Rational Method

Lecture 14, 05/16/2013

Arturo Leon, Oregon State University (Spring 2013)

Adapted from textbook and notes of Philip B. Bedient and Areeya Rittima

Peak Flow discharge using the Rational Method

2

In urban or rural developments, it is necessary to determine the peak flow discharges for different periods of return in order to size the drainage system

③

Peak Flow discharge using the Rational Method (Cont.)

BIO-retention pond

street

4

Peak Flow discharge using the Rational Method (Cont.)

failure of design of "inlet", or underground stormwater system

check dam

Rain garden

5

Rational Method

- Developed in 1800s in England
- Assumes that peak flow($\boldsymbol{Q_p}$) is a function of rainfall intensity ($\boldsymbol{i}$) applied uniformly over the entire watershed for a duration $\boldsymbol{D}$
- Assumes that frequency (return period) of $\boldsymbol{Q_p}$ is equal to frequency of rainfall intensity (works well for large Return periods)
- The proper rainfall duration is equal to the time of concentration.

max. flow is obtained when $D = t_c$

6

Rational Method

$$Q_p = k_c C i A$$

English — Metric

Where:

Q_p = Peak flow (cfs or m^3/s)

C = Runoff coefficient (dimensionless)

i = rainfall intensity (*in/hr* or *mm/hr*)

A = Catchment area (ac or ha)

k_c = conversion factor.

- For U.S. units K_c = 1.008 (~ 1.0)
- For Metric units K_c = 0.00278

What is needed for the Rational Method

7

- Time of concentration ✓
- Rainfall intensity-duration-frequency (IDF) curves
- Drainage area size (*A*)
- Runoff coefficient (*C*)

For different land uses, the runoff coefficient "C" can be obtained as an area-weighted runoff coefficient as follows:

