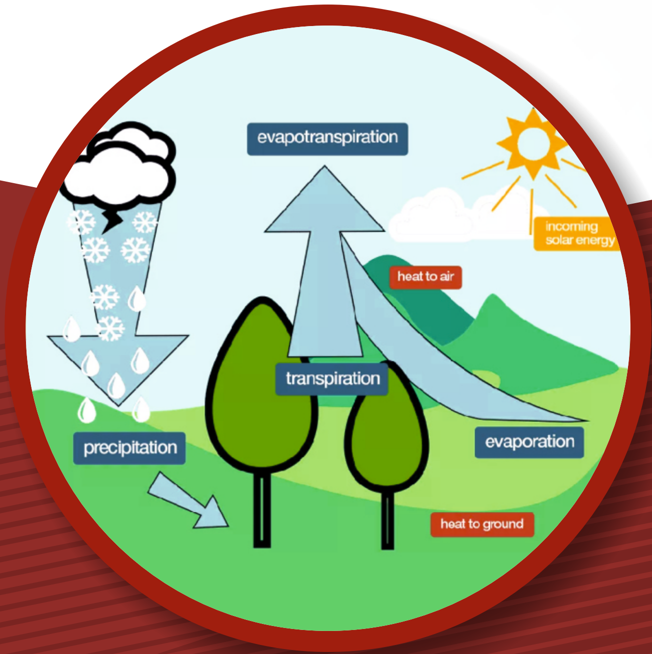
ESE | GATE | PSUs



CIVIL ENGINEERING

HYDROLOGY

Text Book : Theory with worked out Examples and Practice Questions

6 Hydrology

(Solutions for Text Book Practice Questions)

01. Precipitation

01. Ans: (d)

Sol: Existing no.of rain gauge stations m = 6

Average depth of rainfall $\overline{P} = 92.8\,\text{cm}$

Standard deviation of rainfall σ = 30.7 cm

Allowable error (E) = 10%

Optimum no. of rain gauge stations,

$$n = \left[\frac{C_v}{E}\right]^2$$

$$C_V = \frac{100\sigma}{\overline{P}} = \frac{100\times 30.7}{92.8} = 33.08\%$$

$$n = \left[\frac{C_V}{E}\right]^2 = \left[\frac{33.08}{10}\right]^2 = 10.94 \approx 11\text{No's}$$

02. Ans: (b)

Sol: n = 5; $C_V = 33\%$

$$\therefore\ n = \left[\frac{C_V}{E}\right]^2 \Rightarrow 5 = \left[\frac{33}{E}\right]^2$$

E = 14.758%

% Accuracy = 100–% error

= 100–14.758

= 85.24%

03. Ans: (d)

Sol: ∵ $N_A = N_C = N_B \pm 10\%\ N_B$

∴ Simple mean method is used

$$P_B = \frac{P_A + P_C}{2} = \frac{153.0 + 145.0}{2}$$

=149 cm

04. Ans: 1093.43

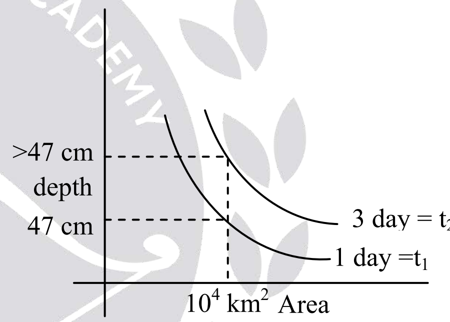
Sol:
$$P_P = \frac{N_P}{m}\left[\frac{P_Q}{N_Q} + \frac{P_R}{N_R} + \frac{P_S}{N_S}\right]$$

$$860 = \frac{780}{3}\left[\frac{930}{850} + \frac{1010}{920} + \frac{P_S}{980}\right]$$

P_s = 1093.43 mm

05. Ans: (b)

Sol:



For 3day storm

Average depth > depth of one day storm > 47 cm

06. Ans: (c)

Refer previous ESE-Obj-(Vol-2) solutions Book (Cha-1, 30th Question -pg: 297)

07. Ans: (c)

Refer previous ESE-Obj-(Vol-2) solutions Book (Cha-1, 12th Question -pg: 293)

08. Ans: (d)

Refer previous ESE-Obj-(Vol-2) solutions Book (Cha-1, 10th Question -pg: 293)

09. Ans: (c)

Refer previous ESE-Obj-(Vol-2) solutions Book (Cha-1, 29th Question -pg: 296)

10. Ans: (b)

Refer previous ESE-Obj-(Vol-2) solutions Book (Cha-1, 35th Question -pg: 297)

Conventional Practice Solutions

01.

Sol: Given:

$N_A \rightarrow 610$ $\quad P_A \rightarrow ?$

$N_B \rightarrow 554$ $\quad P_B \rightarrow 22$

$N_C \rightarrow 468$ $\quad P_C \rightarrow 29$

$N_D \rightarrow 606$ $\quad P_D \rightarrow 35$

$N_E \rightarrow 563$ $\quad P_E \rightarrow 13$

$N_F \rightarrow 382$ $\quad P_F \rightarrow 25$

Arithmetic Average Method:

$$P_A = \frac{P_B + P_C + P_D + P_E + P_F}{m}$$

$$P_A = \frac{22+29+35+13+25}{5}$$

$= 24.8$ mm

Normal Ratio Method:

$$P_A = \frac{N_A}{m}\left(\frac{P_B}{N_B} + \frac{P_C}{N_C} + \frac{P_D}{N_D} + \frac{P_E}{N_E} + \frac{P_F}{N_F}\right)$$

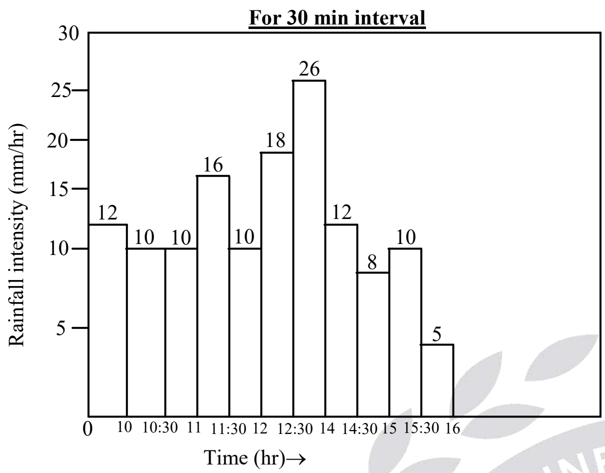
$$P_A = \frac{610}{5}\left(\frac{22}{554} + \frac{29}{468} + \frac{35}{606} + \frac{13}{563} + \frac{25}{382}\right)$$

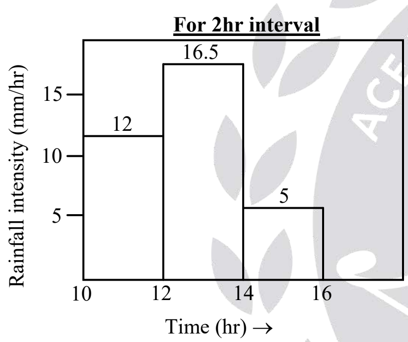
$= 30.25$ mm

02.

Sol:

Time (hrs)	Rainfall (mm)	$i = \frac{P_{n+1} - P_n}{t_{n+1} - t}$ (mm/hr) (30 min)	i = mm/hr (2 hr)
10.00	0		
10.30	6	$i_1 = \frac{6-0}{0.5} = 12$	
11.00	11	$i_2 = \frac{11-6}{0.5} = 10$	$i_1 = \frac{24-0}{2} = 12$
11.30	16	$i_3 = \frac{16-11}{0.5} = 10$	
12.00	24	$i_4 = \frac{24-16}{0.5} = 16$	
12.30	29	$i_5 = \frac{29-24}{0.5} = 10$	
13.00	38	$i_6 = \frac{38-29}{0.5} = 18$	$i_2 = \frac{57-24}{2} = 16.5$
13.30	51	$i_7 = \frac{51-38}{0.5} = 26$	
14.00	57	$i_8 = \frac{57-51}{0.5} = 12$	
14.30	61	$i_9 = \frac{61-57}{0.5} = 8$	
15.00	66	$i_{10} = \frac{66-61}{0.5} = 1$	$i_3 = \frac{67-57}{2} = 5$
15.30	67	$i_{11} = \frac{67-66}{0.5} = 2$	
16.00	67	$i_{12} = 0$	





02. Mean Precipitation Calculation

01. Ans: (a)

Sol: $\overline{P} = \dfrac{P_A A_A + P_B A_B + P_C A_C + P_D A_D}{A_A + A_B + A_C + A_D}$

$= \dfrac{3\times 75 + 5\times 125 + 4\times 150 + 6\times 150}{75 + 125 + 150 + 150}$

$= 4.7$ cm

02. Ans: (b)

Sol: $\overline{P} = P_A \times \dfrac{A_A}{A} + P_B \times \dfrac{A_B}{A} + P_C \times \dfrac{A_C}{A} + P_D \times \dfrac{A_D}{A}$

$\dfrac{A_D}{A} = 1 - \left(\dfrac{A_A}{A} + \dfrac{A_B}{A} + \dfrac{A_C}{A}\right)$

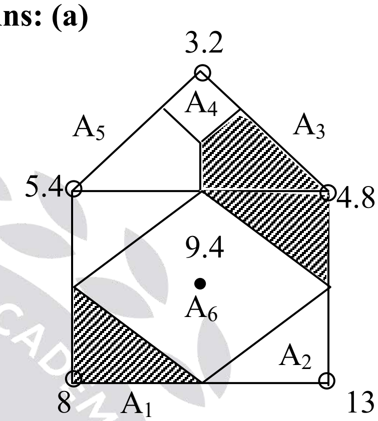
$= 1-(0.1+0.2+0.3) = 0.4$

$\overline{P} = 10\times 0.1 + 15\times 0.2 + 20\times 0.3 + 25\times 0.4$

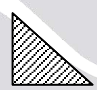
$= 20$ cm

03. Ans: (a)

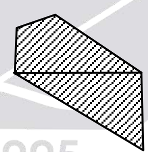
Sol:



$A = 4\times 4 + \dfrac{\sqrt{3}}{4}(4)^2 = 22.928\ \text{km}^2$

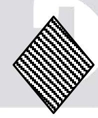


$A_1 = A_2 = \dfrac{1}{2}\times 2\times 2 = 2\ \text{km}^2$



$A_3 = A_5 = \dfrac{1}{2}\times 2\times 2 + \dfrac{1}{3}\times\dfrac{\sqrt{3}}{4}\times(4)^2 = 4.309\ \text{km}^2$

$A_4 = \dfrac{1}{3}\times\dfrac{\sqrt{3}}{4}(4)^2 = 2.308\ \text{km}^2$



$A_6 = \sqrt{8}\times\sqrt{8} = 8\ \text{km}^2$

$\overline{P} = \dfrac{P_1A_1 + P_2A_2 + P_3A_3 + P_4A_4 + P_5A_5 + P_6A_6}{A}$

$\overline{P} = \dfrac{8\times 2 + 13\times 2 + 4.8\times 4.309 + 3.2\times 2.309 + 5.4\times 4.309 + 9.4\times 8}{22.928}$

$\overline{P} = 7.35$ cm

04. Ans: (b)

Sol:

$$\overline{P} = \frac{A_1\left[\frac{P_1+P_2}{2}\right]+......+A_{n-1}\left[\frac{P_{n-1}+P_n}{2}\right]}{A}$$

$$\overline{P} = \frac{92\left[\frac{15+12}{2}\right]+128\left[\frac{12+9}{2}\right]+120\left[\frac{9+6}{2}\right]+175\left[\frac{6+3}{2}\right]+85\left[\frac{3+1}{2}\right]}{600}$$

= 7.4 cm

05. Ans: (b)

Sol:

$$\overline{P} = \frac{30\times12+140\times\left(\frac{12+10}{2}\right)+80\times\left(\frac{10+8}{2}\right)+180\times\left(\frac{8+6}{2}\right)+20\left(\frac{6+4}{2}\right)}{30+140+80+180+20}$$

= 8.84 cm

Note: Formula same as earlier problem

08. Ans: (c)

Sol: P_1 = 45 cm,

P_2 = 55 cm,

P_3 = 65 cm

$$\overline{P} = \frac{A_1\left[\frac{P_1+P_2}{2}\right]+A_2\left[\frac{P_2+P_3}{2}\right]}{A}$$

$$= \frac{100\left[\frac{45+55}{2}\right]+150\left[\frac{55+65}{2}\right]}{100+150}$$

= 56 cm

09. Ans: (c)

Refer previous ESE-Obj-(Vol-2) solutions Book (Cha-1, 5th Question - pg: 292)

10. Ans: (100 cm)

Refer previous ESE-Conv-(Vol-2) solutions Book (Cha-2, 6th Question - pg: 226)

Conventional Practice Solutions

01.

Sol:

(i) Arithmetic Mean Method

$$\overline{P} = \frac{P_1+P_2+P_3+.........P_n}{n}$$

$$\overline{P} = \frac{135+143+137+128+102+115+99+101}{8}$$

= 120 mm

(ii) Thiessen Mean Polygon Method

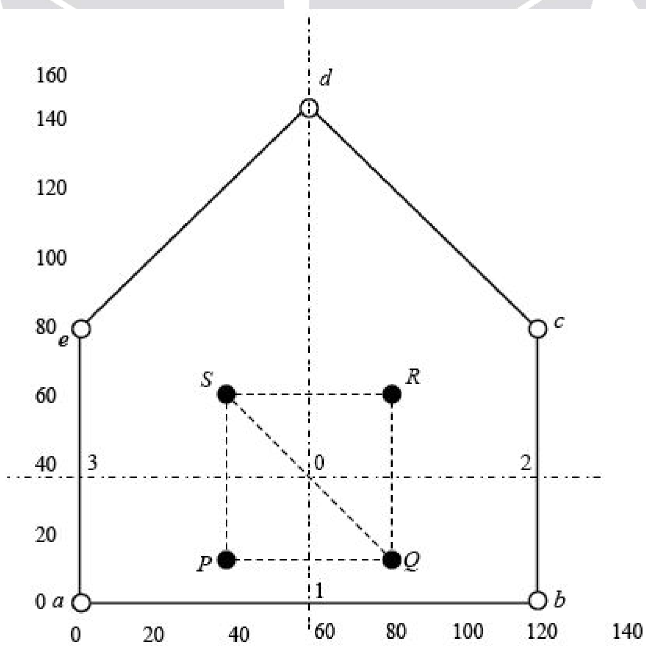
$$= \frac{P_AA_A+P_BA_B+............+P_nA_n}{A}$$

= 120.8 mm

02.

