53:078 Principles of Hydrology
Exam 1
Spring 2003

Name: KEY

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

$$\Delta S = \bar{I} - \overline{Q}$$

$$Z = \frac{1}{V}\sum_{i=1} D_i^6$$

$$Z = \alpha R^{\beta}$$

$$CD = 1 - \frac{P_{gage}}{P_{true}}$$

$$P_x = \sum_{i=1}^{n} w_i P_i$$

$$w_i = \frac{(1/x_i)^2}{\sum_{i=1}^{n}(1/x_i)^2}$$

$$w_i = \frac{1}{n}\frac{N_x}{N_i}$$

$$P_A = \sum_{i=1}^{n} w_i P_i$$

$$\beta = \frac{H_s}{Q_e}$$

$$R_n = H_s + Q_e$$

$$Q_e = \frac{R_n}{1+\beta}$$

$$E = \frac{1}{l_v \rho_v}\frac{R_n}{1+\beta}$$

$$E = KE_p$$

$$\theta = \frac{V_w}{V}$$

$$F_p = i t_p$$

$$f^*(t) = \frac{1}{2}St^{-1/2} + K$$

$$F^*(t) = St^{1/2} + Kt$$

$$t_p = \frac{S^2(i - K/2)}{2i(i-K)^2}$$

$$t_0 = t_p - \frac{1}{4K^2}\left(\sqrt{S^2 + 4KF_p} - S\right)^2$$

$$f^*(t) = f_c + (f_0 - f_c)e^{-kt}$$

$$F^*(t) = f_c t + \frac{(f_0 - f_c)}{k}(1 - e^{-kt})$$

$$t_p = \frac{1}{ik}\left[f_0 - i + f_c \ln\left(\frac{f_0 - f_c}{i - f_c}\right)\right]$$

$$t_0 = t_p - \frac{1}{k}\ln\left(\frac{f_0 - f_c}{i - f_c}\right)$$

1 day = 86400 s

$1\ mi^2 = 640$ ac

$1\ acre = 43560\ ft^2$

$g = 9.8065\ m\ s^{-2}$

$l_v = 2.5 \times 10^6\ J\ kg^{-1}$

$\rho_v = 1000\ kg\ m^{-3}$

$1\ W = 1\ J\ s^{-1}$

$1\ mb = 100\ Pa = 100\ N\ m^{-2}$

(25) 1. Miscellaneous

5 a) Weather radars do not measure rainrate. What do radars measure? How is it related to rainfall? Provide your answer in two or three sentences (**no equations allowed**):

Radar measure the EM reflected back from objects in the beam's path. The energy reflected depends on the number and size of raindrops in the sampling volume.

4 b) The two main factors affecting evaporation from an open water surface are:

supply of energy (net radiation)

transport of vapor away (wind)

5 c) At a meteorological station, the evaporative heat flux is 200 W/m^2 and the sensible heat flux is 100 W/m^2. The evaporation rate is 6.9 mm/day and the Bowen's ratio is 0.5 .

$$Q_e = 200 \text{ W/m}^2$$

$$E = \frac{200 \text{ J s}^{-1} \text{m}^{-2}}{(2.5\times10^6 \text{ J kg}^{-1})(1000 \text{ kg/m}^3)}\left(\frac{1000 \text{ mm}}{\text{m}}\right)\left(\frac{86400 \text{ s}}{\text{day}}\right) = \underline{\underline{6.9 \text{ mm/day}}}$$

$$\beta = H_s/Q_e = 100/200 = \underline{\underline{0.5}}$$

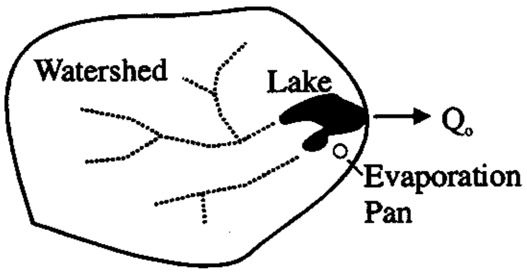
5 d) A streamflow hydrograph can be partitioned into two components. The direct runoff component is water that travels quickly to the stream channel during a storm event. The baseflow component is water that reaches the water table and moves slowly to the stream.

