\right)$

$= \frac{1}{2 \times 287} \times \left(\frac{101.3 \times 10^3}{21.08+273} + \frac{79.86 \times 10^3}{8.08+273}\right) = 1.095\ kg/m^3$

$\therefore$ precipitable water $= \bar{\rho}_a\, \bar{q}_v\, A \Delta Z = 1.095 \times 0.00992 \times 2 \times 2 \times 1000 = 43.44\ kg$

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2009 - 2010 $\boxed{L-3/T-2}$

2| (e) Given,

$R_h = 70\%$

$e_s = 2400$ pa

(i) $e_s = 611 \exp\left(\frac{17.27T}{237.3+T}\right)$

$\Rightarrow 2400 = 611 \exp\left(\frac{17.27T}{237.3+T}\right)$

$\therefore T = 20.4°C$

(ii) Actual vapoure pressure in air, $e = R_h \times e_s$

$= .7 \times 2400 = 1680$ Pa

(iii) $1680 = 611 \exp\left(\frac{17.27 T_d}{237.3+T_d}\right)$

$\therefore T_d = 14.76°C$

$\therefore$ dew point temperature $= 14.76°C$

(iv) specific humidity, $q_v = 0.622 \times e/p$

$= 0.622 \times \frac{1.68}{101.3} = 0.0103$ kg/kg

(v) gas constant, $R_a = R_d(1 + 0.608q_v)$

$= 287 \times (1 + 0.608 \times 0.0103) = 288.8$ J/kg-K

(vi) density of moist air, $\rho_a = \frac{P}{R_a T}$

$= \frac{101.3 \times 10^3}{288.8 \times (273 + 20.4)}$

$= 1.196$ kg/m^3

Example 3.5

A storm with 10.0 cm precipitation produced a direct runoff of 5.8 cm. Given that the time distribution of the storm as below, estimate the ϕ index of the storm.

Time from start	0	1	2	3	4	5	6	7	8
Incremental rainfall in each hour (cm)	0	0.4	0.9	1.5	2.3	1.8	1.6	1.0	0.5

Total infiltration = 10 − 5.8 = 4.2 cm

1st trial

t_e = time of rainfall excess = 8 hr

then, $\phi = \frac{4.2}{8} = 0.525$ cm/hr

trial-2

$t_e = 6$ hr

infiltration = 4.2 − 0.4 − 0.5 = 3.3 cm

then, $\phi = \frac{3.3}{6} = 0.55$ cm/hr

3(e) ϕ - index = 3.0 cm/hr = 1 cm/20 min 2010-11 (L-3, T-2)

time	20	40	60	80	100	120	140
rainfall (cm/20min)	1.1	1.2	3	2.2	0.2	0.3	2
infiltration	1	1	1	1	0.2	0.3	1
runoff	0.1	0.2	2	1.2	0	0	1

(i) total volume of runoff $= \left(\frac{0.1+0.2+2+1.2+1}{100}\right) \times 2 \times (1000)^2$

$= 9000\ m^3$

(ii) total volume of infiltration $= \frac{(1+1+1+1+0.2+0.3+1)}{100} \times 2 \times (1000)^2$

$= 110,000\ m^3$

(iii) time of rainfall excess $= 5 \times 20 = 100$ min

2009-10 (L-3, T-2)

3(e) Given,

~~A~~ catchment area, $A = 0.5\ km^2$

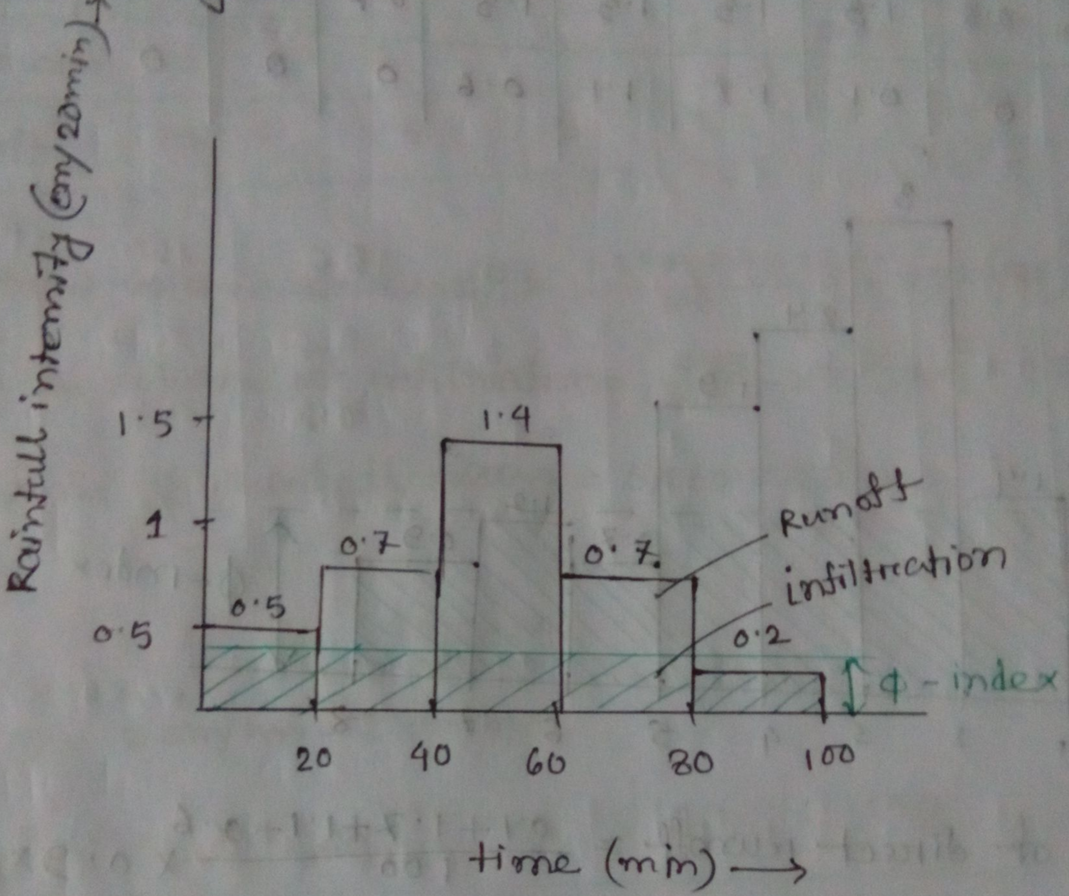
ϕ-index = 0.9 cm/hr = 0.3 cm/20 min

time	20	40	60	80	100
cumulative rainfall	0.5	1.2	2.6	3.3	3.5
~~infiltration~~ incremental rainfall	0.5	0.7	1.4	0.7	0.2
infiltration	0.3	0.3	0.3	0.3	0.2
runoff	0.2	0.4	1.1	0.4	0

