SOLUTION FINAL EXAM 2017

PROBLEM 1 (15 PTS)

A Canadian river is partly or fully covered by ice during the winter (see illustration below). The average fraction of the open water covered by ice is given in the Table 1.

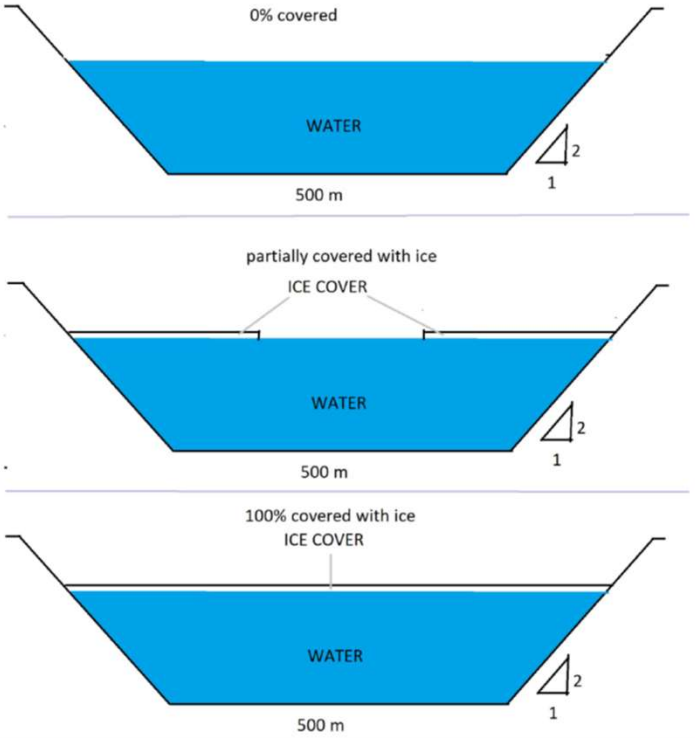


Table 1: fraction of the river surface covered by ice

JAN	FEB	MAR	APRIL
100%	100%	80%	50%
MAY	JUN	JUL	AUG
0%	0%	0%	0%
SEP	OCT	NOV	DEC
0%	0%	50%	80%

PROBLEM 1 (15 PTS)

1. Do you expect the stage-discharge relationship to be constant through the year? Why? **[3 Marks]**
2. Derive the equation of the stage discharge (Q=f(h)) as function of the fraction of open water covered by ice. Assume a Manning coefficient of 0.040 for the whole wetted section. **[3 Marks]**
   The following water levels were measured on the river.

   Calculate the corresponding discharges. **[6 Marks]**

Date	Water level (m)
15/1/2017	1.5
15/3/2017	1.7
15/4/2017	1
15/10/2017	1.5

SOLUTION

a) The stage discharge relationship will change through the year as the presence of ice modifies the wetted perimeter and therefore change the relation between water height (h) and discharge (Q)

$$A = \frac{(b+b+h)*h}{2} = \frac{h(2b+h)}{2}$$

b) $$P = b + 2h\sqrt{1+0.5*0.5} + x(b+h) = b + 2h\sqrt{1.25} + x(b+h)$$

$$Q = \frac{1}{n} \frac{\left(\frac{h(2b+h)}{2}\right)^{5/3}}{\left(b+2h\sqrt{1.25}+x(b+h)\right)^{2/3}} S^{0.5}$$

Date	Water level (m)	X (%)	A (m2)	P (m)	n	S	Q (m3/s)
1/15/2017	1.5	100	751.1	1004.9	0.04	0.001	489.1
3/15/2017	1.7	80	851.4	905.2	0.04	0.001	646.2
4/15/2017	1	50	500.5	752.7	0.04	0.001	301.4
10/15/2017	1.5	0	751.1	503.4	0.04	0.001	775.4

PROBLEM 2 (20 PTS)

The purpose of this problem is the design a pipe culvert ($n = 0.013$) that would carry the discharge for the following conditions: 25-yr return period, 17-acre watershed, short-grass landcover (n=0.03), channel slope of 3.5%, and length of 1,150 ft. The slope of the culvert is 2%. Assume an unsubmerged inlet and outlet.