Sol:

Raingauge Station	**Boundary of Thiessen polygons as in fig.**	**Area (km^2)**	**Weightage Factor = (Fraction of total area)** $= \frac{\text{Area}}{13200}$	**Recorded station rainfall (cm)**	**Weighted station rainfall (cm)**
P	301a	60×40 = 2400	0.1818	120	21.816
Q	102b	60×40 = 2400	0.1818	110	19.998
R	20dc	[(60×40)+(60×60×1/2)]=4200	0.3182	100	31.82
S	30de	[(60×40)+(60×60×1/2)]=4200	0.3182	125	39.775
Total area of catchment =		13200	1.0000		113.41



Average precipitation over the catchment in 2005 = 113.41 cm

03. Frequency of Point Rainfall & Probability

01. Ans: (i) 2.5, (ii) 2, (iii) 1.25

Sol: Return period (T) for a magnitude listed at a position "m" in a total of 'n' entries is

$$T = \frac{n+1}{m}$$

Arrange all flood data in descending order and allot rank to each flood (i.e)

Annual peak flood (m^3/s)	Rank
130	1
120	2
100	3
80	4
75	5
70	6
60	7
50	8
40	9

(i) Return period of flood 80 m^3/sec = $\frac{9+1}{4}$

$$= \frac{10}{4} = 2.5$$

(ii) Return period of flood 75 m^3/sec = $\frac{9+1}{5} = 2$

(iii) Return period of flood 50 m^3/sec = $\frac{9+1}{8}$

$$= \frac{10}{8} = 1.25$$

02. Ans: (d)

Sol: T = 20 years

$$\therefore p = \frac{1}{T} = \frac{1}{20} = 0.05$$

n = 12 years

q = 1 – p = 1 – 0.05 = 0.95

Probability of occurring at least once

$$= 1 - q^n = 1 - 0.95^{12} = 45.96\% \approx 46\%.$$

03. Ans: (c)

Refer previous GATE solutions Book (Cha-1, 2nd Question-(1M) -pg: 662)

04. Ans: (a)

Sol: n = 50 yrs

T = 100 yrs

$$P = \frac{1}{T} = \frac{1}{100} = 0.01$$

q = 1–P = 1–0.01 = 0.99

Risk = $1-(q)^n = 1-(0.99)^{50}$

= 0.395 = 39.5%

05. Ans: (c)

Sol: Risk = 20% = 0.2; n = 10yrs, T =?

Risk = $1-(q)^n$

$0.2 = 1-(q)^{10} \Rightarrow q = 0.9778$

P = 1–q = 0.022

$$T = \frac{1}{P} = \frac{1}{0.022} = 45.45 \approx 45 \text{ yrs}$$

06. Ans: (d)

Sol: For 6 cm rain fall

Rank m = 6

n = 10

(i) Hazen formula,

$$T = \frac{n}{m - 0.5}$$

$$T = \frac{10}{6 - 0.5} = \frac{10}{5.5} = \frac{20}{11}$$

(ii) By Weibull Formula

$$T = \frac{n+1}{m} = \frac{10+1}{6} = \frac{11}{6}$$

07. Ans: (d)

Sol: T = 100 yr

n = 2

$$P = \frac{1}{T} = \frac{1}{100} = 0.01$$

q = 1–P=1–0.01= 0.99

Risk $= 1-(q)^n = 1-(0.99)^2 = 0.0199 = 1.99\%$

08. Ans: (i) 0.025, (ii) 0.397, (iii) 0.975

Sol T = 40 years

(i) $p = \frac{1}{T} = \frac{1}{40} = 0.025$

q = 1 – p = 1 – 0.025 = 0.975

(ii) At least once in next 20 years

Risk $= (1 - q^n) = 1 - 0.975^{20}$

$= 0.3973$

R = 39.73%

(iii) Probability of occurring of flood magnitude less than 4000 $m^3/\sec$

Probability of not occurring a flood of magnitude $\geq 4000\, m^3/\sec$

q = 0.975

09. Ans: (b)

Refer previous ESE-Obj-(Vol-2) solutions Book (Cha-1, 24th Question -pg: 295)

10. Ans: (d)

Refer previous ESE-Obj-(Vol-2) solutions Book (Cha-1, 2nd Question -pg: 292)

11. Ans: (c)

Refer previous ESE-Obj-(Vol-2) solutions Book (Cha-1, 25th Question -pg: 296)

12. Ans: (d)

Refer previous ESE-Obj-(Vol-2) solutions Book (Cha-1, 34th Question -pg: 297)

13. Ans: (c)

Refer previous ESE-Obj-(Vol-2) solutions Book (Cha-1, 42nd Question -pg: 298)

14. Ans: (3574.6 m^3/sec)

Refer previous ESE-Conv-(Vol-2) solutions Book (Cha-7, 04th Question -pg: 260)

Conventional Practice Solutions

01.

Sol:

(i) $n \rightarrow 10$ years, $T = 50$ years

$$p = \frac{1}{T} = \frac{1}{50} = 0.02$$

$$q = 1 - p \Rightarrow 1 - 0.02 = 0.98$$

once in next 10 years

$n \rightarrow 10$ years, $r = 1$

$$P(1,10) = \frac{n!}{(n-r)!r!}(p)^r (q)^{n-r}$$

$$= \frac{10!}{9!}(0.02)^2(0.98)^{10-2}$$

$$= 0.166 = 16.67\%$$

(ii) Twice in next 10 years

$$P_{(2,10)} = \frac{10!}{(10-2)!2!}(0.02)^2(0.98)^{10-2}$$

$$= \frac{10!(0.02)^2}{8!\times 2!}(0.98)^8$$

$$= 0.0153 = 1.53\%$$

(iii) Occurring at least once in 10 years = Risk

$$R = (1 - q^n) \Rightarrow (1 - 0.98^{10})$$

$$= 0.1829 = 18.29\%$$

02.

Sol: $T = 100$ years

$$p = \frac{1}{T} = \frac{1}{100} = 0.01$$

$$q = 1 - p \Rightarrow 1 - 0.01 = 0.99$$

(i) Will not occur in the next 50 years

$$= (q^n) \Rightarrow (0.99^{50})$$

$$= 0.605 = 60.5\%$$

(ii) Will occur in the next 1 year

$$= 1 - (q^n) \Rightarrow 1 - (0.99)^1 = 0.01 = 1\%$$

04. Evaporation & Evapotranspiration

01. Ans: 5.157

Sol: Depth of water removed,

$$Z = \frac{4.2\times 10^{-3}}{\frac{\pi}{4}(1.22)^2}\times 1000 = 3.592\,\text{mm}$$

Pan evaporation

$$E = P \pm Z = 8.75 - 3.592 = 5.157 \text{ mm}$$

02. Ans:11.94 mm & 8.35 mm

Sol: Depth of water added

$$(Z) = \frac{8.75\times 10^{-3}}{\frac{\pi}{4}(1.2)^2}\times 1000 = 7.736\,\text{mm}$$

Pan evaporation, $E = p \pm Z$

$= 4.2 + 7.736$

$= 11.936$ mm ($+Z \rightarrow$ water added

$-Z \rightarrow$ water removed)

(Actual evaporation = $C_P \times$ pan evaporation)

$= 0.7 \times 11.936$

$= 8.35$ mm

03. Ans: 61.08

Sol: Increase in storage

$= 103.258 - 103.2 = 0.058$ m

$\sum I - \sum O = \pm \Delta S = +\Delta S$

($\because + \rightarrow$ increase)

$[I+P]-[O+E+S] = +\Delta S$

$$\left[\frac{6\times 30\times 24\times 60\times 60}{5000\times 10^4}\times 1000+145\right]$$

$$-\left[\frac{6.5\times 30\times 24\times 60\times 60}{5000\times 10^4}\times 1000-E+0\right]$$

$= 0.058\times 1000$

$[456.04]-[336.96-E] = 0.058\times 1000$

$E = 61.08$ mm

$\therefore$ Evaporation loss in that month

$E = 61.08$ mm

04. Ans: (d)

Sol: $\sum I - \sum O = \pm \Delta S$

Plan area of reservoir = 1 km^2

$= 1\times 100 = 100$ ha

$$=\left[10+\frac{3}{100}\times 100\right]-\left[20+\frac{12\times 0.7}{100}\times 100+\text{seepage}\right]$$

$$=\frac{-20}{100}\times 100$$

$$\underset{(\text{Ha.m})}{[\text{inflow}} + \underset{(\text{Ha.m})}{\text{Precipitation}]} - \underset{(\text{Ha.m})}{[\text{outflow}} + \underset{(\text{Ha.m})}{\text{Evaporation}} + \underset{(\text{Ha.m})}{\text{seepage}]}$$

$$= \underset{(\text{Ha.m})}{\text{change in storage}}$$

$[10 + 3]-[20 + 8.4 + \text{seepage}] = -20$

$\therefore$ seepage loss = 4.6 Ha.m

Note: All values substitute in above equation in Ha.m

05. Ans: (a)

Sol: $R = 200$ watt/m^2

$L = 2441$ kJ/kg $= 2441\times 10^3$ J/kg;

$\rho_w = 997$ kg/m^3

$$E = \frac{R}{\rho_w L} = \frac{200}{997\times 2441\times 10^3}$$

$= 8.218\times 10^{-8}$ m/sec $\simeq 7.1$ mm/day

06. Ans: (c)

Sol: $P = 7.2\%$,

$T_m = 18°C$,

$K = 0.7$

Consumptive use

$$= \text{PET} = \frac{KPT_m}{100}\times 2.54\,\text{cm/month}$$

$$\text{PET} = \frac{0.7\times 7.2\times (1.8\times 18+32)}{100}\times 25.4\,\frac{\text{mm}}{\text{month}}$$

$= 82.44$ mm/month

$\therefore$ consumptive use

$$\text{PET} = \frac{82.44}{30} = 2.74\,\text{mm/day}$$

07. Ans: (a)

Sol: $$K = \frac{\text{consumptive use}}{\text{pan evaporation}}$$

$$0.52 = \frac{\text{consumptive use}}{9.5}$$

Consumptive use $= 9.5\times 0.52$

$= 4.94$ cm/month

January no.of days = 31

Consumptive use

$$= 4.94\times \frac{10}{31} \simeq 1.6\ \text{mm/day}$$

08. Ans: (c)

Sol: Indian standard pan

$\therefore\ C_P = 0.8$

Pan evaporation = 4.0 cm

Actual evaporation from reservoir

$= C_p \times$ pan evaporation

$= 0.8 \times 4 = 3.2$ cm

Volume of water evaporated = plan area of reservoir× actual evaporation loss

$$= 100 \times \frac{3.2}{100} \times 10^4 = 3.2 \times 10^4 \text{ m}^3/\text{day}$$

09. Ans: (d)

Refer previous ESE-Obj-(Vol-2) solutions Book (Cha-2, 08th Question -pg: 309)

11. Ans: (d)

Refer previous ESE-Obj-(Vol-2) solutions Book (Cha-2, 9th Question -pg: 309)

12. Ans: (d)

Refer previous ESE-Obj-(Vol-2) solutions Book (Cha-2, 04th Question -pg: 308)

13. Ans: (a)

Refer previous ESE-Obj-(Vol-2) solutions Book (Cha-2, 3rd Question -pg: 308)

Conventional Practice Solutions

01.

Sol: $\Sigma I - \Sigma O = I\Delta S$

$I = I + P$

$O = O + E + S$

Area of lake, a = 15.8 km^2

P (Rainfall) = 73.6 mm

$$\text{Inflow ratio} = \frac{32.5 \times 7 \times 24 \times 60 \times 60 \text{ m}^3/\text{week}}{15.8 \times 10^6 \text{ m}^2}$$

($\because$ km = 1000 m

$1\text{km}^2 = (10^3)^2 \text{ m}^2 = 10^6 \text{ m}^2$)

= 1.244 m/week

= 1244 mm/week

$$\text{Out flow rate} = \frac{40.2 \times 7 \times 24 \times 60 \times 60}{15.8 \times 10^6 \text{ m}^2} \text{m}^3/\text{week}$$

= 1.538 m/week

= 1538 mm/week

Change in storage (ΔS) = 9180 –8630

= 550 ha-m

$$\text{Storage depth} = \frac{550 \times 10^4 \text{ m}^3}{15.8 \times 10^6 \text{ m}^2}$$

= 0.34810 m

= 348.10 mm

$$\text{Seepage flow} = S \Rightarrow \frac{0.25 \times 10^6 \text{ m}^3}{15.8 \times 10^6 \text{ m}^2}$$

= 0.0158 m

= 15.822 mm

$\Sigma I - \Sigma O = \Delta S$

$(I + P) - (O + E + S) = -\Delta S$

(decrease in seepage –ve)

$(1244 + 73.6) - (1538 + E + 15.822) = -348.10$

$E = 111.78$ mm

02.