(ii) Total runoff $= \frac{0.2+0.4+1.1+0.4}{100} \times 0.5 \times (1000)^2$

$= 10500\ m^3$

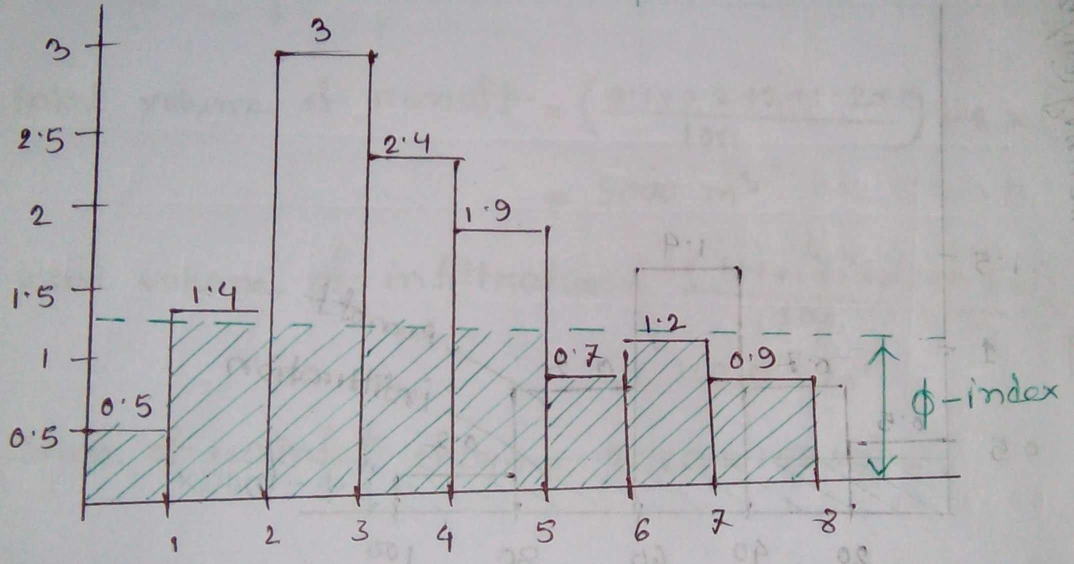
(i) rainfall hyetograph



~~11(e)~~ ~~2009-10~~ ~~L-3 T-2~~

ϕ - index = 1·3 cm/hrs

time	1	2	3	4	5	6	7	8
incremental rainfall	0·5	1·4	3	2·4	1·9	0·7	1·2	0·9
infiltration	0·5	1·3	1·3	1·3	1·3	0·7	1·2	0·9
runoff	0	0·1	1·7	1·1	0·6	0	0	0



(ii) volume of direct runoff $= \frac{0·1+1·7+1·1+0·6}{100} \times 0·9 \times (1000)^2$

$= 31500\ m^3$

(iii) volume of infiltration $= \frac{0·3+1·3\times4+0·7+1·2+0·9}{100} \times 0·9 \times (1000)^2$

$= 76500\ m^3$

(iv) Time of ~~infiltration~~ rainfall excess = 4 hrs

(v) Runoff co-efficient $= \frac{0·1+1·7+1·1+0·6}{0·5+1·4+3+2·4+1·9+0·7+1·2+0·9}$

$= 0·29$

2014-15

3) (b) $\phi = 2$ cm/hr $= 1$ cm/30 min

time	30	60	90	120	150	180	210
rainfall cm/30min	2.25	2.5	4	3	0.75	0.5	2
infiltration	1	1	1	1	0.75	0.5	1
runoff	1.25	1.5	3	2	0	0	1

(i) total volume of runoff $= \frac{1.25+1.5+3+2+1}{100} \times 2 \times (1000)^2 = 175000\ m^3$

(ii) total volume of infiltration $= \frac{6.25}{100} \times 2 \times (1000)^2 = 125000\ m^3$

(iii) time of rainfall excess $= 5 \times 30 = 150$ min

2013-14

2) (d) $\phi = 2$ cm/hr $= 1$ cm/min

time (min)	30	60	90	120	150	180
rainfall	1.65	1.8	4.5	3.3	0.3	0.45
~~infi~~ infiltration	1	1	1	1	0.3	0.45
runoff	0.65	0.8	3.5	2.3	0	0

(i) total volume of runoff $= \frac{0.65+0.8+3.5+2.3}{100} \times 3 \times (1000)^2$

$= 217500\ m^3$

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(II) total volume of infiltration = $\frac{4.75}{100} \times 3 \times (1000)^2$

$= 142,500 \ m^3$

(III) Duration of rainfall = $4 \times 30 = 120$ min

2012-13

21 (e) $\phi = 3$ cm/hr = 1 cm/20 min

time (min)	20	40	60	80	100	120	140
rainfall	1.1	1.2	3	2.2	0.2	0.3	2
infiltration	1	1	1	1	0.2	0.3	1
runoff	0.1	0.2	2	1.2	0	0	1

(I) total volume of runoff = $\frac{0.1+0.2+2+1.2+1}{100} \times 2 \times (1000)^2 = 90,000 \ m^3$

(II) total volume of infiltration = $\frac{5.5}{100} \times 2 \times (1000)^2 = 110,000 \ m^3$

(III) time of rainfall excess = $5 \times 20 = 100$ min

Hydrograph

1. Arithmetic mean method:

$$\bar{P} = \sum_{i=1}^{n} P_i/n$$

where, $\bar{P}$ = Average precipitation depth (mm)

P_i = Precipitation depth at gage i (within the topographic basin)

n = Total number of gages with the topographic basin

2. Thiessen polygon method:

$$\frac{1}{A}\sum_{i=1}^{n} A_i P_i \qquad \text{where, } A = \sum_{i=1}^{n} A_i$$

A = area of watershed

A_i = rainfall recorded at gage i

P_i = rai

3. Isohyetal method:

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

where, A_i = area between each pair of isohyets with watershed

P_i = Isohyetal cell average precipitation

n = number of isohyetal cells

A = Area of watershed.