1. Calculate the time of concentration of the watershed. [4 Mark]
2. Calculate the peak flow in the watershed. [4 mark]
3. Calculate the diameter of the culvert. [4 Mark]
4. If the diameter of the pipe is doubled, what's the return period of the flow it can handle? [8 Mark]

SOLUTION

a)

$$\Delta h = 1150 * \frac{3.5}{100} = 40.25\,ft$$

$$t_c = 0.0078\left(L^3/\Delta h\right)^{0.385} = 6.44\,\text{min}$$

$$\left.\begin{array}{l} T = 25Yr \\ t_c = 6.44\,\text{min} \end{array}\right\} \Rightarrow i = 8.1 in/h$$

b) $C = 0.6$

$$Q = CIA = 0.6 * 8.1 * 17 = 82.62 cfs$$

c) $D = 1.33\left(Qn\right)^{3/8} S^{-3/16} = 2.84\,ft$

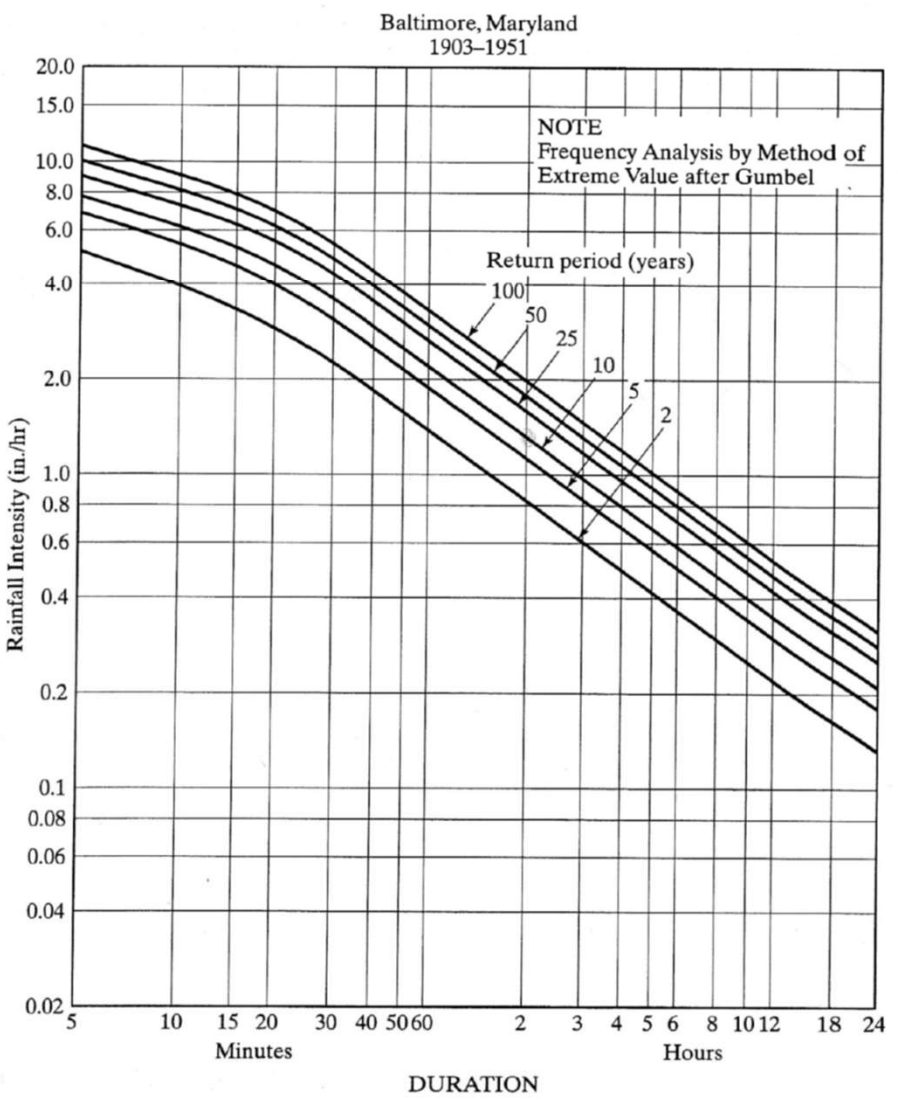


Figure 4.4 Rainfall intensity-duration-frequency (National Weather Service, 1961).