$$C_w = \frac{C_A \cdot A_A + C_B A_B}{A_A + A_B}$$

$$C = \frac{\sum C_i A_i}{\sum A_i}$$

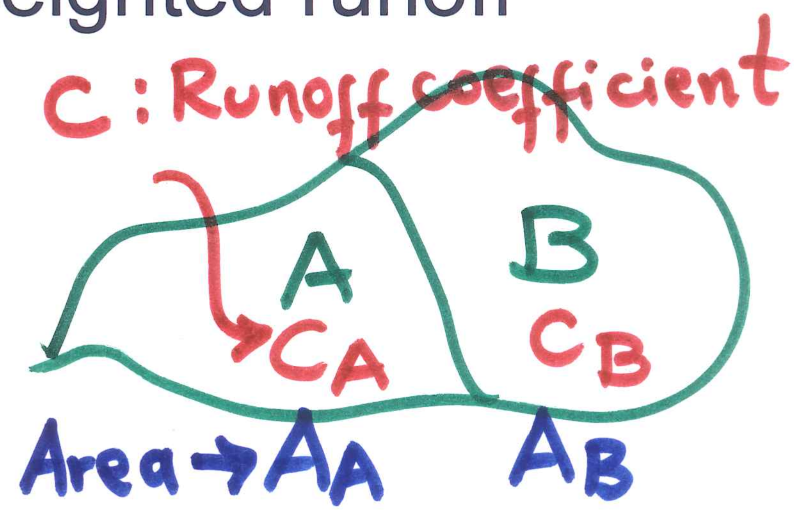
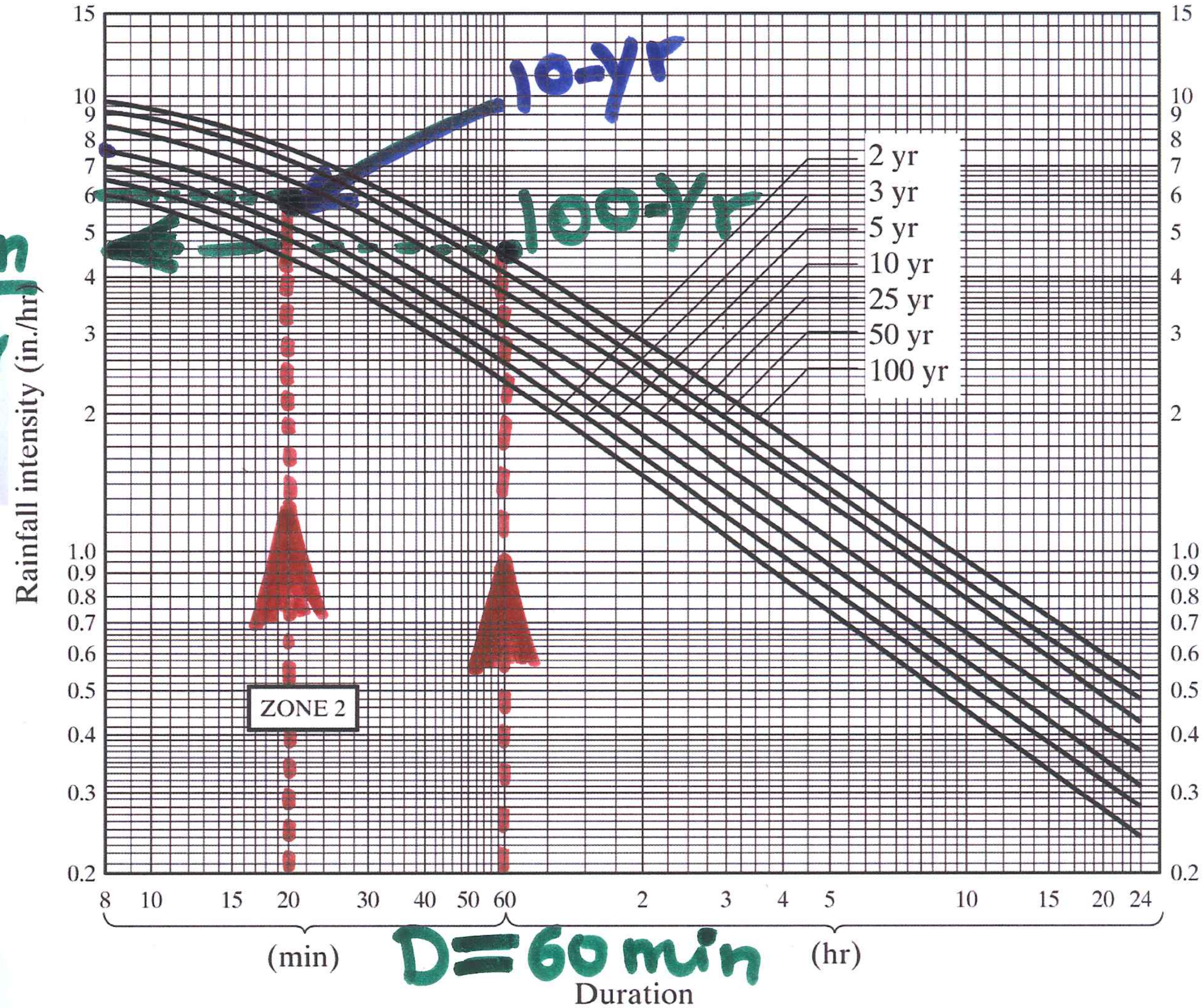