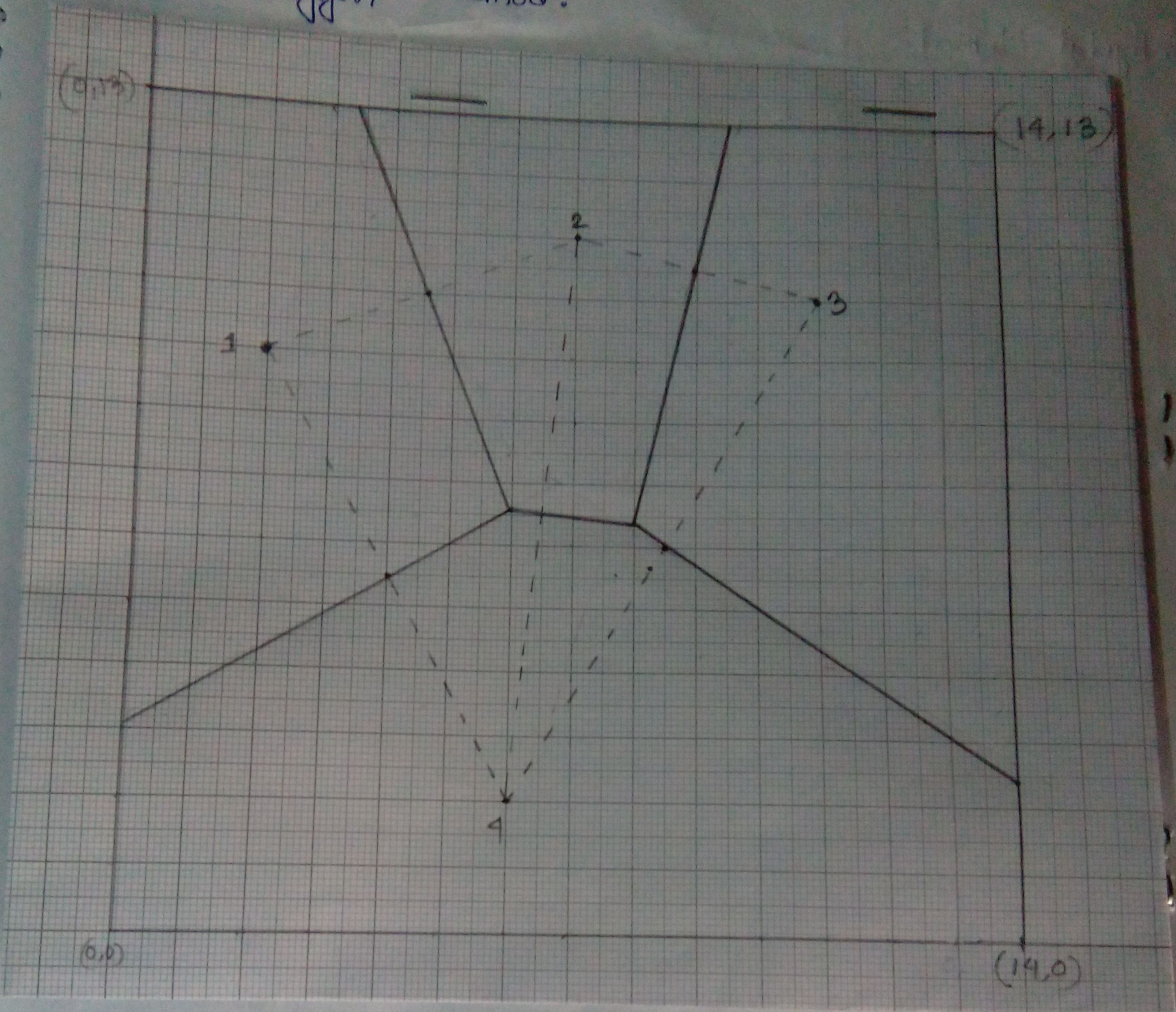
উচ্চের contour আঁকার সময় minimum value থেকে কিছু বেশি এবং maxm value থেকে কম value নিয়ে আঁকাতে হবে।

Arithmetic mean method:

Raingage location	Rainfall (mm)
(2,9)	20
(7,11)	25
(12,10)	30
(6,2)	40
total =	115

$\therefore$ Average rainfall $= \frac{115}{4} = 28.75$ mm.