6

Runoff Generation Mechanism	Definition
e) Subsurface stormflow	Water infiltrates and moves rapidly downslope through the unsaturated zone to the stream.
f) saturation excess	Runoff is generated when the water table reaches the ground surface. Runoff consists of return flow and precipitation on saturated areas.
g) infiltration excess	Runoff is generated when the rainrate exceeds the infiltration capacity.

(25) 2. Water Budget

Over a 30-day period, the areal average precipitation (P) over the region (*including* both the lake and the watershed) is 2.0 inches and the pan evaporation (E_p) is 7.0 inches. During this period, the lake outflow (Q_o) is a constant 1.5 cfs. Groundwater flows into and out of the lake and the watershed are negligible. Perform a water budget to determine the change in *lake storage* for the month.



Some hydrologic parameters for the lake and watershed:

Pan coefficient (K):	0.60
Runoff coefficient (C):	0.20 (discharge as a fraction of precipitation)
Bowen's Ratio:	0.40
Watershed drainage area:	1920 acres (excluding the lake area)
Lake area:	18 acres (constant)

4 a) Derive the lake water budget equation. Define any symbols use (if they are not defined above). For you final answer, include only those terms that are relevant for the 30-day period. To receive full credit, CLEARLY MARK YOUR FINAL ANSWER.

6 b) The lake evaporation is ___6.3___ acre-feet.

15 c) The change in lake storage is ___-28.6___ acre-feet.

a) Lake water budget

GW negligible

$$\Delta S = (P - E) + (Q_i - Q_o) + (\cancel{G_i} - G_o)$$

$\Delta t = 30$ days

$$\boxed{\Delta S = (P - E) + (Q_i - Q_o)}$$

units ac-ft

Precip

Evaporation

surface outflow

surface inflow

change in Lake storage

b) $E = k_p E_p = 0.6(7^{in}) = 4.2^{in}$

For the lake area:

$$E = 4.2^{in}(18\,ac)\left(\frac{ft}{12^{in}}\right) = \underline{\underline{6.3\ ac\text{-}ft}}$$

c) $\Delta S = (P - E) + (Q_i - Q_o)$ units: $\underline{\underline{ac\text{-}ft}}$

$$P = 2^{in}(18ac)\left(\frac{ft}{12^{in}}\right) = 3.0\ ac\text{-}ft$$

Q_i = amount of discharge

$= CPA_w$

$$= 0.2(2^{in})(1920\,ac)\left(\frac{1\,ft}{12^{in}}\right) = 64.0\ ac\text{-}ft$$

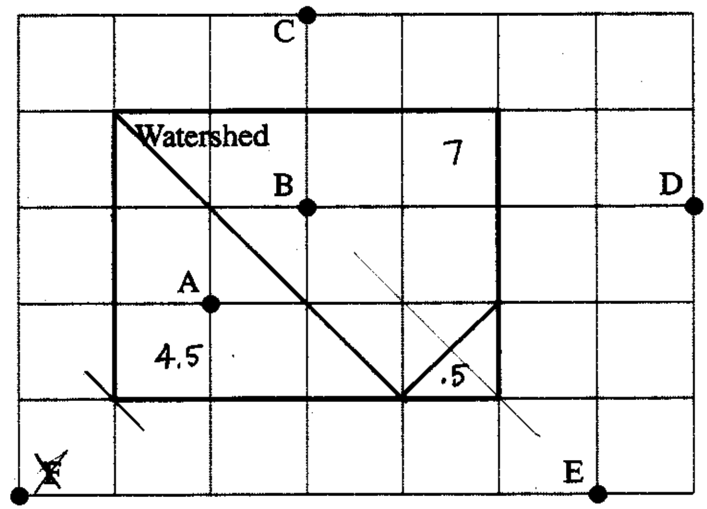
$$Q_o = \frac{\left(1.5\frac{ft^3}{s}\right)\left(\frac{86400s}{day}\right)(30\,day)}{43560\,ft^2/ac} = 89.26\ ac\text{-}ft$$