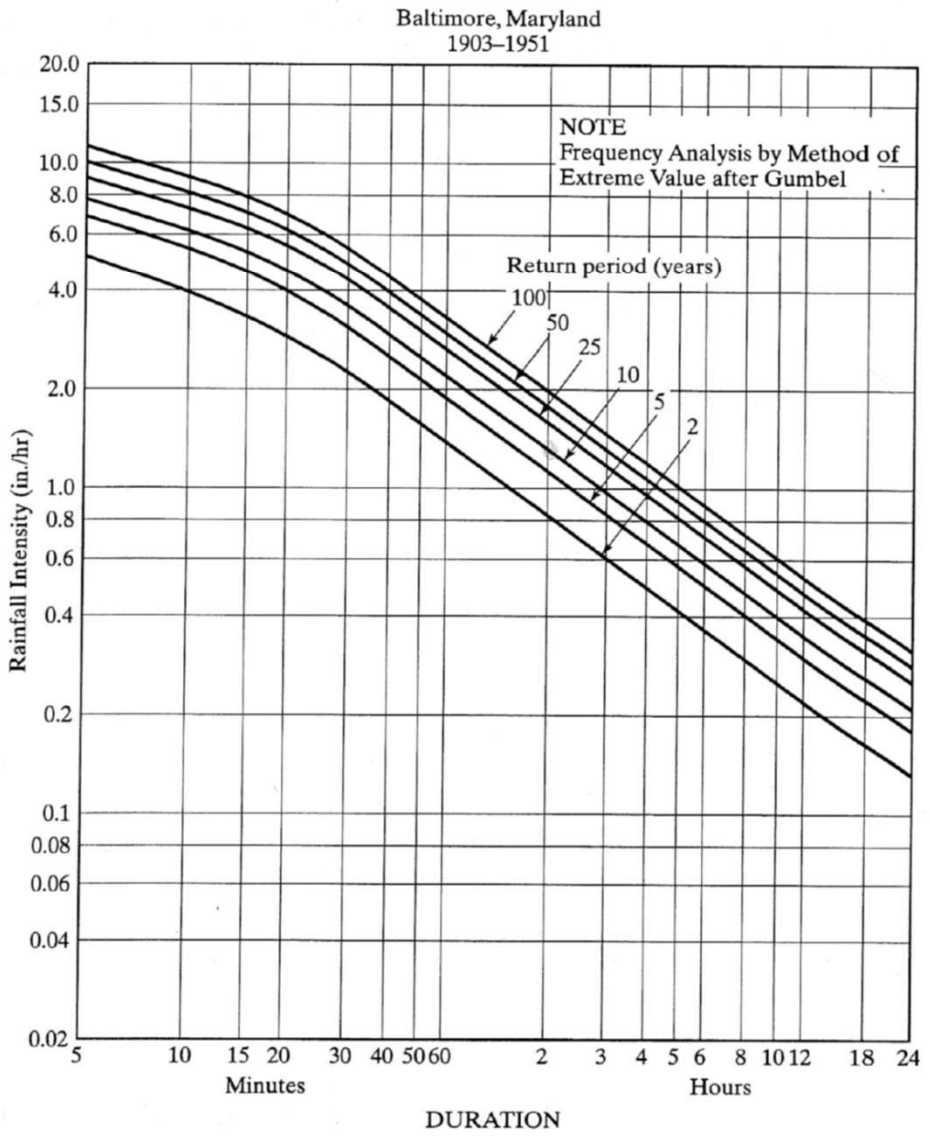
SOLUTION

d) If D is doubled, the peak flow would be:

$$Q = \frac{1}{n}\left(\frac{(2*D)}{1.33S^{-3/16}}\right)^{\frac{8}{3}} = 524cfs$$

$$i = \frac{Q}{CA} = \frac{524}{0.6*17} = 51.43cfs$$

$$T >> 100Yr$$



PROBLEM 3 (15 PTS)

A 2-hour unit hydrograph is given by a triangle whose base is 4 hours and height at the midpoint of the base is 0.5/hour.