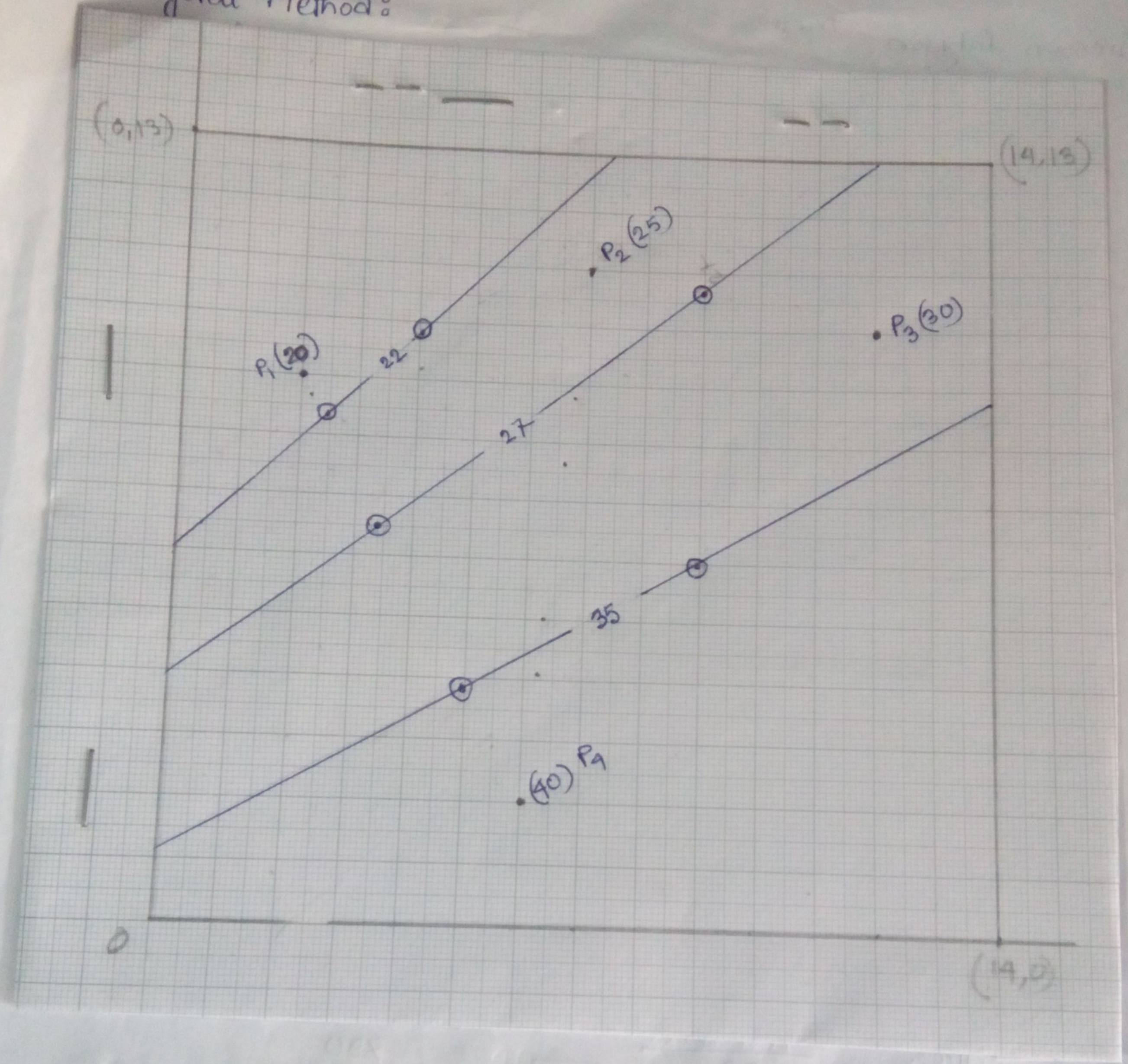
Thiessen Polygon method:



Gage	Area	Rainfall	Area x rainfall
1	39.5	20	790
2	27.5	25	687.5
3	46	30	1380
4	69	40	2760
			~~5497.5~~
			5617.5

$\therefore$ Average rainfall $= \frac{5617.5 \; \cancel{5497.5}}{182} = 30.87$ mm

3. Isohyetal Method:



Isohyets	Area	Average rainfall	rainfall volume
~~<22~~ <22	29.5	20	590
22-27	27.5	24.5	~~538~~ 673.75
27-35	55.5	31	1720.5
>35	73.5	40	2940
	182		5844.25

$$\therefore \text{Average rainfall} = \frac{5844.25}{182} = 32.11 \text{ mm}$$

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2014-15

11(d)

Gage number	coordinates	recorded rainfall (mm)
1	(3,4)	60
2	(-2,5)	40
3	(-3,-3)	100
4	(2,-3)	50
5	(7,0)	90

polygone co-ordinates : (6,6), (-6,6), (-6,-6), (0,-12), (6,-6) !

Arithmetic mean method:

Total rainfall = $(60+40+100+50+90)$ mm = 340 mm

$\therefore$ Average rainfall = $\frac{340}{5}$ = 68 mm.