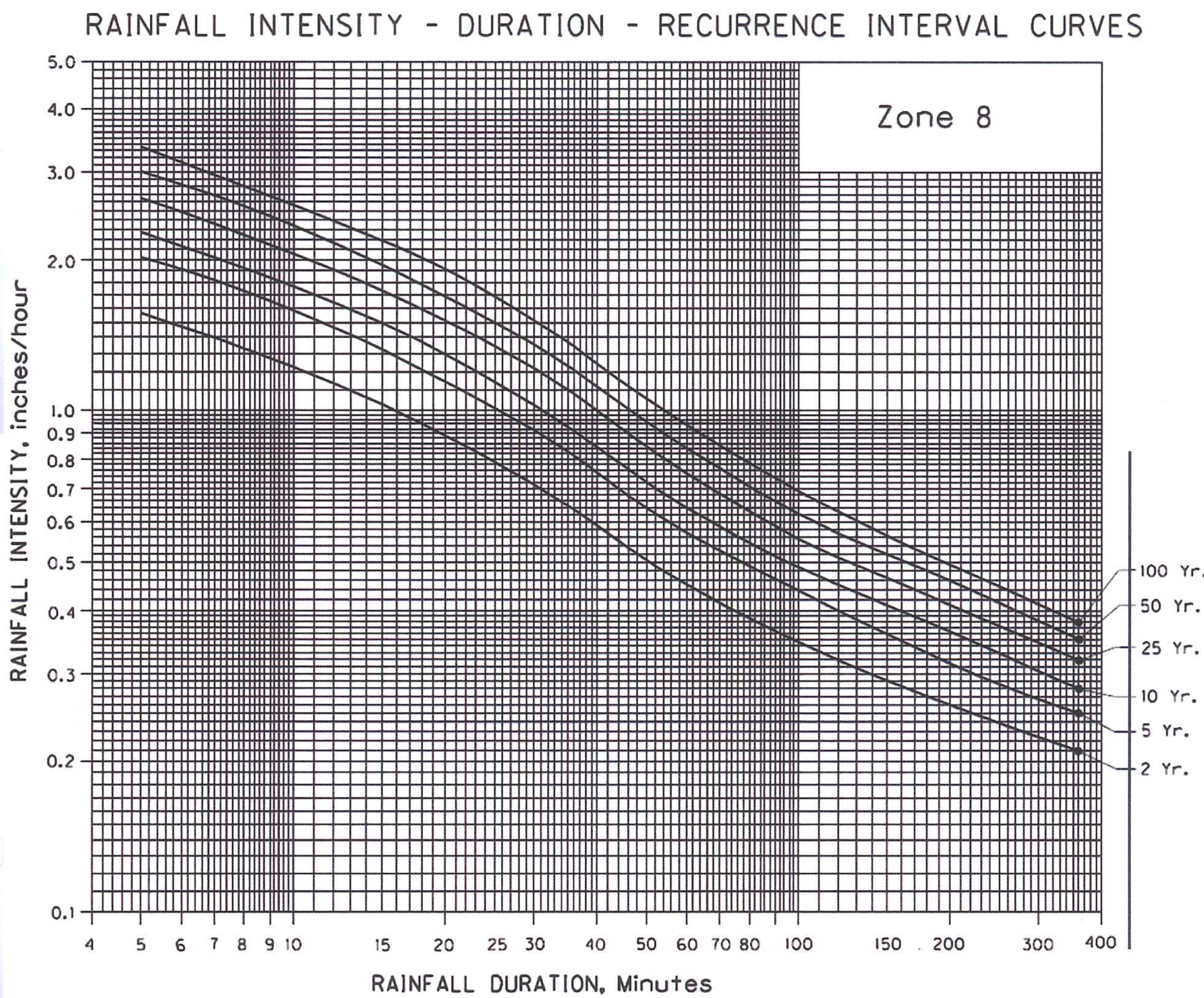
Figure 6-5 IDF curves for the Tallahassee, Florida, region



Source: K. E. Weldon, in "FDOT Rainfall Intensity_Duration_ Frequency Curve Generation," in *Stormwater Management, An Update*, M. P. Wanielista and Y. A. Yousef, eds., Environmental Systems Engineering Institute, University of Central Florida, Orlando, FL, July, pp.11–31, © 1985)

Intensity-Duration-Frequency Curves for Corvallis, OR

9



Source: ODOT Hydraulics manual

Table 6-5 Typical Runoff Coefficients for 2-yr to 10-yr Frequency Design

Table 6–5 Typical Runoff Coefficients for 2-yr to 10-yr Frequency Design

Description of Area	Runoff Coefficients
Business	
Downtown areas	0.70–0.95
Neighborhood areas	0.50–0.70
Residential	
Single-family areas	0.30–0.50
Multi-units, detached	0.40–0.60
Multi-units, attached	0.60–0.75
Residential (suburban)	0.25–0.40
Apartment dwelling areas	0.50–0.70
Industrial	
Light areas	0.50–0.80
Heavy areas	0.60–0.90
Parks, cemeteries	0.10–0.25
Playgrounds	0.20–0.35
Railroad yard areas	0.20–0.40
Unimproved areas	0.10–0.30

10

$0 \leq C \leq 1$

more permeable ← → more imp.