Sol:

(i) $PET = \frac{KPT_m}{100}$ inch/month

$T_m \rightarrow$ °F (mean monthly temperature)

$P \rightarrow$ Monthly % of annual day time hours

$K \rightarrow$ Consumptive use factor

Month	**T_m (^oC)**	**P**	**K**	**T_m =1.8°C+32 (F)**	**PET = $\frac{KPT_m}{100} \times 25.4$ (mm/month)**
June	31.0	8.6	1.15	87.8	220.56
July	30.8	8.82	1.30	87.44	254.66
August	30.0	8.75	1.25	86	238.92
Sep	29.5	8.26	1.10	85.1	196.39
October	28.1	8.33	0.90	82.58	157.25

Peak consumptive use = 254.66 mm/month

= 7639.8 mm/day

(ii) Seasonal consumptive use

$= \sum \frac{KPT_m}{100} = 220.56 + 254.66 + 238.92$

$+ 196.39 + 157.25 = 1067.79$ mm/season

05. Infiltration

01. Ans: (a)

Sol: $f < f_c$ when $i<f_c$

02. Ans: (b)

Sol: Hydraulic conductivity of soil

$f_c = 0.2$ cm/hr

$i = 0.5$ cm/hr [$\because i>f_c$]

$f_a = f_c = 0.2$ cm/hr

03. Ans: (d)

Sol: $f_t = f_c+(f_0-f_c)\, e^{-kt}$

$f_t = 1.34+(7.62-1.34)e^{-4.182t}$

$f_2 = 1.34+(7.62-1.34)e^{-4.182\times 2} = 1.34$

$f_2 = f_c$

$\therefore$ steady state attained

Total infiltration in 2hrs

$= f_c \times t + \frac{f_0 - f_c}{K}$

$= 1.34 \times 2 + \frac{7.62 - 1.34}{4.182} = 4.18\,\text{cm}$

04. Ans: 4.375

Sol: $f_0 = 2$ cm/hr; $f_c = 0.5$ cm/hr; $K = 4hr^{-1}$

Infiltration in 8hr = $f_c \times t + \frac{f_o - f_c}{K}$

$$= 0.5 \times 8 + \frac{1.5}{4} = 4.375 \text{ cm}$$

05. Ans: 40320 m^3

Sol: In 24 hrs Rainfall = 10 cm

In 24 hrs evaporation = $C_P \times$pan evaporation

$= 0.7 \times 0.6$

In 24 hrs infiltration = $f_c \times t + \frac{f_0 - f_c}{K}$

$$= 0.3 \times 24 + \frac{1 - 0.3}{5}$$

$$= 7.34 \text{cm}$$

Run off = P–E–I

Runoff (R) = 10–(0.7×0.6)–7.34=2.24 cm

Depth of runoff = 2.24 cm

Volume of runoff

= Area of catchment × depth of Runoff

$$= 1.8 \times (1000)^2 \times \frac{2.24}{100} = 40320 \text{ m}^3$$

06. Ans: 10.71 mm /hr & 11.31 mm/hr

Sol: $f_c = 6$ mm/hr; $f_0 = 16+6 = 22$mm/hr;

$K = 2\ hr^{-1}$

Depth of infiltration in first 45 min

i.e., $t = \frac{45}{60} hr = 0.75 hr$

$$= \int_0^{0.75} (6 + 16e^{-2t}) dt$$

$$= 6[t]_0^{0.75} + \frac{16}{-2}[e^{-2t}]_0^{0.75}$$

$$= 6 \times 0.75 - 8[e^{-2\times0.75} - e^{-2\times0}]$$

$= 10.71$ mm

Avg. Infiltration rate for first 75 min

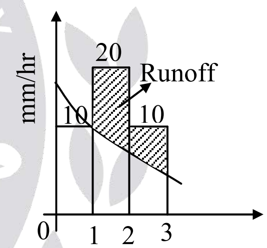
$$\left(t = \frac{75}{60} = 1.25 \text{hr}\right)$$

$$= \int_0^{1.25} \frac{f_t.dt}{\text{time}} = \frac{1}{1.25}\left[6 \times (t)_0^{1.25} + \frac{16}{-2}[e^{-2t}]_0^{1.25}\right]$$

$= 11.31$ mm/hr

07. Ans: (d)

Sol: Runoff = Area of hyetograph above IC curve



Area of hyetograph above IC curve

$$= \begin{bmatrix}\text{Total area of hyetograph} \\ \text{between 1hr to 3hr}\end{bmatrix} - \begin{bmatrix}\text{Area below IC} \\ \text{curve between 1hr to 3hr}\end{bmatrix}$$

$$= [20 \times 1 + 10 \times 1] - \int_1^3 f_t.dt$$

$$= 30 - \left[\int_1^3 (6.8 + 8.7e^{-t}) dt\right]$$

$$= 30 - \left[6.8 \times (t)_1^3 + \frac{8.7}{-1}[e^{-t}]\right]_1^3$$

$$= 30 - [6.8 \times [3 - 1] - 8.7[e^{-3} - e^{-1}]]$$

= 13.63 mm

08. Ans: 0.42 hr^{-1}

Sol: f_o = 10mm/hr f_c = 1.2 mm/ hr

Total infiltration = 33 mm

Total infiltration = $f_c \times t + \frac{f_0 - f_c}{K}$

$33 = 1.2 \times 10 + \frac{10-1.2}{K}$

K = 0.419 hr^{-1}

09. Ans: (b)

Sol: $\phi_{index} = 0.5 cm/h$

P = 2 cm; T = 6 hour

Given, Uniform rate R = ?

$W_{index} = \frac{P - R - losses}{t}$

$0.50 = \frac{2 - R - 0}{6}$ R = -1 cm

Runoff = 0 cm

10. Ans: (d)

Sol: The total observed runoff volume

= $25.2\times10^6 m^3$

Area of basin = 280 km^2

Rainfall intensity = 4hr

Duration of rain = 4 hr

Total rainfall in 4hr, P = 2.8×4 = 11.2 cm

Runoff depth (R)

$$= \frac{25.2 \times 10^6}{280 \times (1000)^2} \times 100 = 9 cm$$

Average infiltration

$$= \frac{P-R}{t} = \frac{11.2-9}{4} = 0.55 \text{ cm/hr}$$

= 5.5 mm/hr

11. Ans: (a)

Sol: $\phi_{index} = \frac{P_{e_1} - R_1}{t_{e_1}} = \frac{P_{e_2} - R_2}{t_{e_2}}$

$\Rightarrow \frac{4-2}{4} = \frac{10-R_2}{8} \Rightarrow R_2 = 6$ cm

Linked answer questions for 12 & 13

12. Ans: (a)

Sol: Storm – I

i_e = 2 cm/hr

t_e = 5 hr, R = 4 cm

$P_e = i_e t_e$ = 2×5 = 10 cm

$\phi_{index} = \frac{P_e - R}{t_e} = \frac{10-4}{5} = 1.2 cm/hr$

13. Ans: (d)

Sol: R_2 = 8.4 cm ; ϕ = 1.2 cm/hr; t_e = 8hr

$\phi = \frac{P_{e_2} - R_2}{t_{e2}} = \frac{P_{e_2} - 8.4}{8} \Rightarrow P_{e_2} = 18 cm$

Intensity $= \frac{P}{t} = \frac{18}{8} = 2.25 cm/hr$

14. Ans: (c)

Sol: P = 7 + 18 + 25 + 17 +11 +3

P = 81cm

$W_{index} = \frac{P - R - losses}{t}$

$= \frac{81-39}{6} = 7mm/hr$

$\phi_{index} > W_{index}$

$\therefore$ 8 mm/h > 7mm/h

ϕ_{index} = 8 mm/h

15. Ans: (b)

Sol: W_{index} :

$$P = \sum i_i \times t_i$$

$$P = [1.6 + 3.6 + 5 + 2.8 + 2.2 + 1] \times \frac{30}{60} = 8.1\,cm$$

$t = 3hr$; $R = 3.6cm$

$$W_{index} = \frac{P - R - losses}{t} = \frac{8.1 - 3.6 - 0}{3}$$

$= 1.5$ cm/hr

ϕ_{Index}:

$\phi_{index} > W_{index}$

$$P_e = [1.6 + 3.6 + 5 + 2.8 + 2.2] \times \frac{30}{60}$$

$= 7.6\,cm$

$t_e = 2.5$ hr; $R = 3.6$ cm

$$\phi_{index} = \frac{P_e - R}{t_e} = \frac{7.6 - 3.6}{2.5} = 1.6\,cm/hr$$

16. Ans: (a)

Sol: W_{index} :

$P = 1.6 + 5.4 + 4.1 = 11.1$ cm

$R = 4.7cm$, $t = 24hr$, losses $= 0.6$ cm

$$W_{index} = \frac{P - R - losses}{t} = \frac{11.1 - 4.7 - 0.6}{24}$$

$= 0.241$ cm/h

ϕ_{index}:

$\phi_{index} > W_{index}$

$$P_e = [5.4 + 4.1] = 9.5\,cm$$

$t_e = 16$ hr

$$\phi_{index} = \frac{P_e - R}{t_e} = \frac{9.5 - 4.7}{16} = 0.3\,cm/hr$$

17. Ans: (c)

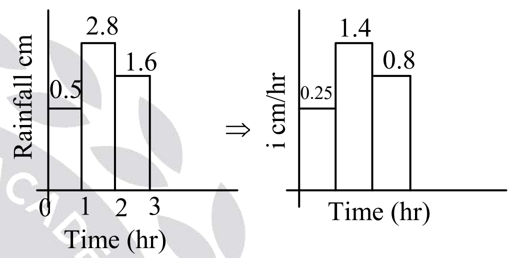
Sol: W_{index} :

$P = \sum i_i t_i = 0.5 + 2.8 + 1.6 = 4.9$ cm

$R = 3.2$ cm

$$W_{index} = \frac{P - R - losses}{t} = \frac{4.9 - 3.2 - 0}{6}$$

$= 0.283$ cm/hr



ϕ_{index} :

$P_e = 1.4 \times 2 + 0.8 \times 2 = 4.4$ cm

$t_e = 4$ hr, $R = 3.2$ cm

$$\phi_{index} = \frac{P_e - R}{t_e} = \frac{4.4 - 3.2}{4} = 0.3 \text{ cm/hr}$$

18. Ans: (c)

Sol: $\phi_{index} = 10$ mm/hr

$P_e = i_e \times t_e$ $\quad$ ($i_e \rightarrow i > \phi_{index}$)

$= 28 \times 1 + 12 \times 1 = 40$ mm

$t_e = 2$ hr

$$\phi_{index} = \frac{P_e - R}{t_e} \Rightarrow 10 = \frac{40 - R}{2} = 20 \text{ mm}$$

19. Ans: (c)

Refer previous GATE - solutions Book (Cha-4, (2M) 3rd Question -pg: 681)

20. Ans: (d)

Refer previous ESE-Obj-(Vol-2) solutions Book (Cha-3, 11th Question -pg: 313)

Conventional Practice Solutions

01.

Sol:

Time (t)	Cumulated rainfall 'P'	$i = \frac{P_{n+1} - P_n}{t_{n+1} - t_n}$ (mm/hr)	$f_{ct} = f_c + (f_{co} - f_c)\, e^{-kt}$ $f_{ct} = 1.5 + 5e^{-0.15t}$
0	0		$f_{co} = 1.5 + 5e^{-0.15(0)} = 6.5$
		$i_1 = 10$	
1	10		$f_{c1} = 5.8$
		$i_2 = 12$	
2	22		$f_{c2} = 5.2$
		$i_3 = 8$	
3	30		$f_{c3} = 4.69$
		$i_4 = 9$	
4	39		$f_{c4} = 4.24$
		$i_5 = 6.5$	
5	45.5		$f_{c5} = 3.86$
		$i_6 = 4.5$	
6	50		$f_{c6} = 3.53$
		$i_7 = 5.5$	
7	55.5		$f_{c7} = 3.25$
		$i_8 = 4.5$	
8	60		$f_{c8} = 3$
		$i_9 = 4$	
9	64		$f_{c9} = 2.79$
		$i_{10} = 4$	
10	68		$f_{c10} = 2.61$

Rainfall = $\Sigma i_n t_n = 68\text{mm}$

Infiltration = $\int_0^{10} \left(1.5 + 5e^{-0.15t}\right) dt$

$$= 1.5[t]_0^{10} + \frac{5}{-0.15}\left(e^{-0.15t}\right)_0^{10}$$

$$= 1.5 \times 10 - \frac{5}{0.15}\left(e^{-0.15\times10} - e^{-0.15\times0}\right)$$

= 40.89 mm

Runoff = Rainfall – infiltration

= 68 – 40.89 = 27.11 mm

Volume of runoff = A × R

$$\Rightarrow 850 \times 10^6 \times \frac{27.11}{1000} \text{m}^3$$

$= 23.043 \times 10^6 \text{ m}^3$

02.

Sol: $f_c = 0.5 + 1.2\,e^{-0.5t}$

$$f_c = \int_0^4 (0.5 + 1.2e^{-0.5t})dt$$

$$f_c = 0.5 \times 4 - \frac{1.2}{0.5}(e^{-0.5\times4} - e^{-0})$$

$= 4.075$ cm

Avg rate of infiltration (in 4 hours) $= \dfrac{4.075}{4}$ = 1.018 cm/hr

03.

Sol: ϕ-index = 3 mm/hr

Initial loss = 0.8 mm

$i_1 = 6$ mm/hr, $i_2 = 6$ mm/hr

$i_3 = 18$ mm/hr, $i_4 = 13$ mm/hr

$i_5 = 2$ mm/hr, $i_6 = 2$ mm/hr

$i_7 = 12$ mm/hr

Time interval = 20 min $\Rightarrow \dfrac{1}{3}$ hr

Rain fall (P) = $\Sigma\, i \times t$

$$P = \left(\frac{6}{3}+\frac{6}{3}+\frac{18}{3}+\frac{13}{3}+\frac{2}{3}+\frac{2}{3}+\frac{12}{3}\right)$$

P = 19.67 mm

$$\text{w-index} = \frac{P - R - \text{losses}}{t}$$

$$\phi\text{-index} = \frac{P_e - R}{t_e}$$

Run off = $\Sigma(i_n - \phi)\, t_n \rightarrow$ neglecting $i_n < \phi$-index

$$= (6-3)\times\frac{1}{3} + (6-3)\times\frac{1}{3} + (18-3)\times\frac{1}{3} + (13-3)\times\frac{1}{3}(12-3)\times\frac{1}{3}$$

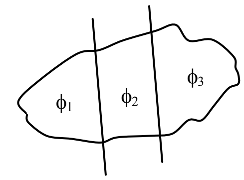
= 13.33 mm

$$\text{w-index} = \frac{19.67 - 13.33 - 0.8}{\frac{140}{60}}$$

= 2.37 mm/hr

04.