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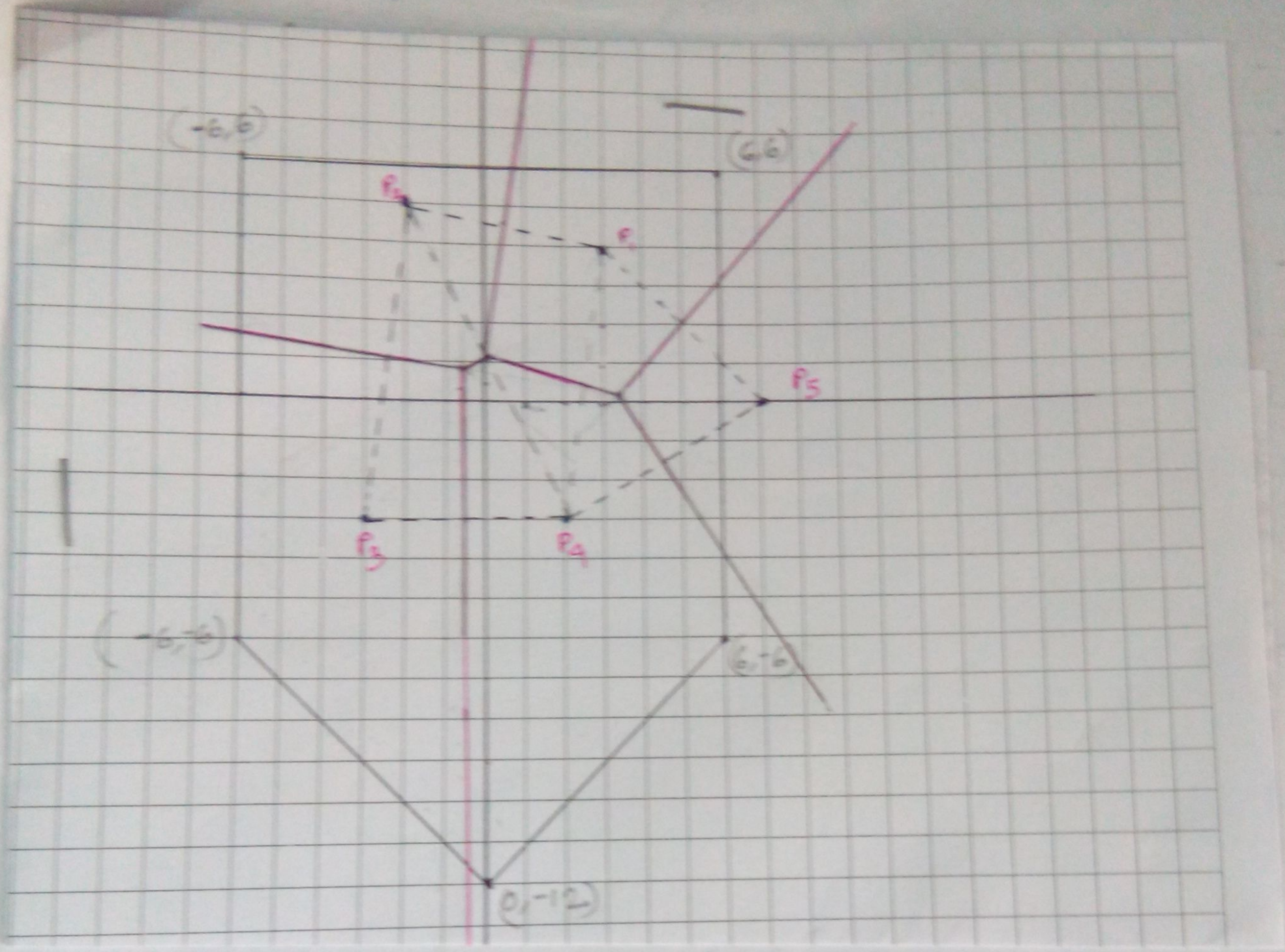
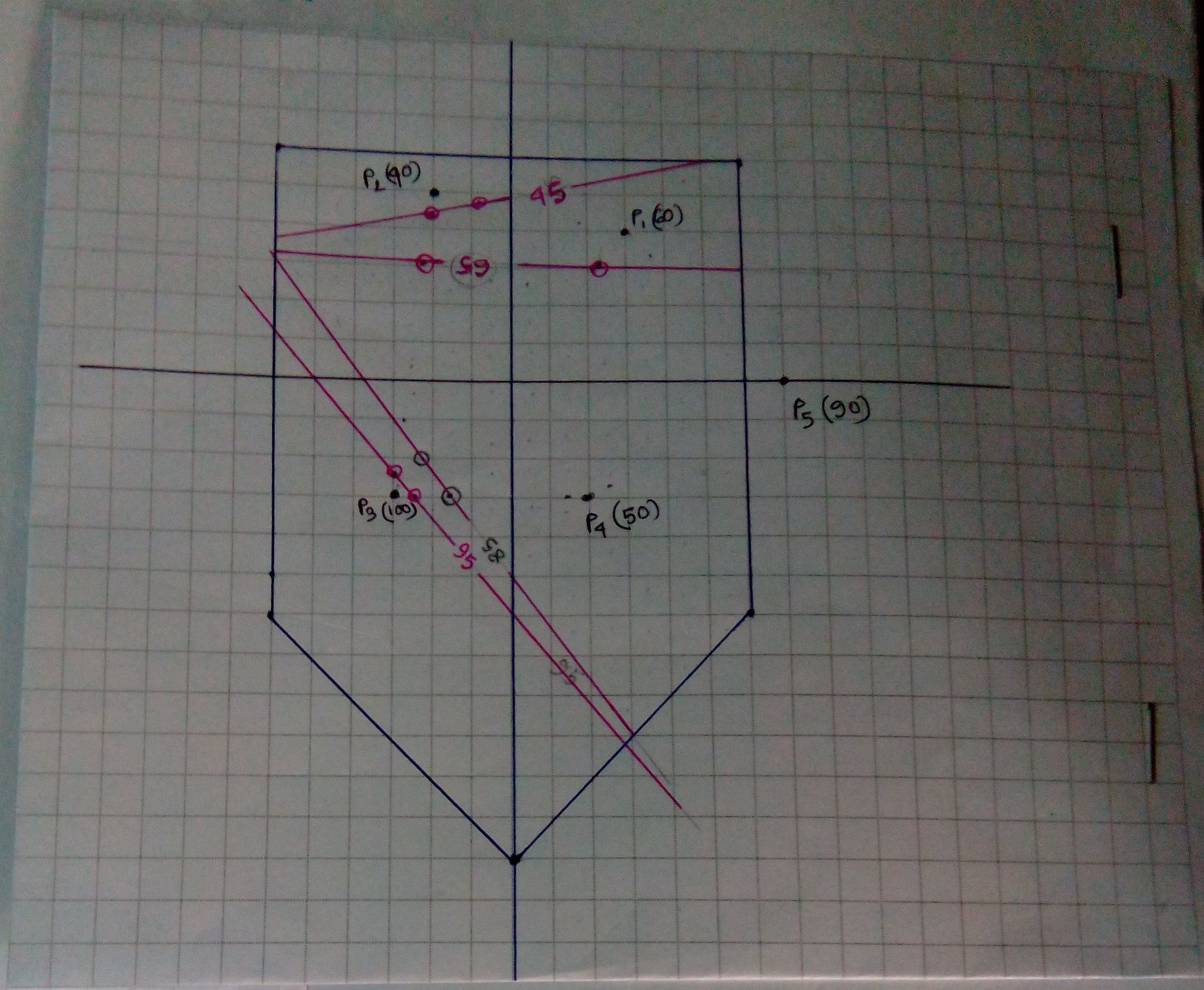
Thiessen Polygon:



Station	Area	observed rainfall	weighted rainfall
P_1	27.5	60	1650
P_2	31.5	40	1260
P_3	54	100	5400
P_4	57.5	50	2875
P_5	9.5	90	882
	180		12067

$\therefore$ Average rainfall $= \frac{12067}{180} = 67.03$ mm

Isohyetal Method:



Isohyets	Average rainfall	Area	rainfall volume
>85	95 $\left(\frac{100+90}{2}\right)$	59	5605
85-65	75	86.5	6487.5
65-45	55	20	1100
<45	40	14.5	580
	4	180	813772.5

$\therefore$ Average rainfall $= \dfrac{13772.5}{180} = 76.5$ mm.

