**Bachelor of Biosystems Technology**
**Faculty of Technology**
**South Eastern University of Sri Lanka**

**BSE 11022 – Hydrology and Meteorology**

**Assignment 4** **Professor M.M.M. Najim**

1. The mass curve of a storm is given below. Determine the effective rainfall and volume of direct runoff from the watershed due to given storm, if the area of watershed is 35 $km^2$. Assume the $\Phi$-index of the watershed as 0.45 cm/h.

| Time or start of storm *h* | 0 | 3 | 6 | 9 | 12 | 15 | 18 | 21 | 24 | 27 |
|---|---|---|---|---|---|---|---|---|---|---|
| Accumulated rainfall (cm) | 0 | 0.75 | 3.50 | 4.75 | 7.15 | 9.20 | 9.90 | 10.50 | 11.75 | 13.0 |

2. Using the data in Question 1, compute the duration of effective rainfall.

3. Compute the effective rainfall due to following storm. Take the $\Phi$-index for watershed as 0.35 cm/h.

| Time since start of rainfall (h) | 0 | 3 | 6 | 9 | 12 |
|---|---|---|---|---|---|
| Accumulated rainfall (cm) | 0 | 4 | 11 | 15 | 17 |

4. On a watershed of area 35 $km^2$, two storms of magnitude 2.5 and 2.0 cm occurring consecutively at 3.0 hour durations. The produced hydrograph at the outlet of watershed is given below. Determine the rainfall excess and $\Phi$-index.

| Time (h) | -3 | 0 | 3 | 6 | 9 | 12 | 15 | 18 | 21 | 24 | 27 | 30 | 33 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Discharge ($m^3/s$) | 4.5 | 4.5 | 11.0 | 23.0 | 16.0 | 14.5 | 11.5 | 7.0 | 6.5 | 5.0 | 4.5 | 4.5 | 4.5 |

5. The followings are the ordinates of 3 hour unit hydrograph of a given watershed. Determine the ordinates of DRH due to ER of 3.0 cm.

| Time (h) | 0 | 3 | 6 | 9 | 12 | 15 | 18 | 21 | 24 | 27 | 30 | 33 | 36 | 39 | 42 | 45 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| OUDH ($m^3/s$) | 0 | 30 | 70 | 105 | 150 | 180 | 205 | 170 | 100 | 85 | 60 | 50 | 35 | 25 | 25 | 15 |

6. At the outlet of a given watershed the following hydrograph was produced by a storm of 4.2 cm. Compute the ordinates of DRH and total volume of surface runoff. Assume the constant base flow as 3.0 $m^3/s$.

| Time (h) | 0 | 3 | 6 | 9 | 12 | 15 | 18 | 21 | 24 |
|---|---|---|---|---|---|---|---|---|---|
| Ordinate of hydrograph ($m^3/s$) | 3.0 | 4.5 | 7.0 | 12.0 | 10.5 | 7.0 | 5.0 | 4.0 | 3.0 |

7. Compute the ordinates of DRH due to two successive storms of 3-h duration having their rainfall excess as 2.5 and 3.0 cm, respectively. The ordinates of unit hydrograph of 3-h duration are the same as given in question 5.

8. Compute the ordinates of hydrograph of 5 cm ER, from the given unit hydrograph in question 5. Consider the constant base flow as $10 m^3/s$.

9. Derive the ordinates of 3-h unit hydrograph for a watershed. The measured discharge rates at the outlet of watershed are given below. The area of watershed is 500 sq km.

| Time (h) | -3 | 0 | 3 | 6 | 9 | 12 | 15 | 18 | 21 | 24 | 27 | 30 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Discharge ($m^3/s$) | 10 | 10 | 10 | 37 | 50 | 75 | 115 | 110 | 101 | 79 | 65 | 61 |
| Time (h) | 33 | 36 | 39 | 42 | 45 | 48 | 51 | 54 | 57 | 60 | 63 | 66 |
| Discharge ($m^3/s$) | 57 | 50 | 47 | 45 | 40 | 33 | 30 | 25 | 17 | 15 | 10 | 10 |

10. Derive a 9-h unit hydrograph from the ordinates of 3-h unit hydrograph given in question 5

11. The following are the ordinates of the flood hydrograph from a catchment area of 780 km2 due to 6 hr storm. Derive the 6 hr unit hydrograph of the basin.

| Time (h) | 6 | 12 | 18 | 24 | 6 | 12 | 18 | 24 | 6 | 12 | 18 | 24 | 6 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Discharge ($m^3/s$) | 40 | 64 | 215 | 360 | 405 | 350 | 270 | 205 | 145 | 100 | 70 | 50 | 40 |

