

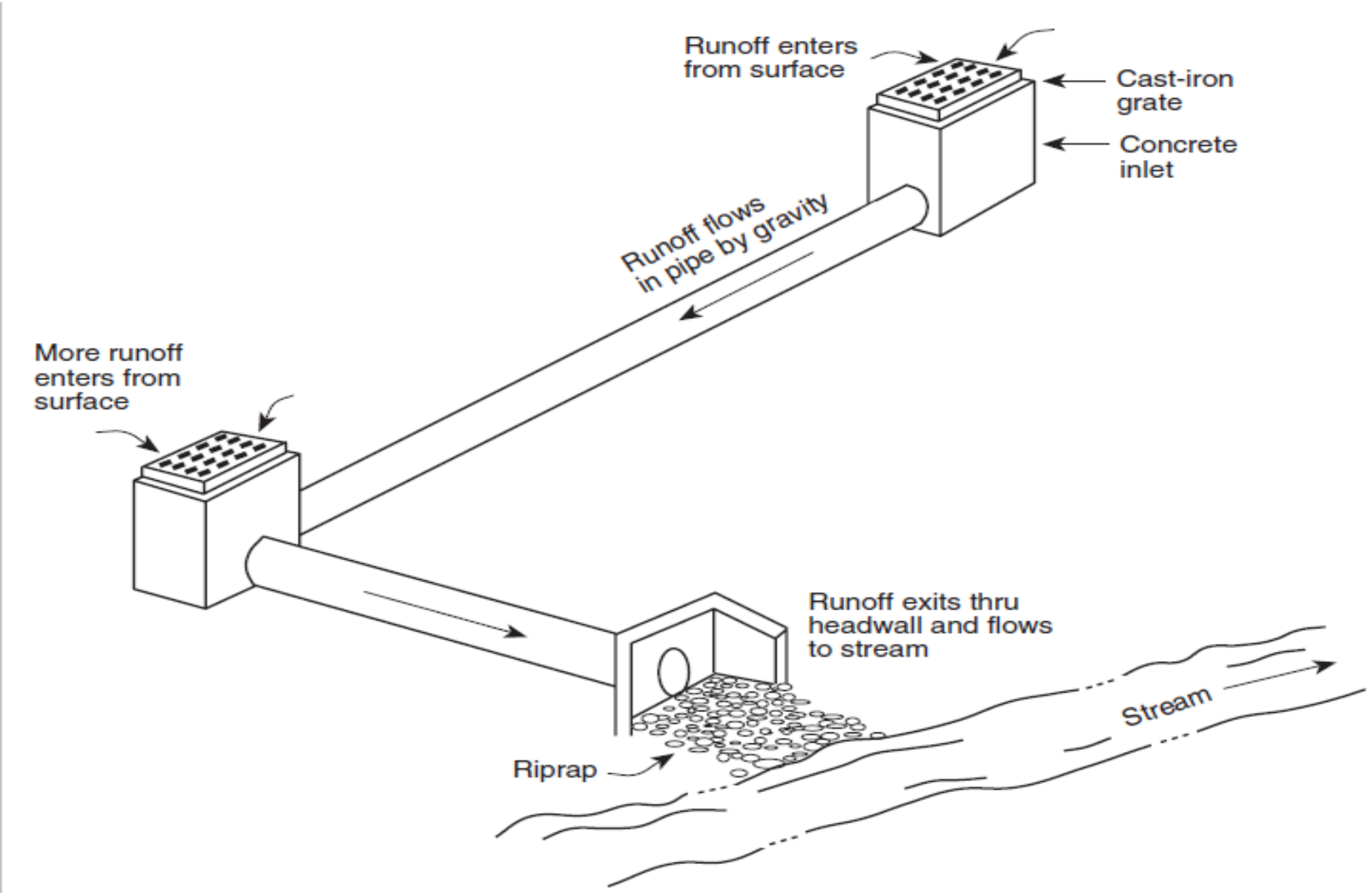
Design of Storm Sewer Systems



Introduction

- When rain falls on a certain area,
  - a portion will be lost by evaporation,
  - a portion will be lost by infiltration into ground,
  - a portion will be intercepted by vegetation,
  - a portion will be held in depression, and
  - a portion will flow overland (run off).
- Storm sewers should be designed to carry the **maximum (peak) rain runoff** produced from a certain drainage area (catchment basin).