Rain gage location	Rainfall (mm)
(2, 9)	18
(7, 11)	25
(12, 10)	35
(6, 2)	42

Arithmetric mean method:

Total rainfall $= 18 + 25 + 35 + 42 = 120$ mm

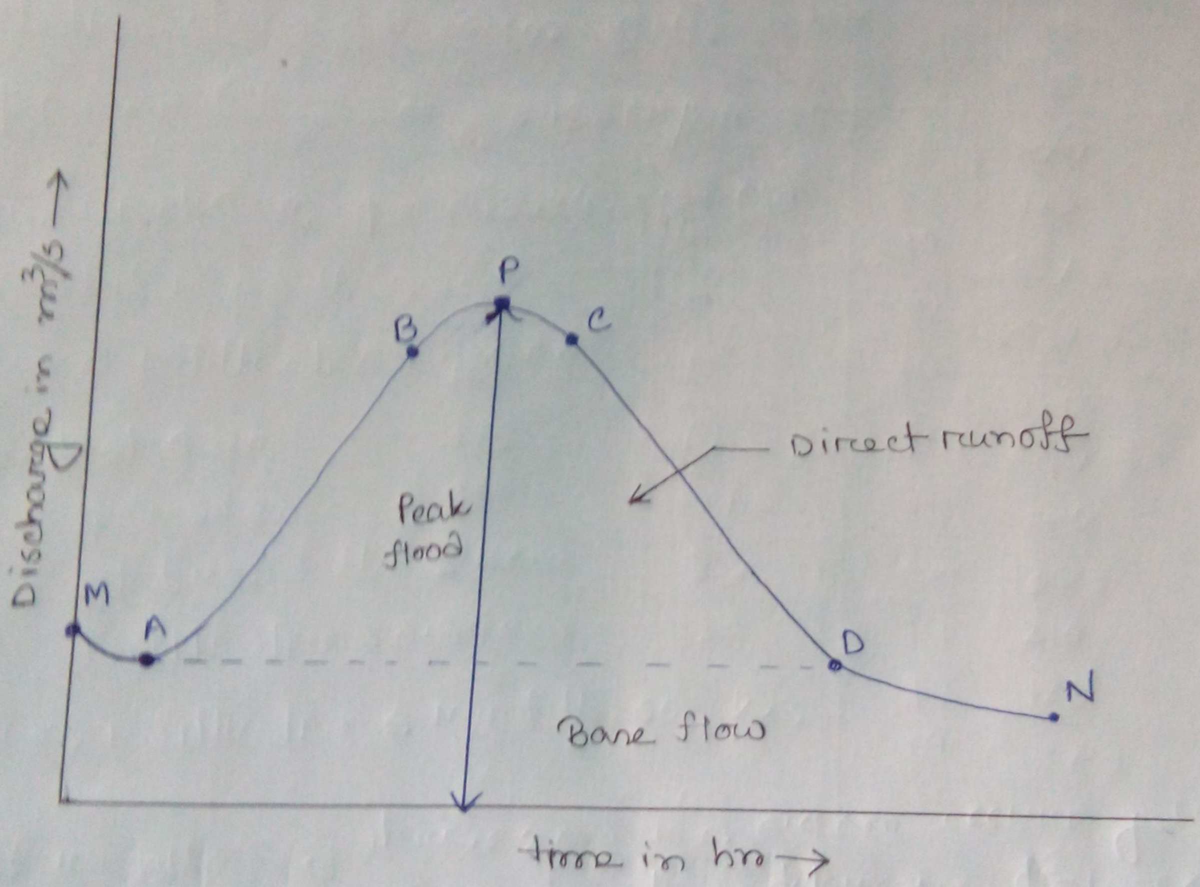
Average rainfall $= \frac{120}{4} = 40$ mm

Thiesen polygon method:

station	Area	observed rainfall	weighted rainfall.
1	39.5	18	711
2	27.5	25	687.5
3	46	35	1610
4	69	42	2898
	182		~~3336.5~~
			5906.5

$\therefore$ Average rainfall $= \cancel{\dfrac{3336.5}{182}} = \dfrac{5906.5}{182} = 32.45$ mm

Hydrograph



Discharge in m^3/s →
M
A
B
P
C
D
N
Peak flood
Direct runoff
Base flow
time in hrs →

Example 6.2

time from start of rainfall (h)	-6	0	6	12	18	24	30	36	42	48	54	60
observed flow (m^3/s)	6	5	13	26	21	16	12	9	7	5	5	4.5

rainfall of magnitude 3.8 cm and 2.8 cm occuring on two consecutive 4-h durations on a catchment of area 27 km^2 produced the following hydrograph of flow at the outlet of the catchment. Estimate the rainfall excess and ϕ index.

Solve:

$N = 0.83 \times (27)^{0.2} = 1.6$ days $= 38.5$ h

By inspection, DRH starts at $t=0$, has the peak at $t=12$ hr. and ends ~~N =~~ and ends at 48 hr.

$\therefore N = 48-12 = 36$ h

$N = 36$ hr is more satisfactory than $N = 38.5$ hr.

$\therefore N = 36$ hr

base flow $= 5\ m^3/s$

so,

time from start of rainfall	0	6	12	18	24	30	36	42	48
observed flow	5	13	26	21	16	12	9	7	5
runoff	0	8	21	16	11	7	4	2	0

Area of DRH $= 60 \times 60 \times 6 \times (0+8+21+16+11+7+4+2) = 1.4904 \times 10^6\ m^3$

= total direct runoff due to storm

Runoff depth = $\frac{1.4904\times10^6}{27\times(10^3)^2} = 0.0552\,m = 5.52\,cm$

= rainfall excess

Total rainfall = 3.8 + 2.8 = 6.6 cm

$\therefore$ runoff co-efficient = $\frac{5.52}{6.6} = 0.836$

let, time of rainfall excess = $(\underset{3.8\,cm}{4} + \underset{2.8\,cm}{4}) = 8$ hrs

ϕ-index = $\frac{6.6 - 5.52}{8} = 0.135$ cm/hr

for first 4 hrs, $\phi = 0.135\times4 = 0.54$ cm

total rainfall = 3.8 cm

and infiltration = 0.54 cm

for Last 4 hrs,

$\phi = 0.54$ cm

total rainfall = 2.8 cm

infiltration = 0.54 cm

Here, infiltration $\leq$ rainfall, so - ok.

If rainfall magnitude 6.2 cm and 0.4 cm occuring on two ~~for~~ consecutive 4-hrs duration, determine ϕ-index.

Here, let, time of rainfall excess = 8 hrs

total rainfall = 6.2 + 0.4 = 6.6 cm

$\therefore \phi = \frac{6.6 - 5.52}{8} = 0.135$ cm/hr

loss for 4 hrs = $0.135\times4 = 0.54$ cm

which is greater than 0.4 cm.