Sol:



Portion 1:

$\phi_1 = 0$

A_1 = 40% of 750

$= \dfrac{40}{100} \times 750 = 300\ \text{km}^2$

Run off = Rainfall = $\Sigma i_n\, t_n$

= (6 + 9 + 20 + 16 + 4 + 14 + 12 + 2)1

= 83 mm

Portion 2:

ϕ = 15 mm/hr

Run off = $\Sigma(i_n - \phi)\, t_n \rightarrow$neglect $i_n \le \phi$

= (20 – 15)1 + (16 – 15)1 = 6 mm

$A_2 \rightarrow \dfrac{30}{100} \times 750 = 225\ \text{km}^2$

Portion 3:

ϕ = 7.5 mm/hr,

$A_3 \rightarrow \dfrac{30}{100} \times 750 = 225\ \text{km}^2$

Runoff = $\Sigma\,(i_n - \phi)\, t_n \rightarrow$ neglect $i_n \le \phi$

= (9 – 7.5)1 + (20 – 7.5)1 + (16 – 7.5)1 + (14 – 7.5)1

+ (12 – 7.5)

= 33.5 mm

Volume of Runoff =?

Run off depth =?

$$\overline{R} = \frac{R_1A_1 + R_2A_2 + R_3A_3}{A_1 + A_2 + A_3}$$

$$= \frac{83 \times 300 + 6 \times 225 + 33.5 \times 225}{300 + 225 + 225}$$

R = 45.05 mm

Volume of runoff = Area × depth of run off

$$= 750 \times 10^6 \times \frac{45.05}{1000} = 33.78 \text{ Mm}^3$$

05.

Sol:

(i) In the first 0.5 hour,

$$F_{p1} = \int_0^{0.5} (3.0 + e^{-2t})dt = \left[3.0t - \frac{1}{2}e^{-2t}\right]_0^{0.5}$$

$=[(3.0\times0.5)–(1/2)(e^{-(2\times0.5)}]–[–(1/2)]$

= (1.5 – 0.184) + 0.5

= 1.816 cm

(ii) In the second 0.5 hour,

$$F_{p2} = \int_{0.50}^{1.0} (3.0 + e^{-2t})dt = \left[3.0t - \frac{1}{2}e^{-2t}\right]_{0.5}^{1.0}$$

$=[(3.0\times1.0)–(1/2)(e^{-2}] –$

$[(3.0 \times0.5)–(1/2) (e^{-(2 \times0.5})]$

= (3.0 –0.0677) – (1.5 – 0.184) = 1.616 cm

06.

Sol: $$R_1 = \frac{(0.2\times 0) + (0.3 \times 0) + (0.5 \times 0.5)}{(0.2 + 0.3 + 0.5)}$$

= 0.25 cm

$$R_2 = \frac{(0.2\times 1.3) + (0.3 \times 1.35) + (0.5 \times 2)}{(0.2 + 0.3 + 0.5)}$$

= 1.665 cm

$$R_3 = \frac{(0.2\times 0.5) + (0.3 \times 0.25) + (0.5 \times 0.3)}{(0.2 + 0.3 + 0.5)}$$

= 0.325 cm

Runoff R = $R_1 + R_2 + R_3$ = 0.25 + 1.665 + 0.325

= 2.24 cm

06. Runoff

Conventional Practice Solutions

01.

Sol: Mean precipitation

$$\overline{P} = \frac{\sum A_i\left(\frac{P_i + P_{i+1}}{2}\right)}{A} \rightarrow \text{Isohyetal method}$$

$$\overline{P} = \frac{50\left(\frac{140+135}{2}\right)+300\left(\frac{135+130}{2}\right)+450\left(\frac{130+125}{2}\right)+700\left(\frac{125+120}{2}\right)+600\left(\frac{120+115}{2}\right)+400\left(\frac{115+110}{2}\right)+200\left(\frac{110+105}{2}\right)}{50+300+450+700+600+400+200}$$

$\overline{P} = 121.018$ cm

Run off coefficient =?

Total run off volume

= 65 × 365 × 24 × 60 × 60

$$\text{Depth of runoff} = \frac{\text{Volume of runoff}}{\text{Catchment area}}$$

$$= \frac{65 \times 365 \times 24 \times 60 \times 60}{2700 \times 10^6}$$

= 75.92 cm

Run off coefficient (or) runoff factor (I (or) k) $= \frac{\text{Runoff}}{\text{Rainfall}} = \frac{75.92}{121.02} = 0.627$

07. Hydrographs

01. Ans: (d)

Sol: Volume of runoff = Area of DRH

$$= \frac{1}{2} \times 80 \times 200 \times 60 \times 60$$

$$= 28.8 \times 10^6 \text{ m}^3$$

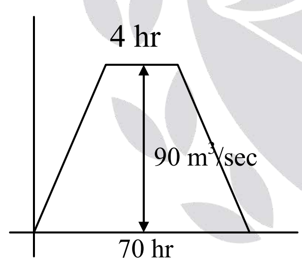
$$\text{Runoff depth} = \frac{\text{Volume of runoff}}{\text{Area of catchment}}$$

$$= \frac{28.8 \times 10^6}{1440 \times 10^6} \times 100$$

$$= 2 \text{ cm}$$

02. Ans: (b)

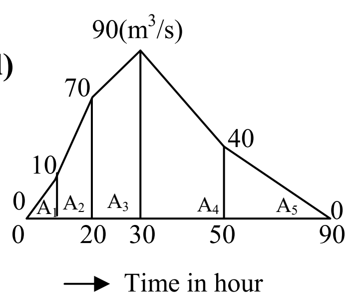
Sol: $\text{Area of catchment} = \frac{\text{Volume of Runoff}}{\text{depth of Runoff}}$



$$\frac{\left[\frac{70+4}{2}\right] \times 60 \times 60 \times 90}{\frac{2}{100} \times (1000)^2} = 599.4 \text{ km}^2$$

03. Ans: (d)

Sol:



$$A_1 = \frac{1}{2} \times 10 \times 10 \times 60 \times 60 = 50 \times 60 \times 60$$

$$A_2 = \left[\frac{10+70}{2}\right] \times 10 \times 60 \times 60 = 400 \times 60 \times 60$$

$$A_3 = \left[\frac{70+90}{2}\right] \times 10 \times 60 \times 60 = 800 \times 60 \times 60$$

$$A_4 = \left[\frac{90+40}{2}\right] \times 20 \times 60 \times 60 = 1300 \times 60 \times 60$$

$$A_5 = \left[\frac{1}{2} \times 40 \times 40 \times 60 \times 60\right] = 800 \times 60 \times 60$$

$A = A_1 + A_2 + A_3 + A_4 + A_5 = 3350 \times 60 \times 60$

Rainfall excess = Runoff

$$= \frac{3350 \times 60 \times 60}{300 \times (1000)^2} \times 100 = 4.02 \text{ cm}$$

04. Ans: 2.67cm

Sol: Area of catchment = 50 km^2

Time	4hr FHG ordinate (m^3/sec)	Base flow (m^3/sec)	4hr DRH ordinate (m^3/sec)
0	6	6	0
6	18	6	12
12	30	6	24
18	24	6	18
24	12	6	6
30	8	6	2
36	6	6	0

Rainfall excess = Runoff depth

Depth of runoff = $\dfrac{\text{volume of run off}}{\text{area of catchment}}$

Volume of runoff = Area of DRH

$$= 6\times60\times60\left[\frac{0+0}{2}+(12+24+18+6+2)\right]$$

$$= 1339200\ \text{m}^3$$

Depth of runoff $= \dfrac{1339200}{50\times(1000)^2}\times100 = 2.67$ cm

05. Ans: (c)

Sol: Volume of runoff = Area of DRH

$$= \frac{1}{2}\times48\times300\times60\times60$$

$$= 25.92\times10^6\ \text{m}^3$$

Runoff depth = $\dfrac{\text{Volume of runoff}}{\text{Area of catchment}}$

Area of catchment = $\dfrac{25.92\times10^6}{\frac{1}{100}}$

$$= 2592\ \text{km}^2$$

06. Ans: (c)

Sol: Volume of runoff = Area of catchment

$$= \frac{1}{2}\times Q\times20$$

$$= 10\times Q$$

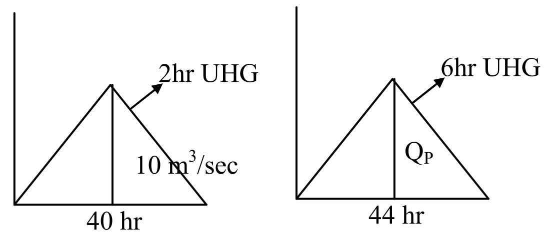
Runoff depth = $\dfrac{\text{Volume of runoff}}{\text{Area of catchment}}$

$$\frac{1}{100} = \frac{10\times Q}{500\times10^4}$$

$$Q = 5000\ \text{m}^3/\text{h}$$

07. Ans: 9.09 m³/sec

Sol:



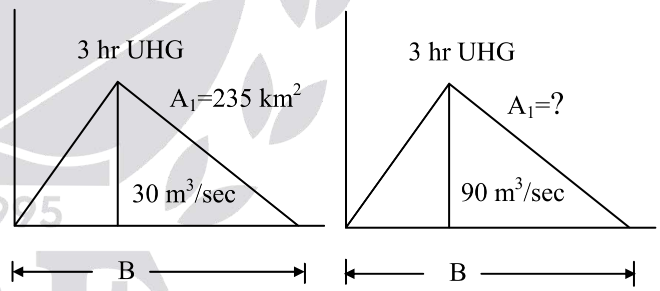
$$\frac{\frac{1}{2}\times10\times40\times60\times60}{\frac{1}{100}} = \frac{\frac{1}{2}\times Q_P\times44\times60\times60}{\frac{1}{100}}$$

$$10\times40 = 44\,Q_p$$

$$Q_P = \frac{10\times40}{44} = 9.09\ \text{m}^3/\text{sec}$$

08. Ans: (d)

Sol:



Same base but peak has increased to 90 m³/sec

i.e., 3 times increase

∴ Area also increase to 3 times

$A_2 = 3A_1 = 3\times235 = 705\ \text{km}^2$

09. Ans: (i) 39 m^3/sec; (ii) 46 m^3/sec

Sol:

Time	2hr UHG ordinate
0	0
1	5
2	15
3	12
4	10
5	6
6	0

Base flow = 7 m^3/sec

$P_e = 4.2$ cm; $t_e = 2$hr

$\phi_{index} = 0.8$ cm/hr

$$\phi_{index} = \frac{P_e - R}{t_e} \Rightarrow 0.8 = \frac{4.2 - R}{2}$$

R = 2.6 cm

Max. discharge of 2hr UHG = 15 m^3/sec

(i) Max. discharge of 2hr DRH = UHG×R

= 15×2.6 = 39 m^3/sec

(ii) Max. flood discharge = Max. DRH + Base flow

= 39+7

= 46 m^3/sec

10. Ans: a) 7.6 cm b) 40 m^3/sec

Sol: Peak flood resulting for 6hr storm

= 150 m^3/sec

Base flow = 6 m^3/sec

Peak flood of 6hr DRH = 150−6

= 144 m^3/sec

Peak ordinate of 6hr UHG = 36m^3/sec

Peak ordinate of 6hr DRH

= Peak ordinate of 6 hr UHG × R

a) 144 = 36 ×R

$$R = \frac{144}{36} = 4\,cm; \phi = 6\,mm/hr$$

$$\phi = \frac{P_e - R}{t_e} \Rightarrow 6 = \frac{P_e - 40}{6} \Rightarrow P_e = 76\,mm$$

P_e =7.6cm = depth of storm rainfall

b) 15th hr

Time interval	6hr UHG
0	0
3	15
6	36
9	30
12	17.5
15	8.5

6hr UHG ordinate at 15th hr = 8.5 m^3/sec

6hr DRH ordinate at 15th hr

= 6 hr UHG ×R

= 8.5×4 = 34 m^3/sec

6hr storm flow at 15th hr = 34 + 6 = 40 m^3/sec

11. Ans: (b)

Sol: P_e = 2.7 cm, t_e = 3hr, ϕ = 0.3 cm/hr

$$\phi = \frac{P_e - R}{t_e} \Rightarrow 0.3 = \frac{2.7 - R}{3} \Rightarrow R = 1.8\,cm$$

Peak of 3hr FHG = 210 m^3/sec

Base flow = 20 m^3/sec

Peak of 3hr DRH = Peak of 3hr FHG

Base flow = 210 – 20

= 190 m^3/sec

Peak of 3hr

$$\text{UHG} = \frac{\text{Peak of 3hr DRH}}{R} = \frac{190}{1.8}$$

$$= 105.55\, m^3/\text{sec}$$

12. Ans: 70 m^3/sec

Sol: Peak of 6hr FHG = 470 m^3/sec

P_e = 8 cm

ϕ = 0.25 cm/hr; t_e = 6hr

Base flow = 15 m^3/sec

$$\phi = \frac{P_e - R}{t_e} \Rightarrow \frac{8-R}{6} = 0.25 \Rightarrow R = 6.5\,\text{cm}$$

Peak of DRH = peak of FHG–Base flow

= 470–15 = 455 m^3/sec

$$\text{Peak of UHG} = \text{Peak of } \frac{\text{DRH}}{R}$$

$$= \frac{455}{6.5} = 70\, m^3/\text{sec}$$

Linked answers (13 & 14)