10-yr

2-yr

Table 6-5 (continued) Typical Runoff Coefficients for 2-yr to 10-yr Frequency Design

Table 6–5 Typical Runoff Coefficients for 2-yr to 10-yr Frequency Design

Description of Area	Runoff Coefficients
Streets	
Asphalt	0.70–0.95
Concrete	0.80–0.95
Brick	0.70–0.85
Drives and walks	0.75–0.85
Roofs	0.75–0.95
Lawns, sandy soil	
Flat, 2%	0.05–0.10
Average, 2%–7%	0.10–0.15
Steep, 7%	0.15–0.20
Lawns, heavy soil	
Flat, 2%	0.13–0.17
Average, 2%–7%	0.18–0.22
Steep, 7%	0.25–0.35

These runoff coefficients are typical values for return periods of 2–10 yr. Higher values are appropriate for higher return periods.
Source: ASCE and WPCF (1969).

11

Tr=2-yr

Tr=10-yr

Example 6-5 RATIONAL METHOD DESIGN WITH INLET TIMES

The 10-yr peak flow at a stormwater inlet in Tallahassee, Florida, is to be determined for a 40-ha area in rolling terrain. An inlet time of 20 min may be assumed. Land use is as follows.

time of concentrat.

Land Use	Area (ha)	Runoff Coefficient*
Single-family residential	30	0.40
Commercial	3	0.60
Park	7	0.15

*From Table 6–5.

$Q_p(10\text{-yr}) = ??$, $A = 40\text{-ha}$

$t_c = 20$ min

Example 6-5 (continued) RATIONAL METHOD DESIGN WITH INLET TIMES

D = tc

We find an area-weighted runoff coefficient:

$$\overline{C} = \frac{\Sigma A_i C_i}{\Sigma A_i} = \frac{30 \times 0.4 + 3 \times 0.6 + 7 \times 0.15}{30 + 3 + 7} = 0.37.$$

time of concentration

From Figure 6–5, for an inlet time of 20 min and return period of 10 yr, the average intensity is 5.6 in./hr (142 mm/hr). The peak flow from Equation (6–8) is

$$Q_p = 0.00278 \times 0.37 \times 142 \times 40$$
$$= 5.8\ m^3/s.$$

$Q_p (m^3/s)$

$K_c = 0.00278$

$C = 0.37$

$i (mm/hr) = 142.4\ mm/hr$

$A (ha) = 40$

$$5.6 \frac{in}{hr} = 5.6 (25.4) \frac{mm}{hr} = 142.4\ mm/hr$$

DCIA = Directly connected impervious area

Example 6-7 RATIONAL METHOD DESIGN WITH SUBAREA CHECKS

14

$1 \text{ ac} = 43{,}560 \text{ ft}^2$

$Q_p = k_c \cdot C \cdot i \cdot A$

$k_c \sim 1.0$ (U.S)

RATIONAL METHOD DESIGN WITH SUBAREA CHECKS

A Tallahassee subdivision contributes drainage from the segment shown in Figure E6–7. Each of the five homes has a DCIA of 3200 ft^2, which drains to the street. The street drains to the two inlets indicated. Lawns are on "sandy soil of average slope." A 10-yr design standard is appropriate for residential subdivisions and streets. Runoff coefficients should be taken at the "high" end of ranges. Inlet times are 8 min for the impervious area of the subdivision and 20 min for the total area (impervious plus lawns). What is the design flow at the inlets (treated as one inlet)?

