53:078 Principles of Hydrology
Exam 2
Spring 2003

Name: KEY

Equations and constants you may (or may not) find useful:

$$f^* = K\left[\frac{\psi\Delta\theta}{F^*}+1\right]$$

$$F^*(t) = Kt + \psi\Delta\theta \ln\left[1+\frac{F^*}{\psi\Delta\theta}\right]$$

$$t_p = \frac{K\psi\Delta\theta}{i(i-K)}$$

$$t_0 = t_p - \frac{1}{K}\left[F_p - \psi\Delta\theta\ln\left(1+\frac{F_p}{\psi\Delta\theta}\right)\right]$$

$$f^* = \phi$$

$$P_e = \frac{(P-I_a)^2}{P-I_a+S}$$

$$I_a = 0.2S$$

$$S = \frac{1000}{CN} - 10$$

$$Q(t) = Q_0 K^{(t-t_0)}$$

$$V_d = Ar_d$$

$$t_l = 0.6t_c$$

$$t_p = \frac{t_r}{2} + t_l$$

$$q_p = \frac{483.4A}{t_p}$$

$$R_{k+1} = \alpha R_k + \frac{(1+\alpha)}{2}(Q_{k+1} - Q_k)$$

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

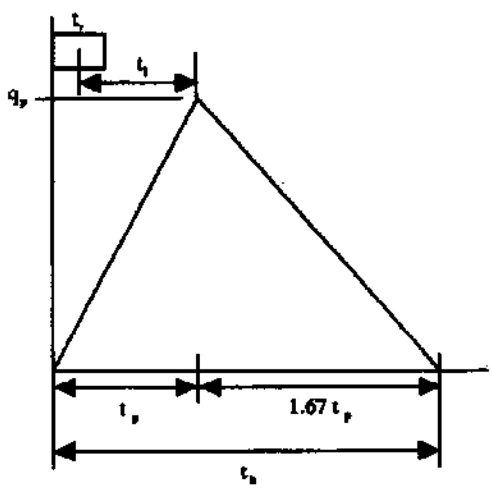
1 ft = 12 in

1 mi^2 = 640 ac

1 acre = 43560 ft^2

1 hr = 3600 s

1 day = 86400 s



(25) 1. Miscellaneous

The Dirty Creek watershed has the following watershed characteristics:

Area (mi^2)	Hydrologic Soil Group	Cover type	CN	CN×A
6.0	A	Open Space (Good condition)	39	234
3.5	B	Residential districts (1/2 acre lots)	70	245
0.5 /Σ 10	B	Impervious areas (paved; open ditches)	89	44.5
				Σ 523.5

Time of concentration (t_c): 20 hours

Use the Soil Conservation Service (SCS) methods to answer the (a) and (b):

8 a) The composite runoff curve number (CN) for Antecedent Moisture Condition II is 52.4.
If a storm produces 1 inch of rainfall in 30 minutes, the rainfall excess is 0.

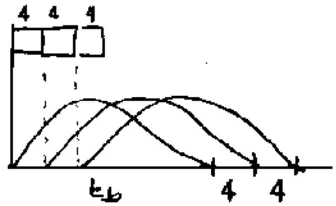
$CN = \frac{\Sigma(CN \cdot A)}{\Sigma A} = \frac{523.5}{10} = 52.4$ $S = \frac{1000}{52.4} - 10 = 9.10$ $I_a = 0.2(9.10) = 1.82$

$P < I_a \therefore P_e = 0$

7 b) The time base (t_b) of the 4-hour unit hydrograph is 37.33 hours. If this 4-hour unit hydrograph is used for streamflow prediction for a storm an effective duration of 12-hours, the time base (t_b) of the direct runoff hydrograph is 45.33 hours.

$t_\ell = 0.6(20) = 12^{hr}$ $t_b = 2.67 \times 14 = 37.33$ $\therefore t_{b-DRH} = 37.33 + 4 + 4 =$

$t_p = \frac{4^{hr}}{2} + 12^{hr} = 14^{hr}$



6 c) A 40-year return period discharge would inundate a new temporary storage structure. The temporary structure will be used for a 5-year period. The probability that the structure will not be inundated is any given year is 0.975. The risk of flooding during the 5-year design life is 0.1189.

$T = 40$ $P(\text{no flood}) = 1 - p = 1 - (1/40) = 0.975$

$p = 1/40$

$R = 1 - (1-p)^N = 1 - (1 - (1/40))^5 = 1 - (0.975)^5 = 0.1189$

4 d) You are given a streamflow hydrograph for a flood event. Provide a step-by-step explanation on how to do baseflow separation using the straight-line method B:

1) Plot Q vs t and log Q v. t

2) Identify when direct runoff begins (the start of the rising limb of the hydrograph.