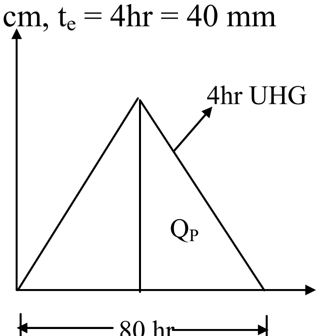
13. Ans: (b)

Sol: Area of catchment = 720 km^2

Base flow = 30m^3/sec

ϕ_{index} = 1mm/hr

P_e = 4 cm, t_e = 4hr = 40 mm



∵ UHG runoff depth = 1 cm

Volume of runoff = Area of catchment × Depth of runoff

$$\frac{1}{2} \times Q_P \times 80 \times 60 \times 60 = 720 \times (1000)^2 \times \frac{1}{100}$$

Q_P = 50 m^3/sec

14. Ans: (a)

Sol: $$\phi_{index} = \frac{P_e - R}{t_e} \Rightarrow 1 = \frac{40 - R}{4}$$

$R = 36\,\text{mm} = 3.6$ cm

Peak ordinate of 4hr DRH = Peak ordinate of 4hr UHG × R

= 50×3.6 = 180 m^3/sec

Peak flood discharge = Peak DRH+ Base flow

= 180+30 = 210 m^3/sec

Common data for Q 15 & 16

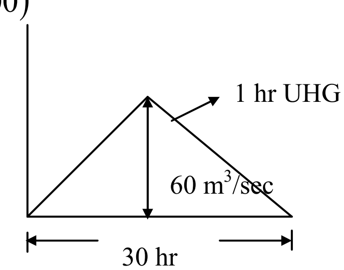
15. Ans: (c)

Sol: ϕ_{index} = 0.4 cm/hr

Base flow = 15 m^3/sec

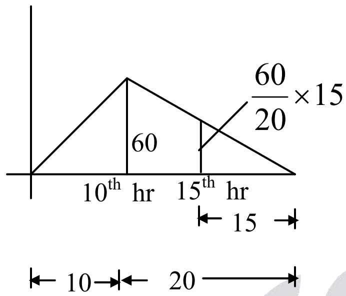
$$\text{Area of catchment} = \frac{\text{Volume of Runoff}}{\text{depth of Runoff}}$$

$$= \frac{\frac{1}{2} \times 60 \times 30 \times 60 \times 60}{\frac{1}{100} \times (1000)^2} = 324\,\text{km}^2$$



16. Ans: (b)

Sol: $\phi_{index} = 0.4$ cm/hr



At 15^{th} hr time interval ordinate of 1 hr

$$\text{UHG} = \frac{60}{20}\times 15 = 45\,m^3/sec$$

$$\phi = \frac{P_e - R}{t_e} \Rightarrow 0.4 = \frac{5.4 - R}{1}$$

Ordinate of 1hr DRH

= ordinate of UHG×R

= 45 × 5 = 225 m^3/sec

FHG ordinate at 15^{th} hr

= DRH + Base flow

= 225+15=240 m^3/sec

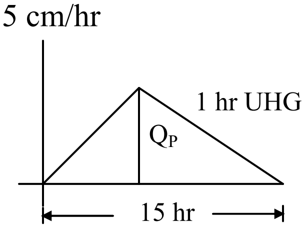
Common data for Q 17 & 18

17. Ans: (b)

Sol: Area watershed = 50 km^2

Base flow = 10 m^3/sec

ϕ Index = 0.5 cm/hr



Volume of Runoff = Area of water shed × Runoff depth

$$\frac{1}{2}\times Q_p \times 15\times 60\times 60 = 50\times(1000)^2\times\frac{1}{100}$$

Q_p = 18.52 m^3/sec

18. Ans: (d)

Sol: P_e = 5.5 cm t_e = 1 hr ϕ_{index} = 0.5 cm/hr

Peak ordinate of 1hr UHG = 18.52 m^3/sec

Peak ordinate of 1hr DRH

= Peak ordinate 1hr UHG × R

= 18.52×5 = 92.60 m^3/sec

Peak ordinate of 1hr SHG

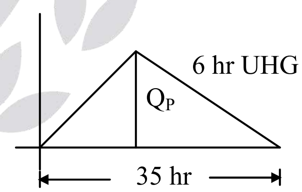
= DRH+ Base flow

= 92.60 + 10

= 102.6 m^3/sec

19. Ans: (c)

Sol: Area of catchment = 252 km^2



$$\frac{1}{2}\times Q_P \times 35\times 60\times 60 = \text{Area}\times\text{depth of Runoff}$$

$$= 252\times(1000)^2\times\frac{1}{100}$$

Q_p = 40 m^3/sec

Peak ordinate of 6hr UHG = 40 m^3/sec

Peak ordinate of 6 hr DRH = Peak ordinate of 6 hr UHG×R

= 40×5 = 200 m^3/sec = 200 cumec

20. Ans: 55 m^3/s

Sol:

Time	**2 hr UH**	**2 hr UH**	**DRH**	**Ord of 4-hr UH**
0	0	-	0	0
1	20	-	20	10
2	60	0	60	30
3	80	20	100	50
4	50	60	110	55
5	20	80	100	50
6	0	50	50	25
		20	20	10
		0	0	0

Common data for Q 21 & 22

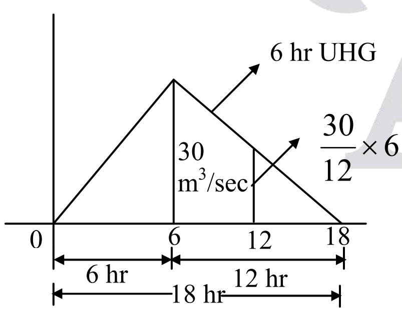
21. Ans: (b)

Sol: $P_e = 16$ cm, $t_e = 12$ hr

$\phi_{index} = 0.5$ cm/hr

$$\phi_{index} = \frac{P_e - R}{t_e} \Rightarrow 0.5 = \frac{16 - R}{12}$$

R = 10 cm



Time	**6hr UHG ordinate**	**6hr lagged 6hr UHG**	**12hr DRH R=2 cm**	**12 hr UHG ordinate**
0	0	–	0	0
6	30	0	30	15
12	15	30	45	22.5
18	0	15	15	7.5
		0	0	0

Peak discharge of 12hr UHG = 22.5 m^3/sec

Peak discharge 12hr DRH

= Peak discharge of 12 hr UHG× R

= 22.5×10 = 225 m^3/sec

22. Ans: (c)

Sol: Area of catchment

$$= \frac{\text{Volume of Runoff}}{\text{depth of runoff}}$$

$$= \frac{\frac{1}{2}\times 30\times 18\times 60\times 60}{\frac{1}{100}\times 10^4} = 9720 \text{ ha}$$

Common data for Q 23 & 24

23. Ans: (d)

Sol: Catchment area $= \dfrac{\text{Volume of Runoff}}{\text{depth of Runoff}}$

$$= \frac{1\times 60\times 60\left[\frac{0+0}{2} + (2+6+4+2+1)\right]}{\frac{1}{100}\times (1000)^2}$$

$= 5.4 \text{ km}^2$

24. Ans: (c)

Sol:

Time (hr)	1hr UHG ordinate (m^3/sec)	1hr delayed 1 hr UHG ordinate (m^3/sec)	2hr delay 1hr UHG (m^3/sec)	3 hr DRH R = 3 cm (m^3/sec)
0	0	–	–	0
1	2	0	–	2
2	6	2	0	8
3	4	6	2	12
4	2	4	6	12
5	1	2	4	7
6	0	1	2	3
		0	1	1

At time interval (t) = 3 hr

3hr DRH ordinate = $12 m^3$/sec ; R = 3 cm

$$\text{3hr UHG ordinate} = \frac{\text{3hr DRH ordinate}}{R}$$

$$= \frac{12}{3} = 4\,m^3/\text{sec}$$

25. Ans: (c)

Sol: $Q_{equi} = 2.778\dfrac{A}{D}$ A = 270 km^2

D = 3 hr

$$Q = 2.778 \times \frac{270}{3} = 250\,m^3/\text{sec}$$

26. Ans: 160 m^3/sec

Sol: t_p = 64 hours

Q_P = 30 m^3/sec

Volume of runoff = Area of DRH

$$= \frac{1}{2}\times 64\times 30\times 3600 = 3.456\times 10^6\ m^3$$

Runoff depth = 1 cm = 0.01 m

$$\text{Runoff depth} = \frac{\text{Volume of runoff}}{\text{Area of catchment}}$$

$$\text{Area of catchment} = \frac{3.456\times 10^6}{0.01}$$

$$= 345.6\ km^2$$

$$\text{Equilibrium discharge} = 2.778\frac{A}{D}$$

$$Q_{eq} = 2.778\times\frac{345.6}{6} \qquad Q_{eq} = 160\ m^3/\text{sec}$$

27. Ans: 256 m^3/sec

Sol:

Time	4H UHG ordinate	S-curve addition	S-curve ordinate (S_A)
0	0		0
2	6		6
4	33	0	33
6	90	6	96
8	119	33	152
10	103	96	199
12	79	152	231
14	50	199	249
16	25	231	256
18	7	249	256
20	0		

Common data for 29 & 30

29. Ans: (c)

Sol: Area of catchment

$$= \frac{\text{Volume of Runoff}}{\text{depth of Runoff}} = \frac{\text{Area of UHG}}{\text{depth of Runoff}}$$

$$= \frac{1\times 60\times 60\left[\dfrac{0+0}{2} + (3+8+6+3+2)\right]}{\dfrac{1}{100}\times(1000)^2}$$

= 7.92 km^2

30. Ans: (a)

Sol:

Time (hr)	2hr UHG Ordinate (m^3/sec)	S-curve Additions (m^3/sec)	S-curve Ordinates (m^3/sec)	3hr lagged S-curve ordinate (m^3/sec)	3hr DRH $S_A – S_B$ (m^3/sec)	3hr UHG $\frac{(S_A - S_B)^2}{3}$ (m^3/sec)
0	0	→	0	–	0	0
1	3	→	3	–	3	2
2	8	→	8	–	8	16/3
3	6	3	9	0	9	6
4	3	8	11	3	8	16/3
5	2	9	11	8	3	2
6	0	11	11	9	2	4/3
		11	11	11	0	0

P_e = 6.6 cm = 66 mm

ϕ_{index} = 2 mm/hr

t_e = 3 hr $\qquad \phi_{index} = \frac{P_e - R}{t_e}$

base flow = 5 m^3/sec $\qquad 2 = \frac{66 - R}{3}$

$\Rightarrow$ R = 60 mm = 6 cm

Peak ordinate of 3hr UHG = 6 m^3/sec

Peak ordinate of 3hr DRH = Peak ordinate 3hr UHG×R

= 6×6

= 36 m^3/sec

Peak ordinate of 3hr SHG = Peak of 3hr DRH + Base flow

= 36+5

= 41m^3/sec

Common Data for 31 & 32

31. Ans: (b)

Sol:

$$Q = 1 - (1 + t)e^{-t}$$

$$\frac{1}{D} = 1\,cm/hr \Rightarrow D = 1hr$$

At $t = \infty$, $Q = E_{quilibrium}$

$Q_{equi} = 1-(1+\infty)e^{-\infty} = 1\ m^3/sec$

But $Q_{equi} = 2.778\frac{A}{D}$

$$1 = 2.778\frac{A}{1}$$

$$\Rightarrow A = \frac{1}{2.778} = 0.36\,km^2$$

32. Ans: (c)

Time	S_A S-curve ordinates $Q = 1-(1+t)e^{-t}$	S_B 2 hr delayed S-curve ordinate	2hr DRH (S_A-S_B)
0	0	–	
1	0.264	–	
2	0.593	0	
3	0.8	0.264	0.8–0.264 = 0.536

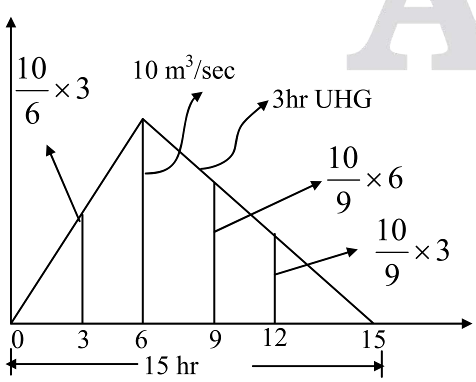
2hr UHG ordinate $= \frac{(S_A - S_B)D}{T} = \frac{0.536\times 1}{2}$

$= 0.27$ m^3/sec

33. Ans: 43.33m^3/sec

Sol:

Storm I	Strom II
$P_{e1} = 3.8$ cm	$P_{e2} = 4.8$ cm
$t_{e1} = 3$ hr	$t_{e2} = 3$ hr
$\phi = 0.6$	$\phi = 0.6$
$0.6 = \frac{3.8 - R_1}{3}$	$0.6 = \frac{4.8 - R_2}{3}$
$R_1 = 2$ cm	$R_2 = 3$ cm



Time	3hr UHG m^3/sec	Ist storm =UHG×R_1 m^3/sec	IIndstorm =UHG×R_2 m^3/sec	6hr H Ordinate m^3/sec
0	0	0	–	0
3	5	10	0	10
6	10	20	15	35
9	6.66	13.33	30	43.33
12	3.33	6.66	20	26.66
15	0	0	10	10
	–	–	0	0

Peak discharge of resulting DRH = 43.33 m^3/sec

34. Ans: 715 m^3/sec

Sol: Ist storm

$t_e = 6$hr

$P_e = 3$ cm

$\phi_{index} = 0.25$ cm/hr

$\phi = \frac{P_e - R_1}{t_e}$

$0.25 = \frac{3 - R_1}{6}$

$R_1 = 1.5$ cm

IInd storm

$t_e = 6$hr

$P_e = 5$ cm

$\phi_{index} = 0.25$ cm/hr

$\phi = \frac{P_e - R_2}{t_e}$

$0.25 = \frac{5 - R_2}{6}$

$R_2 = 3.5$ cm

Time	6hr UHG	I^{st} storm UHG×R_1	II^{nd} storm UHG×R_2	12 hr DRH
0	0	0	-	0
6	20	30	0	30
12	60	90	70	160
18	150	225	210	435
24	120	180	525	705
30	90	135	420	
36	66	99	315	
42	50	75	231	
48	32	48	175	
54	20	30	112	
60	10	15	70	
66	0	0	35	
			0	

<u>24^{th} hr</u>

DRH ordinate = 705 m^3/sec

Base flow = 10 m^3/sec

Storm discharge = DRH + Base flow

= 705+10

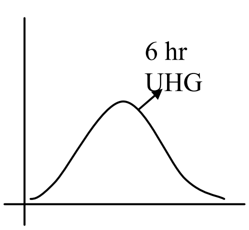
= 715 m^3/sec

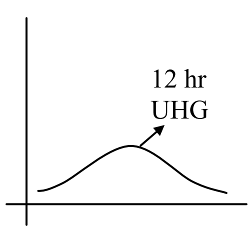
35. Ans: (d)

Sol: 6 hr UHG peak ordinate = 30 m^3/sec

Peak ordinate of 12hr UHG =?