Again, let, time of rainfall excess = 4 hrs

$\therefore \phi = \frac{6.6 - 5.52 - 0.4}{4} = \frac{0.68}{4} = 0.17$ cm/hr

Now loss for 1st 4 hrs = $0.17\times4 = 0.68$ cm ~~which is~~

$\therefore 0.68\,cm < 6.2\,cm \rightarrow$ ok

so, $\phi = 0.17$ cm/hrs for 1st 4 hrs and for last 4 hrs ϕ-index not applicable but hourly loss is 0.4 cm.

good

91(b) 2014-15

$N = 0.83(A)^{0.2} = 0.83 \times (27)^{0.2} = 1.6$ ~~hrs~~ days $= 38.5$ hrs.

peak flow occurs at 12 hrs. and ends at 48 hrs.

$N = 48 - 12 = 36$ hrs.

$\therefore N = 36$ hrs more satisfactory than $N = 38.5$ hr.

$\therefore N = 36$ hrs.

Time from start of rainfall	0	6	12	18	24	30	36	42	48
flow m^3/s	5	13	26	21	16	12	9	7	5
runoff	0	8	21	16	11	7	4	2	0

total direct runoff ~~rainfall~~ excess due to storm $= 6 \times 60 \times 60 \times (0+8+21+16+11+7+4+2) = 1.4904 \times 10^6$ m^3

runoff depth = rainfall excess $= \frac{1.4904 \times 10^6}{27 \times 10^6} = 0.0552$ m $= 5.52$ cm

total rainfall $= 4.8 + 3.8 = 8.6$ cm

let, time of runoff excess $= 10$ hrs.

$\therefore \phi = \frac{8.6 - 5.52}{10} = 0.308$ cm/hrs

for first 5 hrs, $\phi = 0.308 \times 5 = 1.54$ cm

And rainfall $= 4.8$ cm

for 2nd 5 hrs, $\phi = 1.54$ cm

and rainfall $= 4.8$ cm.

$\therefore$ infiltration < rainfall $\rightarrow$ (ok)

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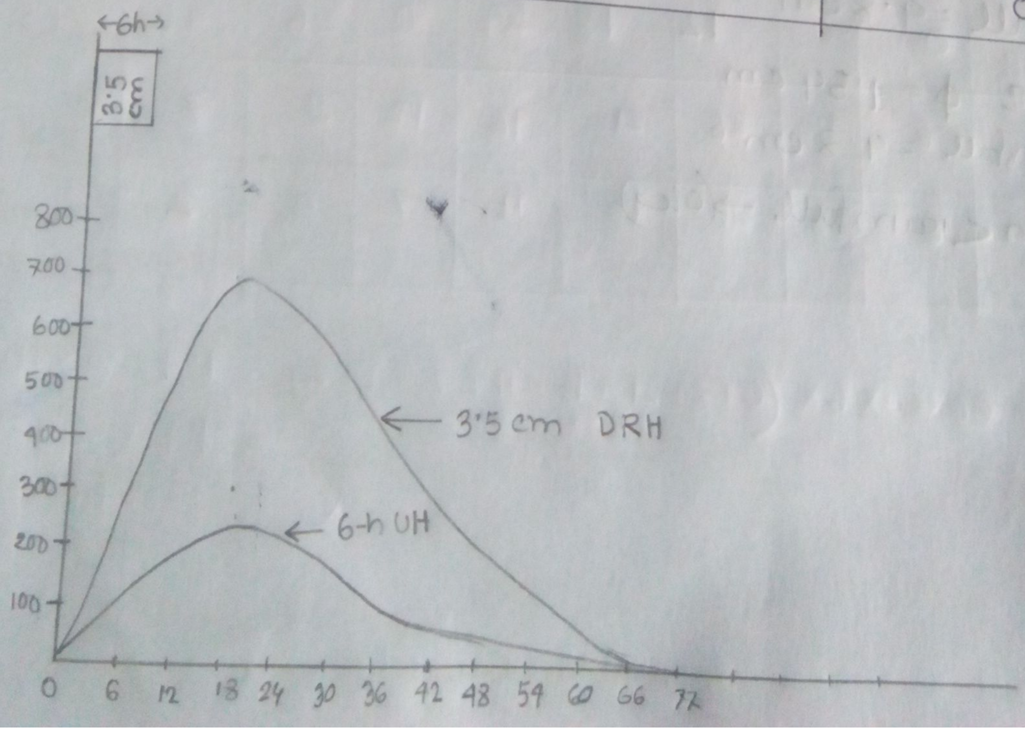
Unit Hydrograph:

Example 6.4

time (h)	ordinate of 6-h unit hydrograph (m^3/s)	ordinate of 3.5 cm DRH (m^3/s)
1	2	3
0	0	0
3	25	87.5
6	50	175
9	85	297.5
12	125	437.5
15	160	560
18	185	647.5
24	160	560
30	110	385
36	60	210
42	36	126
48	25	87.5
54	16	56
60	8	28
69	0	0



Example - 6·5

time	ordinate of 6-h unit hydrograph	ordinate of 3 cm DRH	ordinate of 2cm DRH (lagged by 6h)	ordinate of 5 cm DRH
1	2	3	4	5
0	~~25~~ 0	0	0	0
3	~~50~~ 25	75	0	75
6	~~85~~ 50	150	0	150
9	~~125~~ 85	225	50	275
12	~~160~~ 125	375	100	475
15	~~185~~ 160	480	170	650
18	185	555	250	805
(21)	(172.5)	(517.5)	(320)	(837.5)
24	160	480	370	850
30	110	330	320	650
36	60	180	220	400
42	36	108	120	228
48	25	75	72	147
54	16	48	50	98
60	8	24	32	56
(66)	(2.7)	(8)	(16)	(24)
69	0	0	10.7	
75	0	0	0	

11(b) Given, $\phi = 0.2$ cm/h 2013-14

The effective rainfall for corresponding time intervals (upon deducting the loss) –

0 – 6 hrs : $5.2 - 0.2 \times 6 = 4.0$ cm

6 – 12 hrs : $4.2 - 0.2 \times 6 = 3$ cm

12 – 18 hrs : $2.7 - 0.2 \times 6 = 1.5$ cm

time	UH	1st storm	2nd storm	3rd storm	Base flow	Flood hydrograph
0	0	0	0	0	10	10
6	50	200	0	0	10	210
12	125	500	150	0	10	660
18	170	680	375	75	12	1142
24	150	600	510	187.5	12	1309.2
30	100	400	450	255	12	1117
36	60	240	300	225	14	779
42	40	160	180	150	14	504
48	15	60	120	90	14	284
54	0	0	45	60	16	121

1(b) Given,

2012-13

$\phi = 0.2$ cm/hr.