3) Identify beginning of next baseflow-only period from log Q v. t plot (the start of straight-line after storm)

4) Draw a line connecting these two points. This is the baseflow hydrograph

(25) 2. **Green-Ampt Infiltration Equations**

A constant intensity rainstorm produces 16 mm of rainfall in 2 hours on a loam soil:

Green-Ampt Parameters: (Loam Soil)

- Initial moisture content θ_i is 0.15
- Hydraulic conductivity K is 1 mm/hr
- Soil suction head ψ is 200 mm
- Soil porosity η is 0.55
- The equivalent time origin t_0 for this storm is 0.683 hours

Compute the following for two different times during the storm.

14 a) The cumulative infiltration (F) at t =1 hours is [7.3 | (8.0) | 8.6 | 13.3] (circle one) mm. In the space below, do the calculations required to justify your selection. Guesses without supporting calculations receive NO CREDIT.

3 b) The infiltration rate (f) at t=1 hours is ___8___ mm/hr.

5 c) The cumulative infiltration (F) at t =2 hours is [9.9 | 10.0 | (15.4) | 19.2] (circle one) mm. In the space below, do the calculations required to justify your selection. Guesses without supporting calculations receive NO CREDIT.

3 d) The infiltration rate (f) at t =2 hours is ___6.19___ mm/hr.

a) $\Delta\theta = \eta - \theta_i = 0.55 - 0.15 = 0.4$

$\psi\Delta\theta = (200\text{ mm})(0.4) = 80\text{ mm}$

$i = P/\Delta t = 16\text{ mm}/2\text{ hr} = 8\text{ mm/hr}$

$$t_p = \frac{K\psi\Delta\theta}{i(i-K)} = \frac{(1\text{ mm/hr})(80\text{ mm})}{(8\text{ mm/hr})(8-1\text{ mm/hr})} = 1.429\text{ hr}$$

At $t = 1 < t_p$

$\therefore F(1) = it = (8\text{ mm/hr})(1\text{ hr}) = \underline{\underline{8\text{ mm}}}$

b) At $t = 1 < t_p$

$\therefore f(1) = i = \underline{\underline{8\text{ mm/hr}}}$

c) At $t = 2^{hr} > t_p$:

$$F(2) = K(t - t_0) + \psi\Delta\theta \ln\left(1 + \frac{F}{\psi\Delta\theta}\right)$$

$$= \underbrace{1(2 - 0.683)}_{1.317} + 80 \ln\left(1 + \frac{F}{80}\right)$$

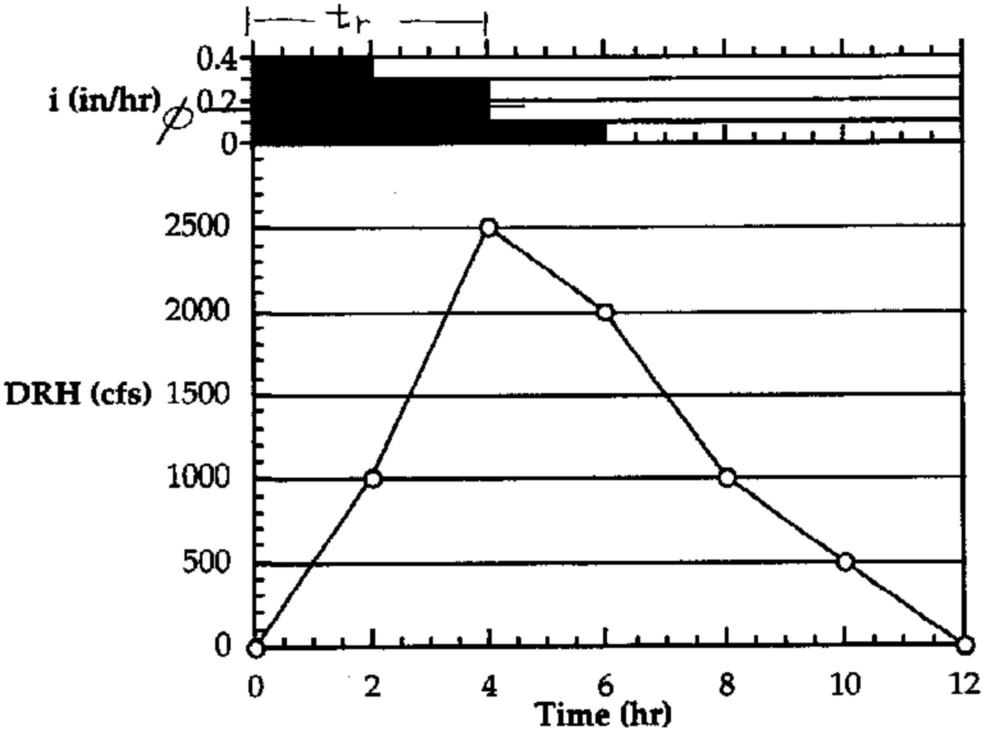
(Guess) F(2)	(computed) F(2)
9.9	9.08
10	10.74
15.4	15.4 ✓
19.2	18.53