Explanation:





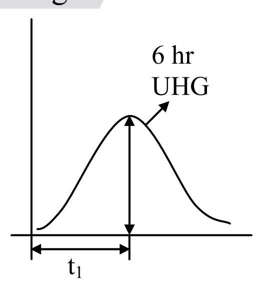
Storms of shorter duration produce more peak than storms of longer duration storm.

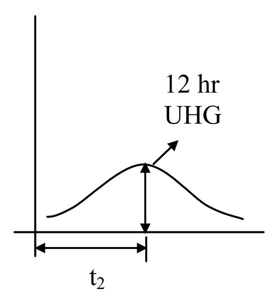
Peak of 12hr UHG<peak of 6hr UHG

∴ Peak ordinate of 12hr UHG < 30 m^3/s

36. Ans: (c)

Sol: Time to peak for shorter duration storms occur much faster then time to peak for longer duration storm.





$t_1 < t_2$

37. Ans: (d)
Refer previous GATE - solutions Book (Cha-4, (1M) 1st Question -pg: 679)

38. Ans: (c)
Refer previous GATE - solutions Book (Cha-4, (1M) 4th Question -pg: 679)

39. Ans: (c)
Refer previous ESE-Obj-(Vol-2) solutions Book (Cha-4, 2nd Question -pg: 320)

40. Ans: (c)
Refer previous ESE-Obj-(Vol-2) solutions Book (Cha-4, 3rd Question -pg: 320)

41. Ans: (a)
Refer previous ESE-Obj-(Vol-2) solutions Book (Cha-4, 18th Question -pg: 323)

42. Ans: (d)
Refer previous ESE-Obj-(Vol-2) solutions Book (Cha-4, 20th Question -pg: 324)

43. Ans: (d)
Refer previous ESE-Obj-(Vol-2) solutions Book (Cha-4, 22nd Question -pg: 324)

Conventional Practice Solutions

01.

Sol:

Time (days)	1 day SHG ordinates (m^3/s)	Base flow (m^3/s)	DRH ordinates = SHG ord –Base flow (m^3/s)
0	20	20	0
1	63	22	41
2	151	25	126
3	133	28	105
4	90	28	62
5	63	26	37
6	44	23	21
7	29	21	8
8	20	20	0
9	20	20	0

Volume of runoff = Area under DRH

$$= \Delta t\left(\frac{I^{st}\,\text{ord.} + \text{last ord.}}{2} + \sum \text{remaining ord.}\right)$$

$$= 1\times 24\times 60\times 60\left(\frac{0+0}{2} + (41+126+105+62+37+21+8\right) = 34.56 \times 10^6\ m^3$$

Rainfall excess = Runoff

$$= \frac{\text{Volume of runoff}}{\text{Catchment area}}$$

$$= \frac{34.56\times 10^6}{600\times 10^6}\times 100 = 5.76\ \text{cm}$$

02.

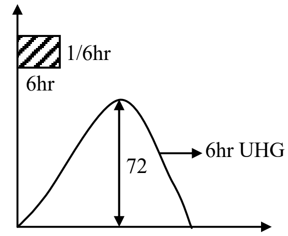
Sol:

Time	**6 hr Stream flow SHG ord (m^3/s)**	**DRH ord SHG – 10 (m^3/s)**	**Runoff**	**UHG ord** $= \frac{\text{DRH}}{\text{Runoff}}$
0	10	0	5	0
6	35	25	5	5
12	185	175	5	35
18	330	320	5	64
24	370	360	5	72
30	320	310	5	62
36	240	230	5	46
42	175	165	5	33
48	115	105	5	21
54	70	60	5	12
60	40	30	5	6
66	20	10	5	2
72	10	0	5	0

Assuming constant base flow = 10 m^3/sec

Effective rainfall = Runoff = 5cm

Area of catchment = Area under the curve of UHG



$$= \Delta t\left[\left(\frac{1^{st}\,ord. + 2^{nd}\,ord.}{2}\right) + (remaining\,ord.)\right]$$

$$= 60\times 60\left[\left(\frac{0+0}{2}\right) + (5+35+64+72+62+46+33+21+12+6+2)\right]$$

$$= 60 \times 60 \times 358 = 1.288 \times 10^6\ m^2 = 1.28\ km^2$$

03.

Sol: Catchment area = 20 km^2

Base flow = 15 m^3/s, R = 6 cm

Time (hr)	1 hr SHG ord	DRH ord = SHG – Base flow	1 hr UHG $= \frac{DRH}{R}$
0	15	0	0
1	25	10	1.66
2	50	35	5.833
3	55	40	6.66
4	48	33	5.5
5	35	20	3.3
6	30	15	2.5
7	27	12	2
8	24	9	1.5
9	20	5	0.83
10	15	0	0

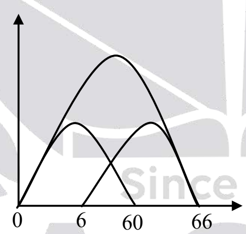
04. Ans:

Sol: T = 12 hr, D = 6 hr

T > D, $h = \frac{T}{D} = \frac{12}{6} = 2cm$

Time	I 6 hr UHG ord (m^3/sec)	II 6 hrs delayed 6 hr UHG (m^3/sec)	12 hr DRH ord (I + II)	12 hr UHG ord $=\frac{DRH}{R}$
0	0	-	0	0
6	5	0	5	2.5
12	13	5	18	9
18	30	13	43	21.5
24	35	30	65	32.5
30	32	35	67	33.5
36	20	32	52	26
42	14	20	34	17
48	8	14	22	11
54	4	8	12	6
60	0	4	4	2
66	-	0	0	0

Super position is used



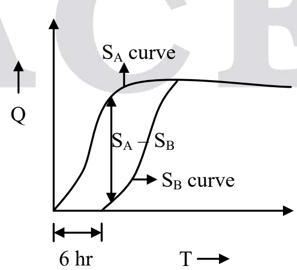
05.

Sol:

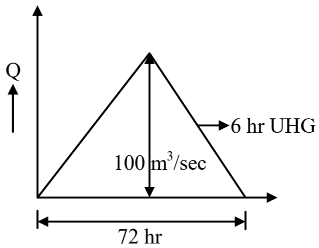
Time (hr)	12 hr UHG (m^3/s)	S-curve additions (m^3/s)	S-curve ordinates 'S_A'	6 hr delayed S-curve ord 'S_B'	6 hr DRH = $(S_A - S_B)$ (m^3/s)	6 hr UHG $= \frac{(S_A - S_B)D}{T}$
0	0		0	-	0	0
6	1		1	0	1	2
12	4	0	4	1	3	6
18	8	1	9	4	5	10
24	16	4	20	9	11	22
30	19	9	28	20	8	16
36	15	20	35	28	7	14
42	12	28	40	35	5	10
48	8	35	43	40	3	6
54	5	40	45	43	2	4
60	3	43	46	45	1	2
66	2	45	47	46	1	2
72	1	46	47	47	0	0
78	0	47	47	47	0	0

6 hr DRH ord → $(S_A - S_B)$,

6 hr UHG ord → $\frac{(S_A - S_B)D}{T}$



06.
Sol:
(i)



Catchment area =?

$$\text{Catchment area (km}^2\text{)} = \frac{\text{Volume of Runoff}}{\text{Depth of runoff}}$$

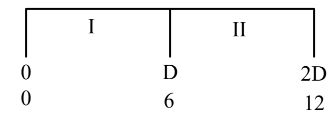
$$= \frac{\text{Area of 6hr UGH}}{1/100} \times \frac{1}{10^6}\,\text{km}^2$$

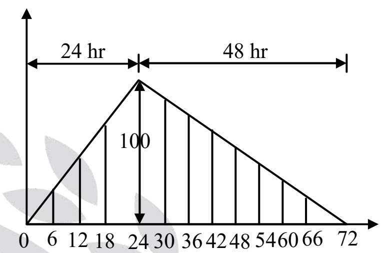
$$= \frac{\frac{1}{2}\times 100\times 72\times 60\times 60}{1/100} \times \frac{1}{10^6} = 1296\ \text{km}^2$$

(ii)

$R_1 \rightarrow 2$ cm

$R_2 \rightarrow 4$ cm





Time	**6hr UHG ord**	**I Storm 6 hr DRH ord 6 hr UGH × R_1**	**II 6hr delayed 6 hr DRH ord 6hr UHG × R_2**	**DRH ord I + II**	**B.F**	**FHG ord DRH + B.F**
0	0	0	-	0	25	25
6	25	50	0	50	25	75
12	50	100	100	200	25	225
18	75	150	200	350	25	375
24	100	200	300	500	25	525
30	87.5	175	400	575	25	600
36	75	150	350	500	25	525
42	62.5	125	300	425	25	450
48	50	100	250	350	25	375
54	37.5	75	200	275	25	300
60	25	50	150	200	25	225
66	12.5	25	100	125	25	150
72	0	0	50	50	25	75
			0	0	25	25

07.

Sol: Area of catchment = 400 km^2

Basin length, L = 35 km

Length up to the centroid of the basin,

L_{ca} = 10 km

Snyder's coefficients: C_t = 1.5 & C_p = 0.7

3hr synthetic unit hydrograph for this basin =?

(i) Basin lag $t_p = C_t (LL_c)^{0.3}$

$= 1.5 (35 \times 10)^{0.3}$

$= 8.69$ hrs

(ii) Peak discharge per unit area of the catchment, $Q_p = \frac{2.778 C_p A}{t_p}$

$= \frac{2.778 \times 400 \times 0.7}{8.69}$

$Q_p = 89.5\ m^3/s$

(iii) $t_b = 3 + \frac{t_p}{8}$

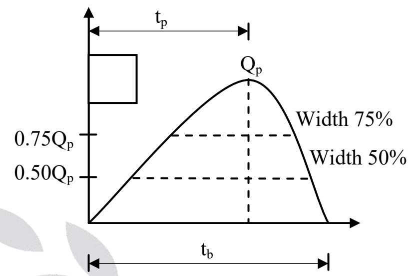
$= 3 + \frac{8.69}{8}$

= 4.086 days = 98.064 hrs

(iv) Width 50% = $5.87\left(\frac{Q}{A}\right)^{-1.08}$

$= 5.87\left(\frac{89.5}{400}\right)^{-1.08}$ = 29.57 hrs

(v) Width 75% $= \frac{W_{50\%}}{1.75} = \frac{29.57}{1.75}$ = 16.89 hrs



08. Maximum Flood Estimation

01. Ans: (d)

Sol: A = 90 ha

I = 4.5 cm/h = 45 mm/h

R = 0.40

Q = $\frac{AIR}{360} = \frac{90 \times 45 \times 0.40}{360}$

Q = 4.5 m^3/sec

02. Ans: (a)

Refer previous ESE-Obj-(Vol-2) solutions Book (Cha-5, 14th Question -pg: 342)

03. Ans: (b)

Sol: 30% $\rightarrow$ 0.40

70% $\rightarrow$ 0.60

I = $\frac{\frac{30}{100} \times A \times 0.40 + \frac{70}{100} \times 0.60 \times A}{A}$

I = 0.54

04. Ans: (d)

Sol: A = 1.5 km^2 = 150 Ha, I = 0.42

$$R = \frac{48}{28} \times 60 = 102.86 \text{ mm/h}$$

$$Q_P = \frac{AIR}{360}$$

$$= \frac{150 \times 0.42 \times (48/28) \times 60}{360}$$

=18 m^3/sec

05. Ans: (c)

Refer previous ESE-Obj-(Vol-2) solutions Book (Cha-5, 13th Question -pg: 342)

06. Ans: 7.08 m^3/s

Sol: I = 0.30

A = 0.85km^2= 85 ha

25 frequency → Culvert design for a rain of 25 year frequency

Duration of storm = time of concentration

= 30 mins

$$R = \frac{\text{depth of rainfall}}{\text{duration of rain}} = \frac{50}{30} \text{mm/min}$$

R = 100 mm/h

$$Q = \frac{AIR}{360} = \frac{85 \times 0.30 \times 100}{360}$$

Q = 7.083 m^3/sec.

07. Ans: (c)

Refer previous GATE - solutions Book (Cha-5, (2M) 1st Question -pg: 696)

08. Ans: (b)

Refer previous ESE-Obj-(Vol-2) solutions Book (Cha-5, 1st Question -pg: 340)

09. Ans: (a)

Refer previous ESE-Obj-(Vol-2) solutions Book (Cha-5, 3rd Question -pg: 340)

10. Ans: (c)

Refer previous GATE - solutions Book (Cha-4, (1M) 2nd Question -pg: 679)

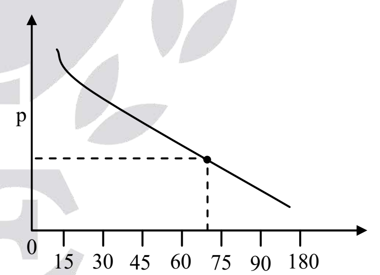
11. Ans: (c)

Refer previous ESE-Obj-(Vol-2) solutions Book (Cha-5, 5th Question -pg: 340)

Conventional Practice Solutions

01.