12. The following data represent the ordinates of hourly interval of one unit hydrograph;

| Time (h) | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| UH coordinates ($m^3$/sec) | 0 | 58 | 110 | 96 | 53 | 26 | 14 | 8 | 5 | 4 | 3 | 1.5 | 1 | 0 |

Compute storm hydrograph resulting from three-hour storm rainfall as;

| Time (h) | 1st hr | 2nd hr | 3rd hr |
|---|---|---|---|
| Rainfall depth (cm) | 4 | 3 | 2.5 |

Take $\Phi$-index as 2 cm/hr and assume a base flow of 2 $m^3$/sec.

13. The flood data and base flow in a storm are estimated for a storm in a catchment area of 600 $km^2$. Estimate the rainfall excess.

| Time in days | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|---|
| Discharge ($m^3$/sec) | 20 | 63 | 151 | 133 | 90 | 63 | 44 | 29 | 20 | 20 |
| Base flow ($m^3$/sec) | 20 | 22 | 25 | 28 | 28 | 26 | 23 | 21 | 20 | 20 |

Assignment 4

| Time since start of Storm (h) | Time interval ($\Delta t$) (h) | Accumulated Rainfall (cm) | Rainfall in time $\Delta t$ (cm) | Loss of water in $\Delta t$ (cm) | Effective Rainfall (cm) | Intensity of ER (cm/h) |
|---|---|---|---|---|---|---|
| 0 | — | 0 | 0 | 0 | 0 | 0 |
| 3 | 3 | 0.75 | 0.75 | 1.35 | 0 | 0 |
| 6 | 3 | 3.50 | 2.75 | 1.35 | 1.40 | 0.467 |
| 9 | 3 | 4.75 | 1.25 | 1.35 | 0 | 0 |
| 12 | 3 | 7.15 | 2.40 | 1.35 | 1.05 | 0.350 |
| 15 | 3 | 9.20 | 2.05 | 1.35 | 0.70 | 0.233 |
| 18 | 3 | 9.90 | 0.70 | 1.35 | 0 | 0 |
| 21 | 3 | 10.50 | 0.60 | 1.35 | 0 | 0 |
| 24 | 3 | 11.75 | 1.25 | 1.35 | 0 | 0 |
| 27 | 3 | 13.0 | 1.25 | 1.35 | 0 | 0 |

Loss of water in $\Delta t$ = $3 \times \phi$ index = $3^{h} \times 0.45$ cm/h = 1.35 cm

Effective rainfall intensity = ER/$\Delta t$ = 1.40/3 = 0.467 cm/h

Effective rainfall = Area of ER hyetograph

$= (0.467 + 0.350 + 0.233)3$

$= 3.15$ cm.

Volume of direct runoff = ER x Area of Watershed

$= \frac{3.15}{100}\ m \times 35 \times 10^6\ m^2$

$= 1.1025 \times 10^6\ m^3$

2. Duration of effective rainfall = 3+3+3 = 9 h

3.

| Time Since RF start (h) | Accumulated RF (cm) | Rainfall in $\Delta t$ (cm) | ER (cm) |
|---|---|---|---|
| 0 | 0 | 0 | 0 |
| 3 | 4 | 4 | $4 - (0.35 \times 3) = 2.95$ |
| 6 | 11 | 7 | $7 - (0.35 \times 3) = 5.95$ |
| 9 | 15 | 4 | $4 - (0.35 \times 3) = 2.95$ |
| 12 | 17 | 2 | $2 - (0.35 \times 3) = 0.95$ |
| | | | Total ER 12.8 cm |

4.