$\therefore F(2) = \underline{\underline{15.4 \text{ mm}}}$

d) $f(2) = K\left[\frac{\psi\Delta\theta}{F} + 1\right] = (1)\left[\frac{80}{15.4} + 1\right] = \underline{\underline{6.19 \text{ mm/hr}}}$

(25) 3. Unit Hydrograph Derivation

A storm produces a flood on a 30 mi^2 watershed. The areal-average rainfall intensity (i) and the direct runoff hydrograph for the event are shown below.



Use this information to estimate the following:

6 a) The volume of direct runoff (V_d) is 1157 acre-feet.

9 b) The ϕ-index is 0.169 in/hr.

5 c) The runoff coefficient (C) is 0.452.

5 d) The peak discharge is 3457 cfs for the 4-hour unit hydrograph derived using this event (by the single event method).

a) $\Sigma Q = (0 + 1000 + 2500 + 2000 + 1000 + 500 + 0) = 7000 \text{ cfs}$

$V_d = (\Sigma Q)\Delta t = (7000 \text{ cfs})(2 \text{ hr}) = 14{,}000 \text{ cfs}\cdot\text{hr}$

$= 14{,}000 \frac{ft^3}{s}\cdot hr \left(\frac{3600 s}{hr}\right)\left(\frac{ac}{43560 ft^2}\right) = \underline{\underline{1157 \text{ ac-ft}}}$

b) $r_d = \frac{V_d}{A} = \frac{(1157 \text{ ac-ft})(12 \text{ in/ft})}{30(640 \text{ ac})} = 0.723 \text{ in}$

Assume $\phi \geq 0.3\,^{in}/_{hr}$:

$r_d = (0.4 - \phi)\Delta t$

$\phi = 0.4 - \frac{r_d}{\Delta t} = 0.4\,\frac{in}{hr} - \left(\frac{0.723^{in}}{2\,hr}\right) = 0.0384\,\frac{in}{hr} < 0.3\,^{in}/_{hr}$ **NO**

Assume $0.3\,^{in}/_{hr} > \phi \geq 0.1\,^{in}/_{hr}$

$r_d = (0.4 - \phi)\Delta t + (0.3 - \phi)\Delta t$

$\frac{r_d}{\Delta t} = 0.7 - 2\phi$

$\phi = \frac{1}{2}\left(0.7 - \frac{r_d}{\Delta t}\right) = \frac{1}{2}\left(0.7\,^{in}/_{hr} - \frac{0.723^{in}}{2\,hr}\right) = \underline{\underline{0.169\,\frac{in}{hr}}}$ ok

c) $C = \frac{\Sigma P_e}{\Sigma P} = \frac{r_d}{\Sigma P}$

$\Sigma P = (0.4 + 0.3 + 0.1)(2\,hr) = 1.6^{in}$

$\therefore C = \frac{0.723^{in}}{1.6^{in}} = \underline{\underline{0.452}}$

d) For single-event method, $UH(t) = DRH(t)/r_d$, so

$UH_p = DRH_p / r_d = \frac{2500\text{ cfs}}{0.723} = \underline{\underline{3457\text{ cfs}}}$

For $\phi = 0.169\,^{in}/_{hr}$, $t_r = 4^{hr}$ (see sketch)

$\therefore t_r\text{-}UH = \underline{\underline{4^{hr}}}$

(25) 4. **Streamflow Prediction**

An extreme rainstorm has occurred at the Dry Creek watershed. The intensity of rainfall excess (i_e) is shown below. Also shown is the 1-hour unit hydrograph for Dry Creek. Assume the baseflow in the creek at the time of the storm is a constant 15 cfs.