Sol:



t (mm)	P (mm)	$i = \frac{P}{t}$
15	40	2.66
30	60	2
45	75	1.66
60	100	1.66
180	120	0.66

$t_c = 0.01947\,(L)^{0.77}\,(S)^{-0.385}$

$= 0.01947\,(1250)^{0.77}\,(0.001)^{-0.385}$

$t_c = 67.45$ minutes

From intensity duration curves

R = 1.6 mm/min

$\Rightarrow 1.6 \times 60 = 96$ mm/hr

$$Q = \frac{AIR}{360}$$

$$\Rightarrow \frac{200 \times 0.2 \times 96}{360} = 10.67\ m^3/sec$$

02.

Sol:

Given the following runoff coefficients for different surfaces,

Paved area = 0.9

Parks = 0.5

Multi unit residential area = 0.7

Assuming runoff coefficients for light Industrial area = 0.6 (Range: 0.5 to 0.8)

$$Q = \frac{AIR}{360}$$

$$I = \frac{\left(\frac{52}{100} \times 3 \times 100\right)0.9 + \left(\frac{20}{100} \times 3 \times 100\right)0.5 + \left(\frac{18}{100} \times 3 \times 100\right)0.7 + \left(\frac{10}{100} \times 3 \times 100\right)0.6}{3 \times 100}$$

$= 0.754$

$$R \rightarrow \frac{P}{T} \Rightarrow \frac{85}{\frac{50}{60}} = 102\ mm/hr$$

$$Q = \frac{300 \times 0.754 \times 102}{360}$$

$= 64.09\ m^3/sec$

03.

Sol: $\overline{X} = 4200\ m^3/s$

$\sigma = 1705\ m^3/s$

$$k_T = \frac{y_T - \overline{y}_n}{\overline{S}_n}$$

$y_T = -\ell n\left(-\ell n - (1 - P)\right)$

$X_T = \overline{X} + k_T\ \sigma$

$9500 = 4200 + k_T\ 1705$

$k_T = 3.1085$

$$k_T = \frac{y_T - \overline{y}_n}{\overline{S}_n}$$

$(3.1085 \times 1.2825) + 0.5778 = y_T$

$y_T = 4.56445$

$P = 1 - e^{-e^{-y_T}}$

$P = 1 - e^{-e^{-4.56445}}$

$P = 0.0103$

$$T = \frac{1}{P} = 96.505\ \text{years}$$

04.

Sol: $x_{50} = 450\ m^3/sec$, T = 50 years

$x_{100} = 600\ m^3/sec$, T = 100 years

$x_{1000} = ?$

$x_{50} = \overline{x} + k_{50}\ \sigma$

$450 = \overline{x} + k_{50}\ \sigma$ _______ (1)

$x_{100} = \overline{x} + k_{100}\ \sigma$

$600 = \overline{x} + k_{100}\ \sigma$ ______ (2)

$x_{1000} = \overline{x} + k_{1000}\ \sigma$

k_{50} (T = 50 years)

$$P = \frac{1}{T} = \frac{1}{50} = 0.02$$

$$y_T = -\ell n(-\ell n(1-P))$$

$$y_{50} = -\ell n(-\ell n(1-0.02)) = 3.9019$$

$$k_{50} = \frac{y_{50} - 0.5778}{1.2825} = 2.5919$$

k_{100} (T = 100)

$$P = \frac{1}{100} = 0.01$$

$$y_{100} = -\ell n(-\ell n(1-0.01)) = 4.600$$

$$k_{100} = \frac{4.600 - 0.5778}{1.2825} = 3.1363$$

k_{1000} (T = 1000), $P = \frac{1}{1000} = 0.001$

$y_T = 6.907$

$k_{1000} = 4.935$

$450 = \bar{x} + 2.5919\,\sigma$ ______ (1)

$600 = \bar{x} + 3.1363\,\sigma$ ______ (2)

By solving (1) & (2)

$\bar{x} = -264.153$

$\sigma = 275.532$

$x_{1000} = \bar{x} + k_{1000}\,\sigma$

$x_{1000} = -264.153 + 4.935 \times 275.532$

$= 1095.66\ m^3/sec$

05.

Sol: n = 20 years

Risk (R) = 5% = 0.05

T =?, $R = 1 - q^n$

$0.05 = 1 - q^{20}$

$-0.05 + 1 = q^{20}$

$(-0.05 + 1)^{1/20} = q$

q = 0.997

$p = 1 - q = 2.56 \times 10^{-3}$

$$T = \frac{1}{P} = 390.41 \text{ years}$$

(b) $P = \frac{1}{T} \Rightarrow \frac{1}{390.41} = 2.56 \times 10^{-3}$

$q = 1 - p \Rightarrow 1 - 2.56 \times 10^{-3}$

$= 0.9974$

n = 50

$R = (1 - q^n) \Rightarrow 1 - (0.9974)^{50}$

R = 0.1220 = 12.2%

06.

Sol: N = 30 years sample size)

$S_n = 1.11238$

$y_n = 0.53622$

Safety = 95% (assurance)

Risk = 100 – % safety

= 100 – 95 = 5% = 0.05

$R = (1 - q^n)$

$0.05 = 1 - q^{50}$ (n = 50)

$q = (0.95)^{1/50} = 0.998$

$P = 1 - q = 1.025 \times 10^{-3}$

$$T = \frac{1}{P} \Rightarrow \frac{1}{1.025 \times 10^{-3}} = 975.2$$

$$k_T = \frac{y_T - \bar{y}_n}{\bar{S}_n} \Rightarrow \frac{6.882 - 0.53622}{1.11238}$$

$= 5.7048$

$y_T = -ln(-ln(1-P))$

$= 6.882$

$x_T = \bar{x} + k_T\sigma$

$x_T = 1200 + 5.7048\,(650)$

$\Rightarrow 4908.172\ m^3/sec$

09. Flood Routing

02. Ans: (a)

Refer previous GATE - solutions Book (Cha-6, (1M) 3rd Question -pg: 697)

03. Ans: 17.748 m^3/sec

Sol: $t_1 = 3$ hr, $t_2 = 4$ hr, $I_3 = 18\ m^3/s$,

$I_4 = 42\ m^3/s$, $C_o = 0.042$, $C_1 = 0.538$,

$Q_3 = 15\ m^3/s$, $Q_4 = ?$,

$C_2 = 1 - C_o - C_1 = 1 - 0.042 - 0.538 = 0.42$

$Q_4 = C_o I_4 + C_1 I_3 + C_2 Q_3$

$= 0.042 \times 42 + 0.538 \times 18 + 0.42 \times 15$

$= 17.748\ m^3/s$

04. Ans: 45.84 m^3/sec

Sol: $C_0 = 0.048$, $C_1 = 0.429$, $C_2 = 0.523$

$Q_1 = 0.048 \times 20 + 0.429 \times 10 + 0.523 \times 10$

$= 10.48\ m^3/s$

$Q_2 = 0.048 \times 40 + 0.429 \times 20 + 0.523 \times 10.48$

$= 15.98\ m^3/s$

$Q_3 = 0.048 \times 60 + 0.429 \times 40 + 0.523 \times 15.98$

$= 28.39\ m^3/s$

$Q_4 = 0.048 \times 50 + 0.429 \times 60 + 0.523 \times 28.39$

$= 42.98\ m^3/s$

$Q_5 = 0.048 \times 40 + 0.429 \times 50 + 0.523 \times 42.98$

$= 45.84\ m^3/s$

$Q_6 = 0.048 \times 30 + 0.429 \times 40 + 0.523 \times 45.84$

$= 42.57\ m^3/s$

Peak value = $45.84\ m^3/s$

05. Ans: (c)

Refer previous ESE-Obj-(Vol-2) solutions Book (Cha-6, 4th Question -pg: 346)

Conventional Practice Solutions

01.

Sol:

$x = 0.28$, $k = 1.6$ days

$= 1.6 \times 24 = 38.4$ hrs

$\Delta t = 6$ hrs

$$C_o = \frac{-kx + 0.5\Delta t}{k - kx + 0.5\Delta t}$$

$$C_1 = \frac{kx + 0.5\Delta t}{k - kx + 0.5\Delta t}$$

$$C_2 = 1 - C_o - C_1$$

$$C_o = \frac{-38.4 \times 0.28 + 0.5 \times 6}{38.4 - 38.4 \times 0.28 + 0.5 \times 6}$$

$= -0.253$

$$C_1 = \frac{38.4 \times 0.28 + 0.5 \times 6}{38.4 - 38.4 \times 0.28 + 0.5 \times 6}$$

$= 0.448$

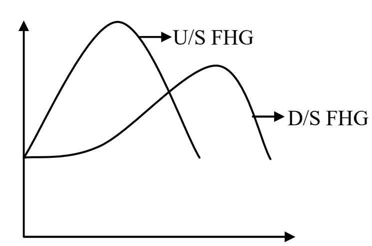
$C_2 = 1 - (-0.253) - 0.448$

$= 0.805$

$Q_n = C_o I_n + C_1 I_{n-1} + C_2 Q_{n-1}$

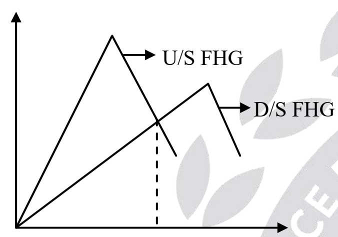
$Q_6 = -0.253 \times 55 + 0.448 \times 35 + 0.805 \times 35$

$= 29.94$



Time	I	Q
0	35	35
6	55	29.94
12	92	25.46
18	130	28.82
24	160	40.96
30	140	69.23

I – Q = DS

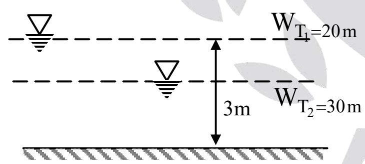


10. Well Hydraulics

01. Ans: (b)

Sol: A = 150Ha, n = 0.4, S_r = 0.15,

$\Delta GW = ?$



$$\Delta GW = s_y \times \text{volume of aquifer}$$

$S_y = n - S_r = 0.4 - 0.15 = 0.25$

volume of aquifer = area of aquifer × drop in level of W.T.

$\Delta GW = 0.25 \times 150 \times (23 - 20)$

$\Delta GW = 112.5$ Ha.m

= volume of water extracted.

02. Ans: (a)

Sol: Volume of GW extracted = $3\times10^6\ m^3$

area = $5km^2$

Drop in water table level =102 – 99 = 3m

Specific yield, S_y = ?

$$S_y = \frac{\text{volume of G.W extracted}}{\text{volume of aquifer}}$$

$$= \frac{3\times10^6}{5\times10^6\times3} = 0.2$$

03. Ans: (b)

Sol: n = 0.3, S_y = 0.2,

A = $100km^2$, $\Delta WT = 0.25m$

Volume of GW extracted =?

Volume of aquifer

$= 100\times10^6\times0.25 = 25\times10^6\ m^3$

Volume of GW extracted = S_y × Volume of aquifer = $0.2\times25\times10^6 = 5\times10^6 m^3 = 5Mm^3$

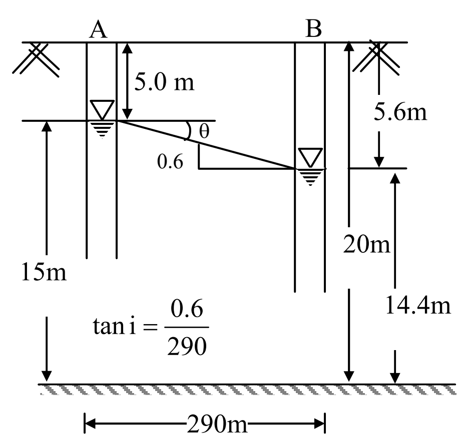
04. Ans: 0.105

Sol: Darcy's equation:

Q = KiA

V = Ki

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



(V = apparent or seepage velocity)

$K = 4 \times 10^{-3}$ cm/sec.

$Q(m^3/day/m)$ width of aquifer = ?

Q = KiA

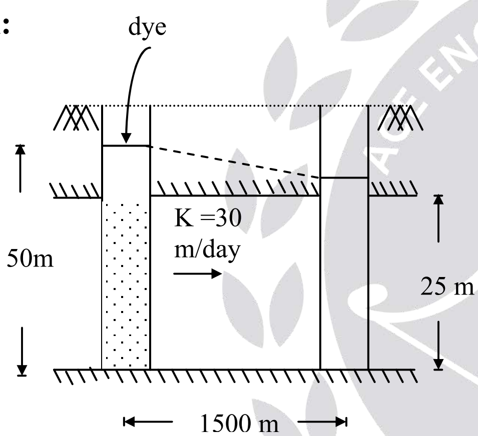
$$= \frac{4\times10^{-3}\times10^{-2}}{1}\times\left(\frac{5.6-5}{290}\right)\times1\times\left(\frac{14.4+15}{2}\right)_{\text{avg.ht}}$$

$Q = 1.216 \times 10^{-6}\ m^3/s$

$Q = 0.105\ m^3/day/m$

05. Ans: (b)

Sol:



1500 m =Distance between wells.

$h_1 = 50m,$ $h_2 = 25$ m

K = 30 m/day

n = 0.25

Time of travel =?