- Compute the direct runoff due to a 4-hour effective rainfall whose intensity is 2 cm/h **[4 Mark]**
- Compute the peak discharge. **[1 Mark]**
- Derive a 3-hour unit hydrograph. **[5 mark]**
- If a 3-hour effective rainfall occurs at a uniform rate of 1 cm/h, what should be the direct runoff volume and the peak discharge? **[5 mark]**

SOLUTION

a) Method 1: use and lag using two precipitation episodes of 2h

Time	UH
0	0
1	0.25
2	0.5
3	0.25
4	0

time	Intensity(in/h)	depth (in)
0 to 2	2	4
2 to 4	2	4

Time	4*UH	4*UH2	DRH
0	0		0
1	1		1
2	2	0	2
3	1	1	2
4	0	2	2
5	0	1	1
6	0	0	0
7	0	0	0
8	0	0	0

SOLUTION

Method 2: derive a 4hUH and multiply by 8

Time	2h-UH	2h-UN	Sum	4h-UH=1/2SUM	DRH=8*4h-UH
0	0		0	0	0
1	0.25		0.25	0.125	1
2	0.5	0	0.5	0.25	2
3	0.25	0.25	0.5	0.25	2
4	0	0.5	0.5	0.25	2
5	0	0.25	0.25	0.125	1
6	0	0	0	0	0
7	0	0	0	0	0
	0	0	0	0	0
	0	0	0	0	0

b) Peak discharge is 2in/h

SOLUTION

c) Derive SH, lag it 3h, take the difference and divide by 3

Time	2h-UH	2h-UN	2h-UH2	SUM	SH=2*SUM	Lagged SH	Difference	3h-UH=diffference/3
0	0			0	0	0	0	0
1	0.25			0.25	0.5	0	0.5	0.166667
2	0.5	0		0.5	1	0	1	0.333333
3	0.25	0.25		0.5	1	0	1	0.333333
4	0	0.5	0	0.5	1	0.5	0.5	0.166667
5	0	0.25	0.25	0.5	1	1	0	0
6	0	0	0.5	0.5	1	1	0	0
7	0	0	0.25	0.5	1	1	0	0
	0	0	0	0.5	1	1	0	0
	0	0	0	0.5	1	1	0	0

d) Rainfall depth is 3cm; answer is 3 times the 3h-UH

Time (h)	3h-UH	3*3h-UH
0	0	0
1	0.166667	0.5
2	0.333333	1
3	0.333333	1
4	0.166667	0.5
5	0	0
6	0	0
7	0	0

e) The peak flow is 1cm/h

PROBLEM 5 (15 PTS)

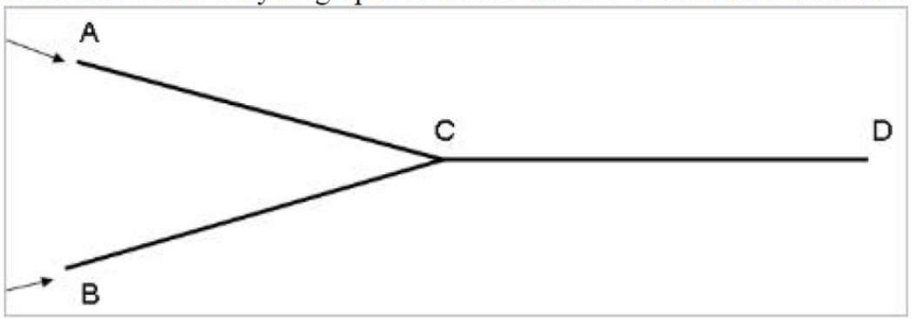
The channels AC and BC joining at the junction C flow into the channel CD. The Muskingum parameters are $K = 30$ minutes and $X = 0.10$ for channels AC and CD and $K = 40$ minutes and $X = 0.08$ for channel BC. The upstream inflow hydrographs are identical for channels AC and BC and are tabulated below.

t (min.)	0	15	30	45	60	75	90	105	120	135	150	165	180	195	210	225
I (cfs)	10	50	134	274	372	400	372	322	234	166	93	53	32	16	10	10

(A) Determine the hydrograph at the upstream end of channel CD between 0 and 90 min. **[7.5 Marks]**

(A) Determine the hydrograph at the downstream end of channel CD between 0 and 90 min. . **[7.5 Marks]**

Hint: The outflow hydrographs from AC and BC combined constitute the inflow hydrograph for CD.