Time (hours)	i_e (in/hr)	P_e (in)
0		
	1.0	2
2		
	1.5	3
4		

Time (hours)	1-hour UH (cfs)
0	0
1	80
2	120
3	60
4	20
5	0
	Σ 280 cfs

Use this information to determine the following.

6 a) The watershed area is 0.434 mi².

15 b) The direct runoff hydrograph (in cfs). *MARK YOUR ANSWER BELOW*

4 c) The peak discharge of the streamflow hydrograph is 395 cfs at time 4 hour.

a) $V_d = (\Sigma Q)\Delta t = (280\text{ cfs})(1\text{ hr}) = 280\text{ cfs}\cdot\text{hr}$

$$A = \frac{V_d}{r_d} = \frac{(280\ \frac{ft^3}{s}\cdot hr)(3600\ s/hr)}{1^{in}\ (1ft/12^{in})}\left(\frac{ac}{43560 ft^2}\right)\left(\frac{mi^2}{640\ ac}\right) = \underline{\underline{0.434\ mi^2}}$$

└ for UH, $r_d = 1^{in}$

b) Need a 2-hr UH for prediction:

t	1-hr UH	0.5×UH		0.5×UH		2-hr UH
0	0	0				0
1	80	40		0		40
2	120	60		40		100
3	60	30	+	60	=	90
4	20	10		30		40
5	0	0		10		10
6				0		0

(b)

t	2-hr UH	2xUH	3xUH	DRH
0	0	0		0
1	40	80		80
2	100	200	0	200
3	90	180	120	300
→ 4	40	80	300	380 ←
5	10	20	270	290
6	0	0	120	120
7			30	30
8			0	0

c) $Q(t) = DRH(t) + Q_b(t)$

$$\therefore Q_p = DRH_p + Q_b$$

$$= 380 + 15$$

$$= \underline{395 \text{ cfs}}$$

$$t_p = \underline{4^{hr}}$$

Table 2-2a.—Runoff curve numbers for urban areas[1]

Cover description		Curve numbers for hydrologic soil group—			
Cover type and hydrologic condition	Average percent impervious area[2]	A	B	C	D
Fully developed urban areas (vegetation established)					
Open space (lawns, parks, golf courses, cemeteries, etc.)[3]:					
Poor condition (grass cover < 50%)		68	79	86	89
Fair condition (grass cover 50% to 75%)		49	69	79	84
Good condition (grass cover > 75%)		39	61	74	80
Impervious areas:					
Paved parking lots, roofs, driveways, etc. (excluding right-of-way)		98	98	98	98
Streets and roads:					
Paved; curbs and storm sewers (excluding right-of-way)		98	98	98	98
Paved; open ditches (including right-of-way)		83	89	92	93
Gravel (including right-of-way)		76	85	89	91
Dirt (including right-of-way)		72	82	87	89
Western desert urban areas:					
Natural desert landscaping (pervious areas only)[4]		63	77	85	88
Artificial desert landscaping (impervious weed barrier, desert shrub with 1- to 2-inch sand or gravel mulch and basin borders)		96	96	96	96
Urban districts:					
Commercial and business	85	89	92	94	95
Industrial	72	81	88	91	93
Residential districts by average lot size:					
1/8 acre or less (town houses)	65	77	85	90	92
1/4 acre	38	61	75	83	87
1/3 acre	30	57	72	81	86
1/2 acre	25	54	70	80	85
1 acre	20	51	68	79	84
2 acres	12	46	65	77	82
Developing urban areas					
Newly graded areas (pervious areas only, no vegetation)[5]		77	86	91	94
Idle lands (CN's are determined using cover types similar to those in table 2-2c).					

[1]Average runoff condition, and $I_a = 0.2S$.
[2]The average percent impervious area shown was used to develop the composite CN's. Other assumptions are as follows: impervious areas are directly connected to the drainage system, impervious areas have a CN of 98, and pervious areas are considered equivalent to open space in good hydrologic condition. CN's for other combinations of conditions may be computed using figure 2-3 or 2-4.
[3]CN's shown are equivalent to those of pasture. Composite CN's may be computed for other combinations of open space cover type.
[4]Composite CN's for natural desert landscaping should be computed using figures 2-3 or 2-4 based on the impervious area percentage (CN = 96) and the pervious area CN. The pervious area CN's are assumed equivalent to desert shrub in poor hydrologic condition.
[5]Composite CN's to use for the design of temporary measures during grading and construction should be computed using figure 2-3 or 2-4, based on the degree of development (impervious area percentage) and the CN's for the newly graded pervious areas.