$Q_p (T = 10 \text{ yr}) = ??$

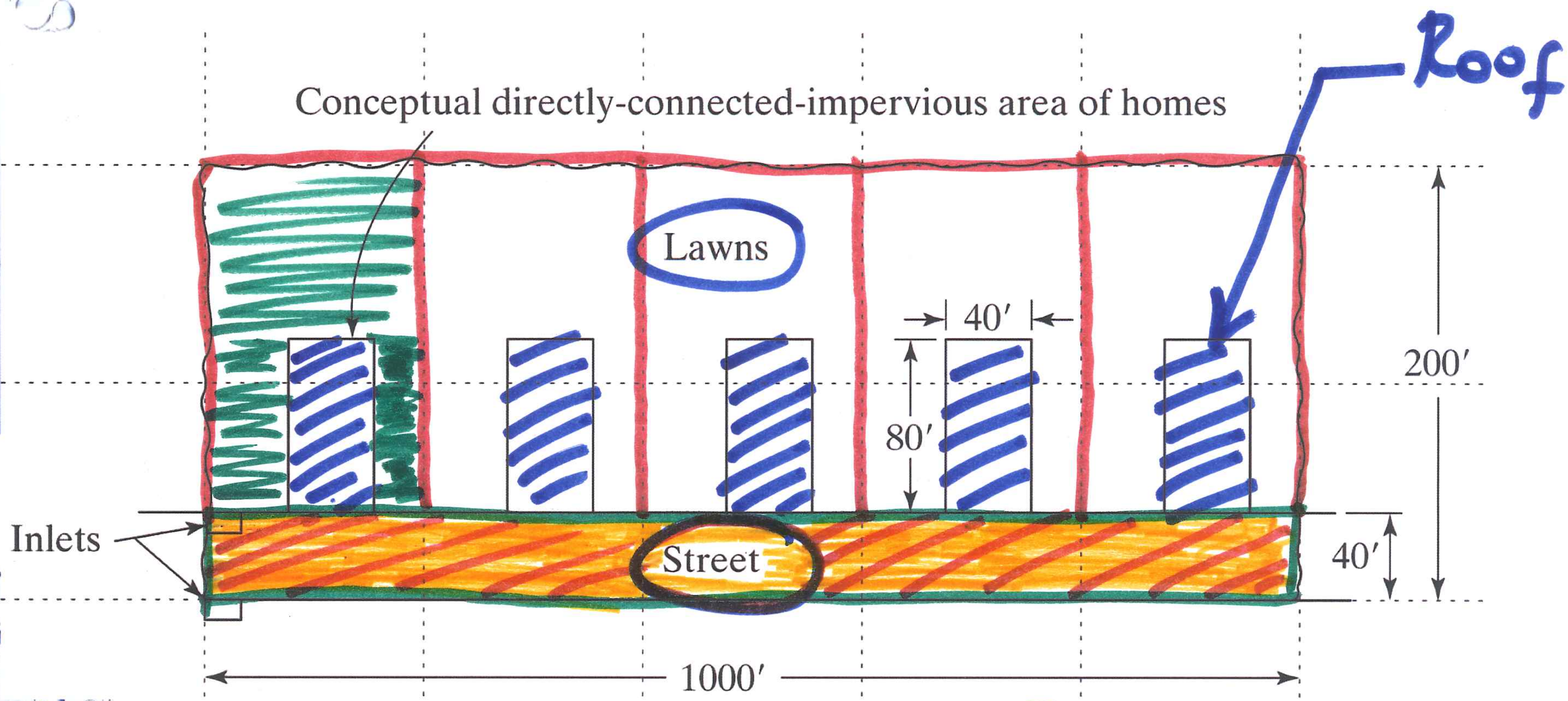
Descript.	Area (ft²)	Area (ac)	C	i (in/hr)	Qp (cfs)
DCIA	56,000	1.29	0.95	7.5	9.19
Lawns	144,000	3.30	0.15		
Total	200,000	4.59	0.37	5.7	9.68

with D = 8 min

D = 20 min

$Q_p = 9.68$ cfs

Figure E6–7 Conceptual sketch of subdivision illustrating DCIA.