| Time (h) | Q ($m^3/s$) | Base flow ($m^3/s$) | ODRH ($m^3/s$) | Volume of Direct Runoff (Area of DRH) ($m^3$) |
|---|---|---|---|---|
| -3 | 4.5 | 4.5 | 0 | 0 |
| 0 | 4.5 | | 0 | 0 |
| 3 | 11.0 | | 6.5 | $\frac{1}{2} \times 3 \times 60 \times 60 \times 6.5$ |
| 6 | 23.0 | | 18.5 | $\frac{1}{2} \times 3 \times 60 \times 60 \times (6.5 + 18.5)$ |
| 9 | 16.0 | | 11.5 | $\frac{1}{2} \times 3 \times 60 \times 60 \times (18.5 + 11.5)$ |
| 12 | 14.5 | | 10.0 | $\frac{1}{2} \times 3 \times 60 \times 60 \times (11.5 + 10)$ |
| 15 | 11.5 | | 7.0 | $\frac{1}{2} \times 3 \times 60 \times 60 \times (10 + 7)$ |
| 18 | 7.0 | | 2.5 | $\frac{1}{2} \times 3 \times 60 \times 60 \times (7 + 2.5)$ |
| 21 | 6.5 | | 2.0 | $\frac{1}{2} \times 3 \times 60 \times 60 \times (2.5 + 2)$ |
| 24 | 5.0 | | 0.5 | $\frac{1}{2} \times 3 \times 60 \times 60 \times (0.5 + 2.0)$ |
| 27 | 4.5 | | 0 | $\frac{1}{2} \times 3 \times 60 \times 60 \times 0.5$ |
| 30 | 4.5 | | 0 | 0 |
| 33 | 4.5 | | 0 | 0 |

$$\frac{1}{2} \times 3 \times 60 \times 60 \left[ 6.5 + (6.5 + 18.5) + (18.5 + 11.5) + (11.5 + 10) + (10 + 7) + (7 + 2.5) + (2.5 + 2) + 0.5 \right]$$

$$= \underline{\underline{631,800 \ m^3}}$$

$$\text{Depth of Runoff} = \frac{\text{Runoff Volume } (m^3)}{\text{Area of basin } (m^2)} = \frac{631\,800 \ m^3}{35 \times 10^6 \ m^2}$$

$$= 0.0181 \ m$$

$$= \underline{\underline{1.81 \ cm}}$$

5.

| Time (h) | OUHG ($m^3/s$) | Ordinates of DRH due to 3 cm ER ($m^3/s$) |
|---|---|---|
| 0 | 0 | 0 |
| 3 | 30 | 90 |
| 6 | 70 | 210 |
| 9 | 105 | 315 |
| 12 | 150 | 450 |
| 15 | 180 | 540 |
| 18 | 205 | 615 |
| 21 | 170 | 510 |
| 24 | 100 | 300 |
| 27 | 85 | 255 |
| 30 | 60 | 180 |
| 33 | 50 | 150 |
| 36 | 35 | 105 |
| 39 | 25 | 75 |
| 42 | 25 | 75 |
| 45 | 15 | 45 |

6.

| Time (h) | Ordinate of hydrograph ($m^3/s$) | Base flow ($m^3/s$) | ODRH ($m^3/s$) |
|---|---|---|---|
| 0 | 3.0 | 0 m³/s | 0 |
| 3 | 4.5 | | 1.5 |
| 6 | 7.0 | | 4.0 |
| 9 | 12.0 | | 9.0 |
| 12 | 10.5 | | 7.5 |
| 15 | 7.0 | | 4.0 |
| 18 | 5.0 | | 2.0 |
| 21 | 4.0 | | 1.0 |
| 24 | 3.0 | | 0 |

Total volume of surface runoff (Area of DRH) ($m^3$)

$$= \frac{1}{2} \times 3 \times 60 \times 60 \left[ 1.5 + (1.5+4.0) + (4+9) + (9+7.5) + (7.5+4) + (4+2) + (2+1) + (1) \right]$$

$$= \underline{313,200 \ m^3}$$

7.

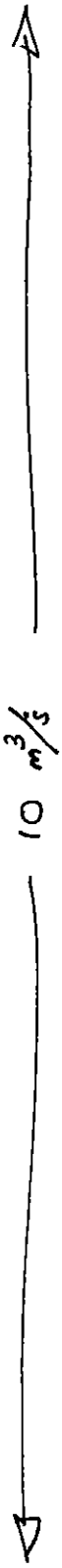
| Time (h) | OUHG ($m^3/s$) | ODRH due to 2.5 cm ER ($m^3/s$) | ODRH due to 3 cm of ER ($m^3/s$) lagged by 3 h | ODRH due to 5.5 cm ER ($m^3/s$) |
|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0 |
| 3 | 30 | 75 | 0 | 75 |
| 6 | 70 | 175 | 90 | 265 |
| 9 | 105 | 262.5 | 210 | 472.5 |
| 12 | 150 | 375 | 315 | 690.0 |
| 15 | 180 | 450 | 450 | 900.0 |
| 18 | 205 | 512.5 | 540 | 1052.5 |
| 21 | 170 | 425 | 615 | 1040 |
| 24 | 100 | 250 | 510 | 760 |
| 27 | 85 | 212.5 | 300 | 512.5 |
| 30 | 60 | 150 | 255 | 405 |
| 33 | 50 | 125 | 180 | 305 |
| 36 | 35 | 87.5 | 150 | 237.5 |
| 39 | 25 | 62.5 | 105 | 167.5 |
| 42 | 25 | 62.5 | 75 | 137.5 |
| 45 | 15 | 37.5 | 75 | 112.5 |
| 48 | 0 | 0 | 45 | 45 |
| 51 | | | 0 | 0 |