Essential elements of a storm sewer system



When Not Having an Efficient Storm Water Collection System














SHERIFF



Main Aspects of Storm Sewer Design

- From an engineering viewpoint, the design of storm water collection systems can be divided into two main aspects:
- Runoff prediction
- Pipe sizing (diameters) and Slopes

Methods to determine the peak runoff

- Empirical formula
- Rainfall runoff correlation studies
- The inlet method
- Digital computer models
- The hydrograph method
- The Rational method
- The *rational method is the most popular method for the* design of storm sewers

The Rational Method

- Relates the peak discharge (q, m3/sec) to the drainage area (A, ha), the rainfall intensity (i, mm/hr), and the runoff coefficient (C)

$$q = \frac{CiA}{360}$$

- It is based on the theory that for a rainfall of average intensity, I, falling over an impervious area of size A, the ***maximum rate of runoff at the outlet of the drainage*** area, Q, occurs when *the whole area is contributing to the runoff at the same time*

Runoff Coefficient (C)

- C relates the combined effects of infiltration, evaporation and surface storage.
- It increases as the rainfall continues (depends on characteristics of drainage area: slope, moisture, soil type, ground cover, etc.).
- For a composite drainage area (e.g. residential area and business area) an effective runoff coefficient can be obtained by estimating the percentage of the total area that is covered by roofs, lawn, etc., multiplying each fraction by the corresponding C and then summing the products:

$$C_{\text{effective}} = C_1 (A_1/A_{\text{total}}) + C_2 (A_2/A_{\text{total}}) + \ldots\ldots\ldots$$

$$C_{\text{effective}} = (C_1 A_1 + C_2 A_2 + \ldots\ldots) / A_{\text{total}}$$

C values for various surfaces

TABLE 13-2
Runoff coefficients for various surfaces

Type of surface	*C*
Watertight roofs	0.70–0.95
Asphaltic cement streets	0.85–0.90
Portland cement streets	0.80–0.95
Paved driveways and walks	0.75–0.85
Gravel driveways and walks	0.15–0.30
Lawns, sandy soil	
2% slope	0.05–0.10
2–7% slope	0.10–0.15
> 7% slope	0.15–0.20
Lawns, heavy soil	
2% slope	0.13–0.17
2–7% slope	0.18–0.22
> 7% slope	0.25–0.35

Runoff Coefficients (C)

Business:	
Downtown areas	0.70–0.95
Neighborhood areas	0.50–0.70
Residential:	
Single-family areas	0.30–0.50
Multiunits, detached	0.40–0.60
Multiunits, 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

Example 1

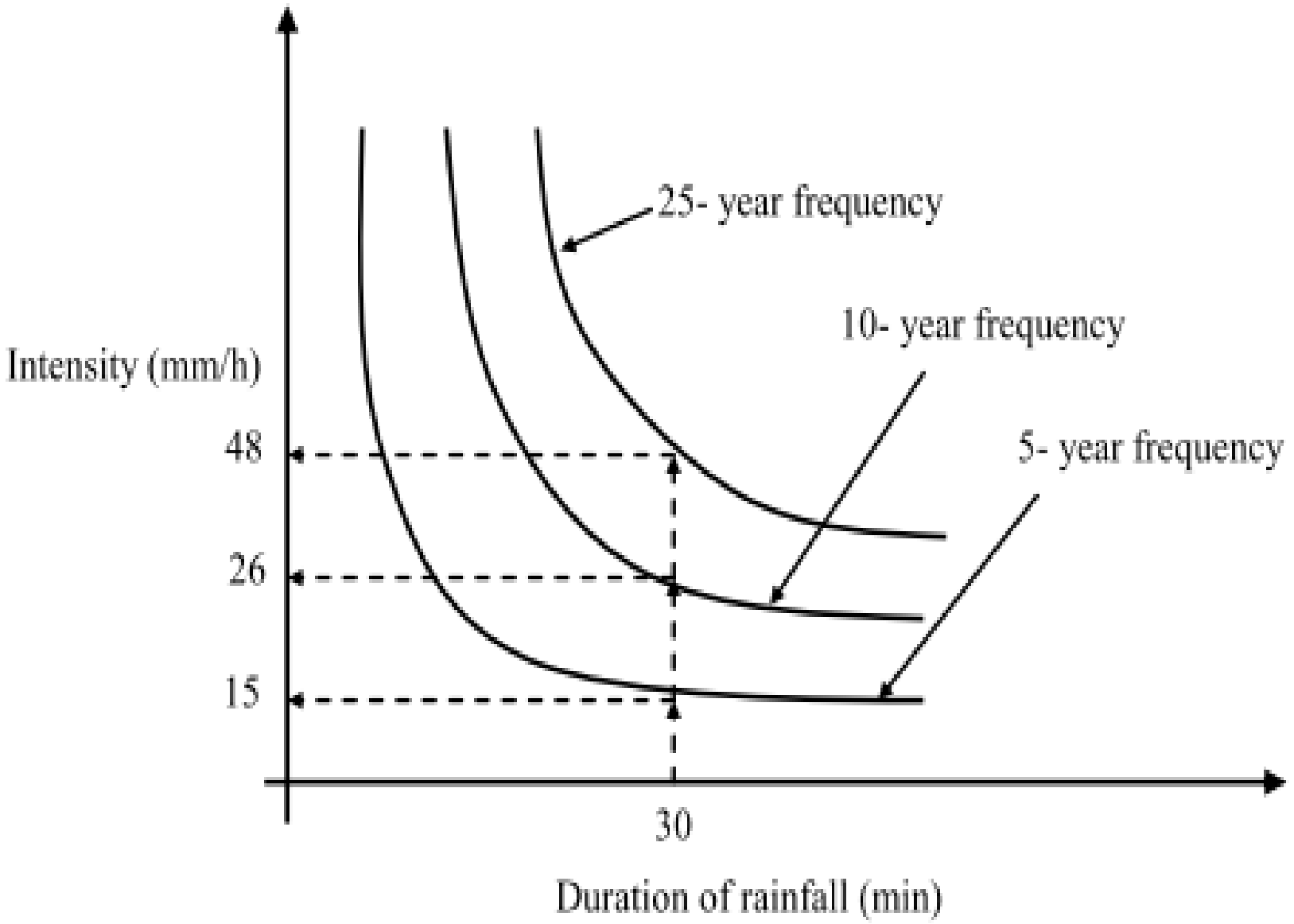
- Determine the run off coefficient for an area of 0.2 Km2, of which 3000 m2 is covered by buildings, 5000 m2 by paved driveways and walk, and 2000 m2 by Portland cement streets. The remaining area is flat, heavy soil covered by grass with a slope of 2 %.