A_{roof} each home = 3200 ft^2 → $A^{(5)}_{roofs}$

T = 10-yr

= 16,000 ft^2

$A_{streets}$ = 40,000 ft^2

∴ A_{DCIA} = 56,000 ft^2

16

Example 6-7 (continued) RATIONAL METHOD DESIGN WITH SUBAREA CHECKS

The area of the street is $1000 \times 40 = 40{,}000 \text{ ft}^2$. The area of the five homes is $5 \times 40 \times 80 = 16{,}000 \text{ ft}^2$. Hence, the total DCIA $= 56{,}000 \text{ ft}^2 = 1.29$ ac. The area of the total subdivision is $200 \times 1000 \text{ ft} = 200{,}000 \text{ ft}^2 = 4.59$ ac. Hence, the area of the lawns is $4.59 - 1.29 = 3.30$ ac.

From Table 6–5, the runoff coefficient for the DCIA subarea is 0.95. The runoff coefficient for the lawns is 0.15. An average runoff coefficient for the entire area is

$$\overline{C} = \frac{1.29 \times 0.95 + 3.30 \times 0.15}{4.59} = 0.37.$$

Example 6-7 (continued) RATIONAL METHOD DESIGN WITH SUBAREA CHECKS

From Figure 6–5, the 10-yr, 8-min rainfall intensity for Tallahassee is 7.5 in./hr, and the 10-yr, 20-min intensity is 5.7 in./hr. Hence, for the DCIA only,

$$Q = C_{\text{DCIA}} i A_{\text{DCIA}} = 0.95 \times 7.5 \times 1.29 = 9.2 \text{ cfs.}$$

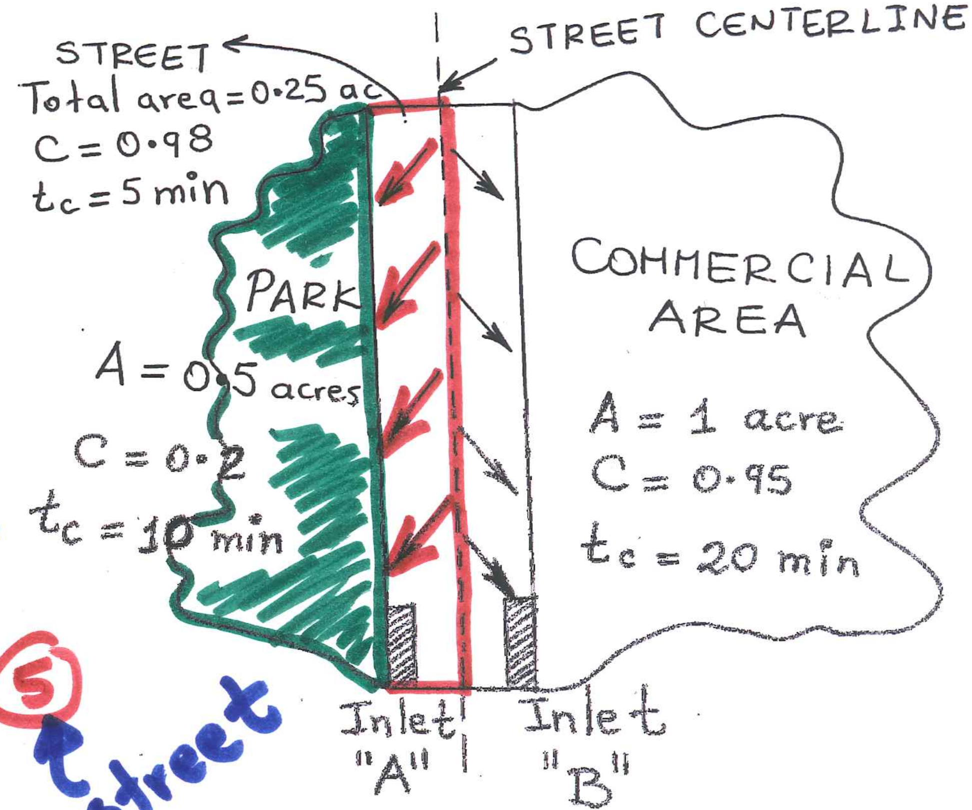
For the total area,

$$Q = \overline{C} i A_{\text{total}} = 0.37 \times 5.7 \times 4.59 = 9.7 \text{ cfs.}$$

The total area governs in this case, and the sewer downstream of the inlet should be sized for 9.7 cfs. But there are frequent occasions when the DCIA will govern. Both areas should be routinely checked during application of the rational method. At this point, the pipe again could be sized, as in Example 6–6, part (b).