Tracer = Will not loose power & never reacts with soil or water & it flows with water.

$$\text{Time} = \frac{\text{Distance traveled by tracer}}{\text{seepage velocity}}$$

$$V_a = \frac{V}{n}, \qquad V = Ki,$$

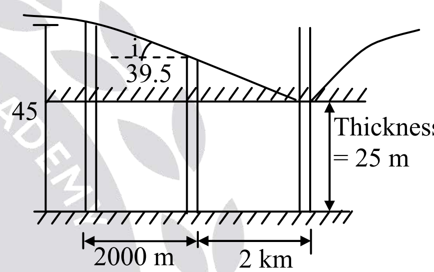
$$i = \frac{50-25}{1500} = 0.0167$$

K = 30×0.0167 = 0.5 m/day

$$V_a = \frac{0.5}{0.25} = 2\,m/day$$

$$\therefore \text{Time} = \frac{1500}{2} = 750\,\text{days}$$

06. Ans: (i) 4125m³/day, (ii) 44.175 m



Width is taken perpendicular to the plane of paper area is taken as perpendicular to the direction of flow.

K = 30 m/day

$$i = \frac{5.5}{2000} = 2.75\times10^{-3}$$

Q = K. i. A

$Q = 30 \times 2.75 \times 10^{-3} \times 2000 \times 25$

$Q = 4125\ m^3/day$

$$\frac{5.5}{2000} = \frac{x}{300}$$

x = 0.825 m

H = 45 – 0.825

H = 44.175 m

07. Ans: 270 m^2/day

Sol: H = 40m, D_{well} = 30cm = 0.3m

Q = 1500 lit/min

$= 1500 \times 10^{-3} \times 24 \times 60\, m^3/day$

= 2160 m^3/day

r_1 = 25m, r_2 = 75m,

h_1 = 3.5m, h_2 = 2m, T = ?

draw down = ?

h_1 = 40 – 3.5 = 36.5m

h_2 = 40 – 2 =38m

$$Q = \frac{\pi k\left[h_2^2 - h_1^2\right]}{\ell n\left(\frac{r_2}{r_1}\right)}$$

$$\therefore k = \frac{Q.\ell n\left(\frac{r_2}{r_1}\right)}{\pi\left(h_2^2 - h_1^2\right)}$$

$$k = \frac{2160 \times \ell n(75/25)}{\pi(38^2 - 36.5^2)} = 6.75\, m/day$$

∴ Transmissibility, T = K.H

T = 6.75×40 = 270 m^2/day

08. Ans: 12.2 m/day

Sol: H = 14.5m, r_1 = 16m,

r_2 = 34m,

s_1 = 2.2m,

$Q = 925\, lit/min = 925 \times 24 \times 60 \times 10^{-3}$

$= 1332\, m^3/day$

S_1 = 2.45

S_2 = 1.20m

K = ?

h_1 = 14.5 – 2.45

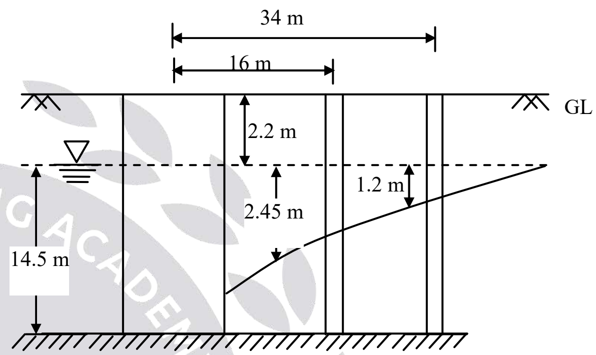
= 12.05m – 2.2 = 9.85m.

h_2 = 14.5 – 1.20

= 13.3m – 2.2 = 11.1m.

$$Q = \frac{\pi k\left[h_2^2 - h_1^2\right]}{\ln\left[r_2/r_1\right]}$$

$$K = \frac{\ln[34/16] \times 1332}{\pi \times \left[11.1^2 - 9.85^2\right]} = 12.2 \text{ m/day}$$



09. Ans :(b)

Sol: Radius of well,

$$r = \frac{20}{2} = 10\, cm = 0.10\, m$$

Discharge, Q = 2720 lit/ min

= 3916.8 m^3/day

At r_1 = 10 m, draw down, S_1 = 3 m

At r_2 = 100 m, draw down S_2 = 0.5 m

$$Q = \frac{2\pi Kb(S_1 - S_2)}{\log_e\left(\frac{r_2}{r_1}\right)}$$

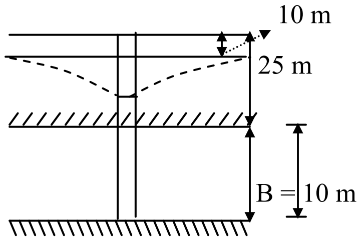
$$Q = \frac{2\pi T(S_1 - S_2)}{\log_e\left(\frac{r_2}{r_1}\right)}\ ;\ T = K.b$$

$$3916.8 = \frac{2\pi T(3 - 0.5)}{\log_e\left(\frac{100}{10}\right)}$$

Transmissivity, T = 574.4 m^2/day

10. Ans: 0.718 m

Sol:



$H = 10+25-10 = 25$ m

$r_1 = r_w$; $S_1 \to S$

$r_2 = R$; $S_2 \to 0$

$$\therefore\ Q = \frac{2\pi KB(S-0)}{\ell n\left(\frac{R}{r_w}\right)}$$

$$\therefore\ \ell n\left(\frac{500}{r_w}\right) = \frac{2\pi \times 48 \times 10 \times 12}{5000} = 7.238$$

$$\therefore\ r_w = 0.718 \text{ m}$$

11. Ans: (i) 10 lit/sec

Sol: $H_1 = 2.5$ m, $H_1 - H_2 = 1.8$ m, $t = 80$ min, $d = 4$ m

$$\therefore\ H_2 = 0.7 \text{ m}$$

(i) When, $H = 3$ m , $C = 2.65\times10^{-4}$ 1/sec

$$Q = C\,AH = \frac{1}{t}\ln\frac{H_1}{H_2}.A.H$$

$$= \frac{1}{80\times60}\ln\left(\frac{2.5}{0.7}\right)\times\frac{\pi}{4}\times4^2\times3$$

$Q = 10$ lit/sec

12. Ans: (d)

Sol: $K = 1.96$ cm/s $= 0.0196$ m/s

$\nu = 1\times10^{-6}$ m^2/s

Intrinsic permeability, K_0 in darcy =?

$$K_0 = \frac{K\nu}{g} = \frac{0.0196\times1\times10^{-6}}{9.81\times9.87\times10^{-13}}$$

$K_0 = 2024.27$ m$^2 \simeq 2026$ m^2

13. Ans: (d)

Refer previous ESE-Obj-(Vol-2) solutions Book (Cha-7, 6th Question -pg: 352)

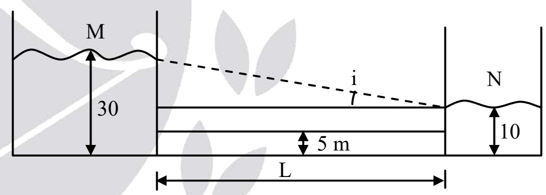
14. Ans: (d)

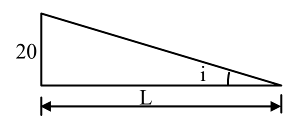
Refer previous ESE-Obj-(Vol-2) solutions Book (Cha-7, 11th Question -pg: 353)

Conventional Practice Solutions

01.

Sol:





Assume that distance between two reservoirs is "L" m

$k = 20$ m/day

$B = 5$ m

$n = 0.30$

$$i = \tan i = \frac{20}{L}$$

$$V = ki \Rightarrow 20\times\left(\frac{20}{L}\right)$$

$$V_a = \frac{V}{n} \Rightarrow \frac{20\times 20}{L\times 0.3}$$

Time taken by the pollutant

$$= \frac{L}{V_a} \Rightarrow \frac{L}{\frac{20\times 20}{L\times 0.3}}$$

$= 7.5 \times 10^{-4}L^2$ days

02.

Sol: k = 50 m/day , H = 3.2 m

R = 150 m, S = 2.4 m

h = 3.2 – 2.4 = 0.8 m

$$Q = \frac{50\times 1(3.2^2 - 0.8^2)}{2\times 150}$$

$= 1.6\ m^3$/sec (bank)

$$Q = \frac{50\times 1(3.2^2 - 0.8^2)}{150}$$

$= 3.2\ m^3$/sec (bed)

03.

Sol: r_1 = 15 m, r_2 = 30 m

d = 45 cm, k = 20 m/day

H_1 = 30 – 5, H_2 = 30 – 4.2,

S_1 = 5.0, S_2 = 4.2 m

$$Q = \frac{\pi k\left(H_2^2 - H_1^2\right)}{\ell n\left(\frac{r_2}{r_1}\right)} \Rightarrow \frac{\pi\times 20\times(25.8^2 - 25^2)}{\ell n\left(\frac{30}{15}\right)}$$

$= 3683.7\ m^3$/day

S_{max} = ?

$$r_1 = r_w = \frac{0.45}{2} = 0.225 \text{ m}$$

r_2 = 30 m

H_1 = h =?

H_2 = 25.8 m

$$Q = \frac{\pi k\left(H_2^2 - H_1^2\right)}{\ell n\left(\frac{r_2}{r_1}\right)} = \frac{\pi k\left(H_2^2 - h^2\right)}{\ell n\left(\frac{r_2}{r_w}\right)}$$

$$3683.7 = \frac{\pi\times 20\times(25.8^2 - h^2)}{\ell n\left(\frac{30}{0.225}\right)}$$

h = 19.46 m

$S_{max} = H - h \Rightarrow 30 - 19.46 = 10.54$ m

04.

Sol: Artesian aquifer (confined aquifer)

Dia of well = 20 cm, S_{max} = 3 m

B = 30 m (length of strainer pipe)

k = 35 m/day, R = 300 m

$$r_1 = r_w = \frac{0.2}{2} = 0.1\text{m}$$

$S_1 = S_{max}$ = 3m

r_2 = R = 300 m

S_2 = 0

$$Q = \frac{2\pi KB(S_1 - S_2)}{\ell n\left(\frac{r_2}{r_1}\right)}$$

$$= \frac{2\pi KB(S_{max} - 0)}{\ell n\left(\frac{R}{r_w}\right)}$$

$$\Rightarrow \frac{2\pi\times 35\times 30\times(3-0)}{\ell n\left(\frac{300}{0.1}\right)}$$

$= 2472.03\ m^3$/day

11. River Gauging

01. Ans: (a)

Sol: $V = aN_s + b$

$$\frac{12}{48}a + b = 0.125 \quad \_\_\_\_ \text{(i)}$$

$$\frac{41}{60}a + b = 0.255 \quad \_\_\_\_\_ \text{(ii)}$$

$$a = 0.3 \quad b = 0.05$$

$$\therefore V = 0.3 \times \frac{24}{50} + 0.05 = 0.194 \text{ m/s}$$

02. Ans: (b)

Sol: $Q_T = 4 \text{ lit/sec} = 4 \times 10^{-3} \text{ m}^3\text{/sec}$

$C_T = 500 \times 10^3 \text{ mg/lit}$

$C_{mix} = 4 \text{ ppm} = 1 \text{ mg/lit}$

$Q_s = ?$

$$C_{mix} = \frac{Q_s C_s + Q_T C_T}{Q_s + Q_T}$$

$$4 = \frac{0 + 4 \times 500 \times 10^3 \times 10^{-3}}{Q_S + 4 \times 10^{-3}}$$

$Q_S = 500 \text{ m}^3\text{/sec}$

Conventional Practice Solutions

01.

Sol:

The calculations are performed in a tabular form

For the first and last sections,

$$\text{Average width, } \overline{W} = \frac{\left(1 + \frac{2}{2}\right)^2}{2 \times 1} = 2.0 \text{ m}$$

For the rest of the segments,

$$\overline{W} = \left(\frac{2}{2} + \frac{2}{2}\right) = 2.0 \text{ m}$$

Since the velocity is measured at 0.6 depth, the measured velocity is the average velocity at that vertical $(\overline{v})$.

The calculation of discharge by the mid-section method is shown in tabular form below.

Discharge in the stream = 6.454 m^3/s

Distance from left water edge (m)	Average width $\overline{W}$ (m)	Depth, y (m)	$N_s = \frac{\text{Rev.}}{\text{second}}$	Velocity $\overline{v}$ (m/s)	Segmental discharge ΔQ_i (m^3/s)
0	0	0			0.0000
1	2	1.10	0.390	0.2289	0.5036
3	2	2.00	0.580	0.3258	1.3032
5	2	2.50	0.747	0.4110	2.0549
7	2	2.00	0.600	0.3360	1.3440
9	2	1.70	0.450	0.2595	0.8823
11	2	1.00	0.300	0.1830	0.3660
12	0	0.00			0.0000
				Sum	6.45393

12. Reservoir Capacity

Conventional Practice Solutions

01.

Sol:

From the given data, the monthly flow volume and accumulated volumes are calculated as in table. The actual number of days in the month are used in calculating of the monthly flow volume. Volumes are calculated in units of cumec-day (= 8.64×10^4 m^3)

Calculation of Mass curve

Month	Mean flow (m^3/s)	Monthly flow volume (cumec-day)	Accumulated volume (cumec-day)
Jan	60	1860	1860
Feb	45	1260	3120
Mar	35	1085	4205
April	25	750	4955
May	15	465	5420
Jun	22	660	6080
July	50	1550	7630
Aug	80	2480	10110
Sep	105	3150	13260
Oct	90	2790	16050
Nov	80	2400	18450
Dec	70	2170	20620

A mass curve of accumulated flow volume against time is plotted. In this figure, all the months are assumed to be of average duration of 30.4 days. A demand line with slope of 40 m^3/s is drawn tangential to the hump at the beginning of the curve; line AB in figure. A line parallel to this line is drawn tangential to the mass curve at the valley portion; line A'B'. The vertical distance S_1 between these parallel lines is the minimum storage required to maintain the demand. The value of S_1 is found to be 2100 cumec. Days = 181.4 million m^3.