Solution

Surface Type	Area (m^2)	C (Table 13-2)	C_i (A_i/A_{total})
Roofs	3000	0.7 – 0.95	0.7 (3000/200,000) – 0.95 (3000/200,000) = 0.0105 – 0.0143
Paved driveway	5000	0.75 – 0.85	0.75 (5000/200,000) – 0.85 (5000/200,000) = 0.0188 – 0.0213
Cement streets	2000	0.8 – 0.95	0.8 (2000/200,000) – 0.95 (2000/200,000) = 0.008 – 0.0095
Lawn (Slope = 2% ≈ flat)	190,000	0.13 – 0.17	0.13 (190,000/200,000) – 0.17 (190,000/200,000) = 0.124 – 0.162
		$C_{effective} = \sum$	0.16 – 0.21

IDF Curves

- Intensity: the average amount of rain falling per unit time (mm/min).
- Duration: the time interval the rain falls with a given intensity (min).
- Frequency (recurrence interval, or return period): the average period in years between rainfalls of a given intensity for a given duration.
- For storms with duration of 30 minutes, the maximum average intensity anticipated once every 5 years is about 15 mm/h, and
- And the maximum average intensity anticipated once every 10 years is 26 mm/h.


25- year frequency
10- year frequency
5- year frequency
Intensity (mm/h)
48
26
15
30
Duration of rainfall (min)