Question of Final Exam of CE 412/512, Spring 2011

A basin is to be developed into a 0.5 acre park (C = 0.2) and 1 acre of a commercial area (C = 0.95). An asphalt street (C = 0.98) having a total area of 0.25 acres separates the future park and commercial area as sketched below. The times of concentration (t_c) for the park, commercial area and street are 10, 20 and 5 minutes, respectively. If the local IDF curve is given by the following relation



$$i = \frac{a}{b + t_r} = \frac{160}{18 + 10}$$

Park → 10 ↔ 5 ← Street

where i = rainfall intensity (in/hr), t_r = duration (min) and "a" and "b" are constants equal to 160 and 18, respectively for a return period of 5-years. What should be the 5-year design peak flow at inlet "A" (see sketch below). Assume that half of the flow of the street drains to each inlet.

Desc.	Area (ac)	C	tc (min)	i in/hr	Q (cfs)
Park	0.5	0.2	10	5.71	0.57
street	0.25/2 = 0.125	0.98	5	6.96	0.85
total	0.625	0.356	10	5.71	1.27

$Q_p = 1.27$ cfs

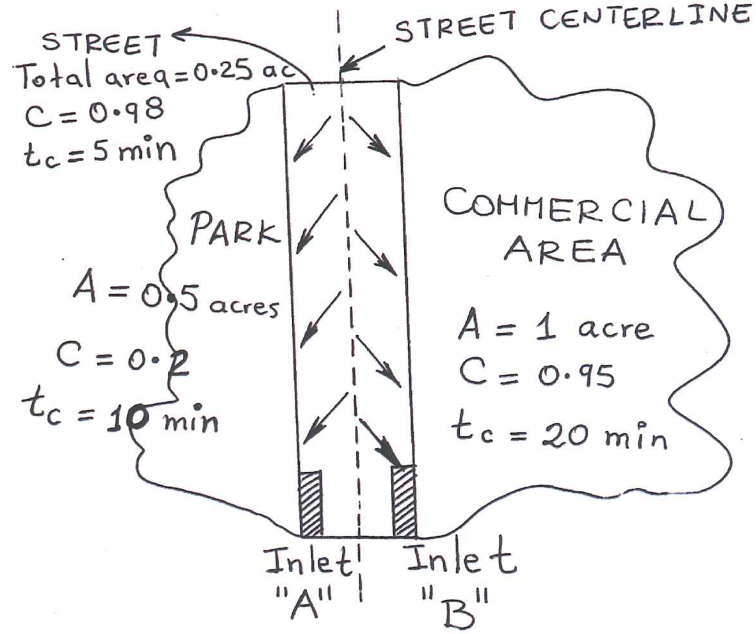
$$Q_p = K_c \times C \times i \times A \qquad K_c \sim 1.0 \text{ (English units)}$$