SOLUTION

Column1	AC	BC	CD
K	30	40	30
x	0.1	0.08	0.1
Dt	15	15	15
C3	34.5	44.3	34.5
C0	0.130435	0.09706546	0.130435
C1	0.304348	0.24153499	0.304348
C2	0.565217	0.66139955	0.565217

Assume inflow=Outflow at the beginning of the time step

	AC		BC		CD	
Time (min)	Inflow	Outflow	Inflow	Outflow	Inflow	Outflow
0	10	10	10	10	20	20
15	50	15.2	50	13.9	29.1	21.2
30	134	41.3	134	34.3	75.6	30.7
45	274	99.9	274	81.6	181.5	64.0
60	372	188.4	372	156.3	344.6	136.4
75	400	271.9	400	232.0	503.9	247.7
90	372	323.9	372	286.2	610.1	372.9
105	322	338.3	322	310.4	648.7	481.1

PROBLEM 6

The following rainfall hyetograph was observed on a watershed:

Time (min)	Rainfall (in/h)
0	0.3
15	0.7
30	1
45	0.3

The 30min unit hydrograph for that watershed is given by:

Time (min)	0	15	30	45	60
UH Ordinates (cfs/in)	0	25	40	25	10

1. Calculate the hydrograph at the outlet of the watershed [**6 Marks**]

A reservoir to control the flood has been designed at the outlet of this watershed. The Storage-Indication curve relationship was determined using a time-step of 5 minutes for this reservoir as:

$$Q = 0.00001\left(\frac{2S}{\Delta t} + Q\right)^3 - 0.003\left(\frac{2S}{\Delta t} + Q\right)^2 + 0.4298\left(\frac{2S}{\Delta t} + Q\right)$$

where, Q has units [cfs] and S has units [ft^3]. Consider the initial storage and outflow equal to zero.

PROBLEM 6 (20 PTS)

2. Route the hydrograph in the above table shown until the outflow hydrograph start decreasing. Show the calculations for all the values obtained. **[6 Marks]**
3. What impact the reservoir has on the peak flow? **[2 Marks]**
4. What impact the reservoir has on time to peak? **[2 Marks]**

SOLUTION

1) First find the 15min UH from the 30min UH (SH, 15min UH)

Time (min)	30min-UH Ordinates (cfs/in)	30min-UH Ordinates (cfs/in)			SUM	SH=0.5*SUM	Lagged SH	Difference	15min-UH=4*Difference
0	0				0	0		0	0
15	25				25	12.5	0	12.5	50
30	40	0			40	20	12.5	7.5	30
45	25	25			50	25	20	5	20
60	10	40	0		50	25	25	0	0
75		25	25		50	25	25	0	0
90		10	40	0	50	25	25	0	0
105			25	25	50	25	25	0	0
120			10	40	50	25	25	0	0
135				25	50	25	25	0	0
150				10	50	25	25	0	0

SOLUTION

Time (min)	Rainfall (in/h)	Depth (in)
0	0.3	0.75
15	0.7	1.75
30	1	2.5
45	0.3	0.75

Time (min)	**Rainfall (in/h)**	**Depth (in)**
0	0.3	0.075
15	0.7	0.175
30	1	0.25
45	0.3	0.075

Time (min)	**0.075*15min-UH**	**0.175*15min-UH**	**0.25*15min-UH**	**0.075*15min-UH2**	**DRH**
0	0				0
15	3.75	0			3.75
30	2.25	8.75	0		11
45	1.5	5.25	12.5	0	19.25
60	0	3.5	7.5	3.75	14.75
75	0	0	5	2.25	7.25
90	0	0	0	1.5	1.5

SOLUTION

2) Routing

Time (min)	I	I1+I2	2S1/dt-Q1	2S2/dt+Q2	Q2
0	0	15	0.0	15.0	5.8
15	15	59	3.4	62.4	17.6
15	44	103	27.3	130.3	27.2
15	59	88	75.9	163.9	33.9
15	29	35	96.1	131.1	27.3
15	6	6	76.5	82.5	20.7

3) The peak flow will be reduced

4) The time to peak will increase