~~0-5 hr:~~

Effective rainfall:

0-5 hr: $3 - 0.2 \times 5 = 2$ cm

5-10 hr: $1 - 0.2 \times 5 = 0$ cm

10-15 hr: $7 - 0.2 \times 5 = 6$ cm

time	UH	1st storm	2nd storm	3rd storm	Base flow	Flood hydrograph
0	0	0	0	0	10	10
5	50	100	0	0	12	112
10	125	250	0	0	14	264
15	185	370	0	300	16	686
20	160	320	0	750	18	1088
25	110	220	0	1110	20	1350
30	60	120	0	960	22	1102
35	36	72	0	660	24	756
40	25	50	0	360	26	436
45	12	24	0	216	28	268
50	0	0	0	150	30	180

1-3, T-2

71(d)

2009 - 2010

Unit Hydrographs of different durations

Method of Superposition:

(Example - 6.9)

time	0	4	8	12	16	20	24	28	32	36	40
UH 4-h	0	20	80	130	150	130	90	52	27	15	5

Calculation of 12-h Unit Hydrograph from a 4-H Unit Hydrog hydrograph :-

time (h)	Ordinate of 4-h UH (m^3/s)			DRH of 3cm in 12-h (A+B+C)=D	Ordinate of 12-h UH (m^3/s)
	A	B lagged by 4-h	C lagged by 8h		
0	0	–	–	0	~~6.67~~ 0
4	20	0	–	20	~~33.3~~ 6.67
8	80	20	0	100	33.3
12	130	80	20	230	76.7
16	150	130	80	360	120
20	130	150	130	410	136.67
24	90	130	150	370	123.33
28	52	90	130	272	90.67
32	27	52	90	169	56.3
36	15	27	52	94	31.3
40	5	15	27	47	15.7
44	0	5	15	20	6.7
48		0	5	5	1.7
52			0	0	0

61(d)

time	ordinate of 2-h UH A	B lagged by 2-h	C lagged by 4-h	D lagged by 6-h	DRH of 4 cm in 8 hr	ordinate of 8 hr UH
0	0	–	–	–	0	0
2	30	0	–	–	30	7.5
4	65	30	0	–	95	23.75
6	105	65	30	0	200	50
8	160	105	65	30	360	90
10	220	160	105	65	550	137.5
12	200	220	160	105	685	171.25
14	(190)	200	220	160	770	192.5
16	180	190	200	220	790	197.5
18	155	180	190	200	725	181.25
20	130	155	180	190	655	163.75
22	(117.5)	130	155	180	582.5	145.625
24	105	117.5	130	155	507.5	126.88
26	86	105	117.5	130	438.5	109.625
28	55	86	105	117.5	363.5	90.875
30	25	55	86	105	271	67.75
32	10	25	55	86	176	44
34	5	10	25	55	95	23.75
36	0	5	10	25	40	10
38		0	5	10	15	3.75
40			0	5	5	1.25
42				0	0	0

11(c) Given, Area = $50\ km^2$

2012-13

Base flow at begining = $10\ m^3/s$

Base flow at end = $10\ m^3/s$

time from start of storm	0	6	12	18	24	30	36	42	48
Discharge (m^3/s)	10	80	105	75	48	32	22	15	10
runoff	0	70	95	65	38	22	12	5	0

volume of DRH = $6 \times 60 \times 60 \times (70+95+65+38+22+12+5) = 66,31,200$

$\therefore$ Depth of runoff = $\frac{6631200}{50 \times (10^3)^2} = 0.1326\ m = 13.26\ cm$

time(h)	Discharge	Base flow	DRH	6h-n UH
0	10	10	0	0
6	80	10	70	5.27
12	105	10	95	7.16
18	75	10	65	4.9
24	48	10	38	2.87
30	32	10	22	1.66
36	22	10	12	0.9
42	15	10	5	0.38
48	10	10	0	0
54	10	10	0	0

$\frac{70}{13.26}$

2013-14

11(a) Given, Area = 489 km^2

Base flow at beginning = 20 m^3/s

Base flow at end = 20 m^3/s

volume of ~~direct run~~ DRH = $4 \times 60 \times 60 \times (10+30+60+90+130+110+90+60+40+30+20+10)$

$= 9.792 \times 10^6$ m^3/s

Depth of runoff = $\frac{9.792 \times 10^6}{489 \times 10^6} = 0.02 m = 2 cm$

time	Discharge	Base flow	DRH	4-hr UH
0	20	20	0	0
4	30	20	10	5
8	50	20	30	15
12	80	20	60	30
16	110	20	90	45
20	150	20	130	65
24	130	20	110	55
28	110	20	90	45
32	80	20	60	30
36	60	20	40	20
40	50	20	30	15
44	40	20	20	10
48	30	20	10	5
52	20	20	0	0
56	20	20	0	0

41(a) Given, Area = 500 km²

2014-15

Begining of Base flow = $50 \; m^3/s$

End of Base flow = $50 \; m^3/s$

Area of DRH = $6 \times 60 \times 60 \times (100 + 250 + 200 + 150 + 100 + 70 + 50 + 35 + 25 + 15 + 5)$

$= 21.6 \times 10^6$

$\therefore$ Depth of runoff = $\frac{21.6 \times 10^6}{500 \times 10^6} = 0.0432 \; m = 4.32 \; cm$

time	Discharge	Base flow	DRH	6-hrs UH
0	50	50	0	0
6	150	50	100	23.15
12	300	50	250	57.87
18	250	50	200	46.29
24	200	50	150	34.72
30	150	50	100	23.15
36	120	50	70	16.2
42	100	50	50	11.57
48	85	50	35	8.1
54	75	50	25	5.79
60	65	50	15	3.47
66	55	50	5	1.16
72	50	50	0	0