$$Q_{p_{park}} = 1.0 \times 0.2 \times 5.71 \times 0.5 = 0.57 \text{ cfs}$$

In-class Assignment 4

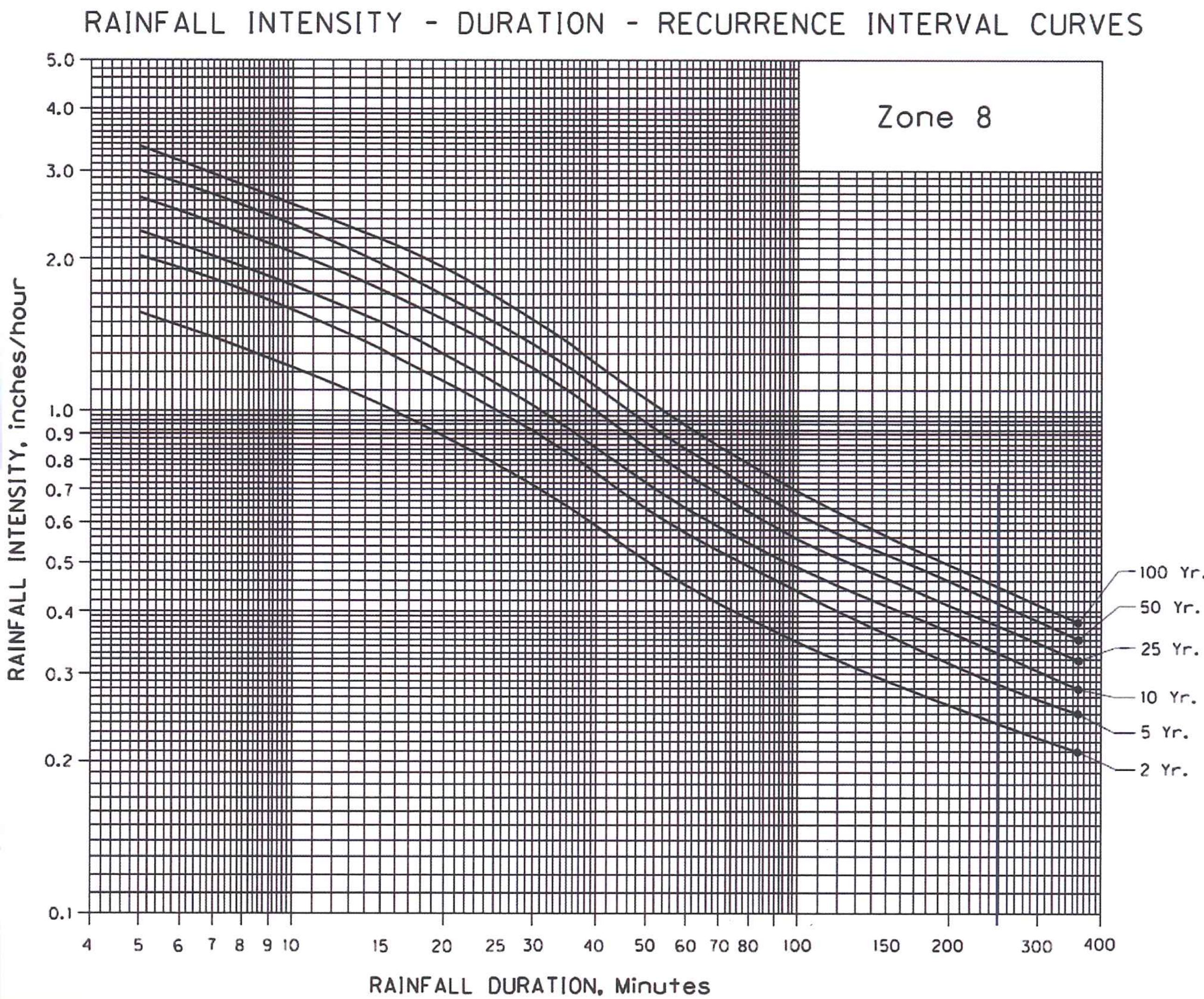
Student Name:

A basin in **Corvallis** is to be developed into a 0.5 acre park (C = 0.2) and 1 acre of a commercial area (C = 0.95). An asphalt street (C = 0.98) having a total area of 0.25 acres separates the future park and commercial area as sketched below. The times of concentration (t_c) for the park, commercial area and street are 10, 20 and 5 minutes, respectively. The Corvallis IDF Curve is given in the next page.



What should be the 5-year design peak flow at **inlet "B"** (see sketch)? Assume that half of the flow of the street drains to each inlet.

Intensity-Duration-Frequency Curves for Corvallis, OR



Source: ODOT Hydraulics manual