$$\therefore\ \Delta S = (3.0 - 6.3) + (64.0 - 89.3)$$

$$= \underline{\underline{-28.6\ ac\text{-}ft}}$$

(25) 3. Storm Analysis During a Flood Event

A prolonged period (1 week) of extreme rainfall produced flooding for a watershed (see sketch). Use the gage information listed below to estimate the rainfall for this storm. If needed, fill in missing gage measurements using the *three nearest gages* with precipitation observations.



Gage	Normal Weekly Precip (mm)	Storm Measured Precip (mm)
A	24	120
B	25	?
C	22	100
D	20	80
E	24	140
F	28	?

9 a) The storm precipitation at B is 112.9 mm based on the Normal Ratio method.

16 b) The areal average precipitation for the watershed is 116.7 mm using the Thiessen Polygon method.

a) The 3 closest gages are A, C, and D:

$$P_B = \frac{N_B}{n}\left\{\frac{P_A}{N_A} + \frac{P_C}{N_C} + \frac{P_D}{N_D}\right\}$$

$$= \frac{25}{3}\left\{\frac{120}{24} + \frac{100}{22} + \frac{80}{20}\right\}$$

$$= \underline{\underline{112.9\ \text{mm}}}$$

b)

i	A_i	P_i	A_iP_i
A	4.5	120	540
B	7	112.9	790.3
E	0.5	140	70
	12		1400.3

$$\overline{P} = \frac{1400.3}{12} = \underline{\underline{116.7\ \text{mm}}}$$

(25) 4. **Infiltration During a Storm**

The properties of a soil in an infiltration basin are:

Soil:	Sand	f_0:	30 cm/hr
η:	0.42	f_c:	3 cm/hr
θ_i:	0.20	k:	2 hr^{-1}

i

For the design event, water flows into the infiltration basin at a constant rate of 10 cm/hr for a 4-hour period.

Answer the following:

14 a) The cumulative infiltration F is 8 cm at a time of 0.8 hr. The infiltration rate f at this time is 10 cm/hr.

7 b) The infiltration rate f is 4 cm/hr at a time of 2.18 hr.

4 c) The soil water content θ at the surface at the end of the design event is 0.42.

$$t_p = \frac{1}{(10)(2)}\left[30 - \overset{\text{cm/hr}}{10} + 3\ln\left(\frac{30-3}{10-3}\right)\right] = 1.202\,hr$$

$\frac{cm}{hr}$ $\frac{1}{hr}$

$$t_o = 1.202 - \frac{1}{2}\ln\left(\frac{30-3}{10-3}\right) = 0.528\,hr$$

$$F_p = it_p = (10\,cm/hr)(1.202\,hr) = 12.02\,cm$$

a) Since $F = 8\,cm < F_p$, then $t < t_p$, hence

$F = it \qquad t = F/i = 8\,cm/10\,cm/hr = \underline{\underline{0.8\,hr}}$

$f = i = \underline{\underline{10\,cm/hr}}$

b) Since $f < i$, then $t > t_p$, so

$$f = f^*(t-t_o) = f_c + (f_o - f_c)e^{-k(t-t_o)}$$

$$e^{-k(t-t_o)} = \frac{f-f_c}{f_o-f_c}$$

$$-k(t-t_o) = \ln\left(\frac{f-f_c}{f_o-f_c}\right)$$

$$\therefore t = t_o - \frac{1}{k}\ln\left(\frac{f-f_c}{f_o-f_c}\right)$$

$$t = 0.528 - \frac{1}{2}\ln\left(\frac{4-3}{30-3}\right) = \underline{\underline{2.18\ \text{hr}}}$$

c) At end of event, $t = 4\text{hr} > t_p$, $\therefore$ ponding (saturation) at surface. Since the porosity η is 0.42,

$$\theta = \underline{\underline{0.42}}$$