8.

| Time (h) | OUHG ($m^3/s$) | Ordinates of DRH due to 5cm ER ($m^3/s$) | Base flow ($m^3/s$) | Ordinate of Hydrograph ($m^3/s$) |
|---|---|---|---|---|
| 0 | 0 | 0 | | 0 |
| 3 | 30 | 150 | | 160 |
| 6 | 70 | 350 | | 360 |
| 9 | 105 | 525 | | 535 |
| 12 | 150 | 750 | | 760 |
| 15 | 180 | 900 | | 910 |
| 18 | 205 | 1025 | | 1035 |
| 21 | 170 | 850 | | 860 |
| 24 | 100 | 500 | 0 | 510 |
| 27 | 85 | 425 | 0 | 435 |
| 30 | 60 | 300 | | 310 |
| 33 | 50 | 250 | | 260 |
| 36 | 35 | 175 | | 185 |
| 39 | 25 | 125 | | 135 |
| 42 | 25 | 125 | | 135 |
| 45 | 15 | 75 | | 85 |
| 48 | 0 | | | 10 |

9.

| Time (h) | Q ($m^3/s$) | Base flow ($m^3/s$) | ODRH ($m^3/s$) | Ordinate of 3h Unit hydrograph ($m^3/s$) |
|---|---|---|---|---|
| -3 | 10 | | 0 | 0 |
| 0 | 10 | | 0 | 0 |
| 3 | 10 | | 0 | 0 |
| 6 | 37 | | 27 | 27/1.83 = 14.75 |
| 9 | 50 | | 40 | 40/1.83 = ~~21.85~~ 21.85 |
| 12 | 75 | | 65 | 65/1.83 = 35.52 |
| 15 | 115 | | 105 | 105/1.83 = 57.38 |
| 18 | 110 | | 100 | 100/1.83 = 54.64 |
| 21 | 101 | | 91 | 49.73 |
| 24 | 79 | | 69 | 37.70 |
| 27 | 65 | | 55 | 30.05 |
| 30 | 61 | | 51 | 27.87 |
| 33 | 57 | | 47 | 25.68 |
| 36 | 50 | | 40 | 21.86 |
| 39 | 47 | | 37 | 20.22 |
| 42 | 45 | | 35 | 19.13 |
| 45 | 40 | | 30 | 16.39 |
| 48 | 33 | | 23 | 12.57 |
| 51 | 30 | | 20 | 10.93 |
| 54 | 25 | | 15 | 8.20 |
| 57 | 17 | | 07 | 3.89 |
| 60 | 15 | | 05 | 2.73 |
| 63 | 10 | | 0 | 0 |
| 66 | 10 | | 0 | 0 |




Total volume of Direct Runoff (Area of DRH)

$= \frac{1}{2} \times 3 \times 60 \times 60 \times 1692 = 9,136,800$

$ER = \frac{\text{Total Direct Runoff}}{\text{Area of Watershed}} = \frac{9\,136\,800}{500 \times 10^6} = 0.0183\,m = 1.83\,cm$

10.

| Time (h) | OUHG ($m^3/s$) | Ordinates of 3h UHG | Ordinates of 3h UHG lagged by 6h. | Ordinates of DRH due to 3cm ER in 9h | Ordinates of 9h UHG ($m^3/s$) |
|---|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0 | 0 |
| 3 | 30 | 0 | 0 | 30 | 10 |
| 6 | 70 | 30 | 0 | 100 | 33.3 |
| 9 | 105 | 70 | 30 | 205 | 68.3 |
| 12 | 150 | 105 | 70 | 325 | 108.3 |
| 15 | 180 | 150 | 105 | 435 | 145 |
| 18 | 205 | 180 | 150 | 535 | 178.3 |
| 21 | 170 | 205 | 180 | 555 | 185 |
| 24 | 100 | 170 | 205 | 475 | 158.3 |
| 27 | 85 | 100 | 170 | 355 | 118.3 |
| 30 | 60 | 85 | 100 | 245 | 81.7 |
| 33 | 50 | 60 | 85 | 195 | 65 |
| 36 | 35 | 50 | 60 | 145 | 48.3 |
| 39 | 25 | 25 | 50 | 100 | 33.3 |
| 42 | 25 | 25 | 25 | 75 | 25 |
| 45 | 15 | 15 | 25 | 55 | 18.3 |
| 48 | 0 | 0 | 15 | 15 | 5 |
| 51 | 0 | 0 | 0 | 0 | 0 |

11.

| Time (h) | Q ($m^3/s$) | Base flow ($m^3/s$) | ODRH ($m^3/s$) | Ordinates of 6h Unit hydrograph ($m^3/s$) |
|---|---|---|---|---|
| 6 | 40 | 40 $m^3/s$ | 0 | 0 |
| 12 | 64 | | 24 | 24/4.92 = 4.88 |
| 18 | 215 | | 175 | 175/4.92 = 35.57 |
| 24 | 360 | | 320 | 65.04 |
| 6 | 405 | | 365 | 74.19 |
| 12 | 350 | | 310 | 63.01 |
| 18 | 270 | | 230 | 46.75 |
| 24 | 205 | | 165 | 33.54 |
| 6 | 145 | | 105 | 21.34 |
| 12 | 100 | | 60 | 12.20 |
| 18 | 70 | | 30 | 6.10 |
| 24 | 50 | | 10 | 2.03 |
| 6 | 40 | | 0 | 0 |

Total volume of Direct Runoff (Area of DRH)

$= \frac{1}{2} \times 6 \times 60 \times 60 \times 3554$

$= 38,383,200\ m^3$

$ER = \frac{\text{Total Direct runoff}}{\text{Area of Watershed}} = \frac{38\,383\,200\ m^3}{780 \times 10^6\ m^2}$

$= 0.0492\ m$

$= 4.92\ cm$

12. $\phi$ index = 2 cm/h

Time (h)

1st hr rainfall excess = 4 − 2 = 2 cm

2nd hr rainfall excess = 3 − 2 = 1 cm

3rd hour rainfall excess = 2.5 − 2 = 0.5 cm

| Time (h) | UHO ($m^3/s$) | ODRH due to 1st storm ($m^3/s$) | ODRH due to 2nd storm ($m^3/s$) | ODRH due to 3rd storm ($m^3/s$) | ODRH due to all storms ($m^3/s$) | Base flow | Storm Hydrograph ($m^3/s$) |
|---|---|---|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0 | 0 | | 0 |
| 1 | 58 | 116 | 0 | 0 | 116 | | 118 |
| 2 | 110 | 220 | 58 | 0 | 278 | | 280 |
| 3 | 96 | 192 | 110 | 29 | 331 | | 333 |
| 4 | 53 | 106 | 96 | 55 | 257 | | 259 |
| 5 | 26 | 52 | 53 | 48 | 153 | | 155 |
| 6 | 14 | 28 | 26 | 26.5 | 80.5 | 2 $m^3/s$ | 82.5 |
| 7 | 8 | 16 | 14 | 13 | 43 | | 45 |
| 8 | 5 | 10 | 8 | 7 | 25 | | 27 |
| 9 | 4 | 8 | 5 | 4 | 17 | | 19 |
| 10 | 3 | 6 | 4 | 2.5 | 12.5 | | 14.5 |
| 11 | 1.5 | 3 | 3 | 2 | 8 | | 10 |
| 12 | 1 | 2 | 1.5 | 1.5 | 5 | | 7 |
| 13 | 0 | 0 | 1 | 0.75 | 1.75 | | 3.75 |
| 14 | | | 0 | 0.50 | 0.50 | | 2.50 |
| 15 | | | | | | | 2.0 |

UHO = Unit Hydrograph Ordinates

13.

| Time (days) | Q ($m^3/s$) | Base flow ($m^3/s$) | ODRH ($m^3/s$) |
|---|---|---|---|
| 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 |

Total volume of direct runoff (Area of DRH)

$$= \frac{1}{2} \times 1 \times 24 \times 60 \times 60 \left[ 41 + (126+41) + (126+105) + (105+62) + (62+37) + (37+21) + (21+8) + 8 \right]$$

$$= 34,560,000 \ m^3$$

$$ER = \frac{\text{Total Direct Runoff}}{\text{Area of watershed}} = \frac{34\,560\,000 \ m^3}{600 \times 10^6 \ m^2}$$

$$= 0.0576 \ m$$

$$= \underline{5.76 \ cm}$$