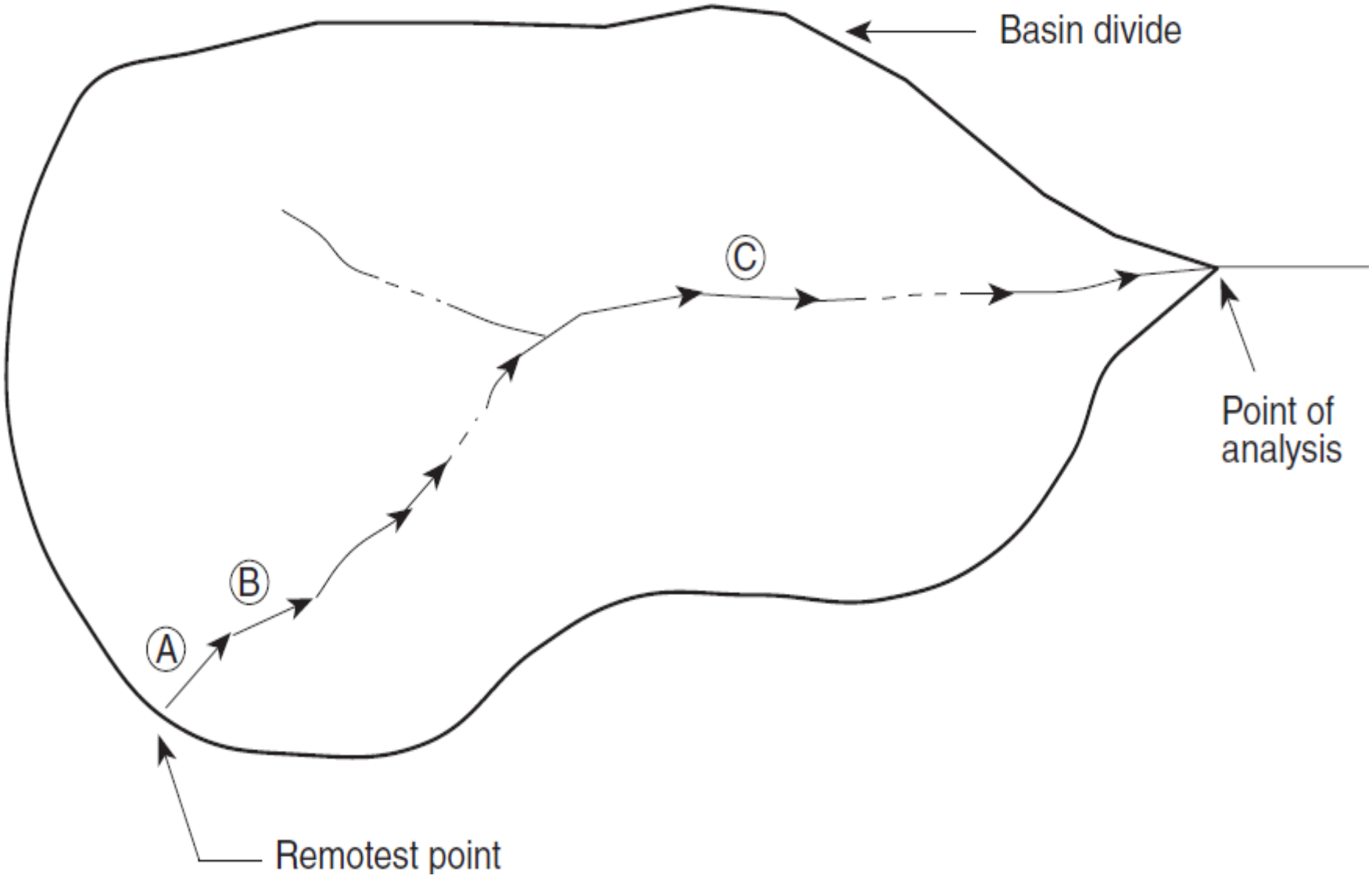
Frequency (return period)

- It establishes the frequency with which the sewer system will be overloaded on an average.
- The frequency chosen is a matter of economics.
- It is too expensive to design a sewer to carry largest flow which could ever occur
- But, flood damage to properties should be avoided whenever possible.
- 5-year frequency is used for residential areas.
- 10-years frequency is used for business areas.
- 15-year frequency is used for high-value districts.

Duration (Time of concentration, tc)

- **Time of concentration**: the time required for the maximum runoff to develop (the time required by the water to reach the outlet or sewer from the most remote point of the drainage area).
- The maximum runoff will be obtained for the rain having a duration equal to the time of concentration (which is called the critical rainfall duration).
- After tc is determined, the intensity can be obtained from the intensity-duration-frequency curve.
- The time of concentration is the sum of: **(i) the inlet time t0** (the time it takes for flow from the remotest point to reach the sewer inlet), and **(ii) the flow time tf** in the upstream sewers connected to the outer point

Tc



Time of Concentration in Sewer Systems

$$t_c = t_o + t_f$$

where *to = overland flow travel time*

tf = channel flow travel time

- The channel flow time is computed by

$$t_f = \frac{L_c}{V}$$

where L_c = channel length
V = average velocity

- The overland flow time to can be estimated by using one of the empirical or semi empirical formulas given in Table 3.2.

TABLE 3.2 Selected Time of Concentration Formulas for Overland Flow

Name	Formula, t_o in min	Remarks
Izzard (1946)	$= 41\left(0.0007i^{1/3} + \frac{k}{i^{2/3}}\right)\left(\frac{L}{S}\right)^{1/3}$	Experimental, for $iL < 500$, value of k see Table 6.16
Kerby (1959)	$= 0.83\left(\frac{N_k L}{\sqrt{S}}\right)^{0.467}$	Empirical, for $L \leq 1200$ ft., see Table 6.17 for values of N_k
Airport	$= 0.39(1.1 - C)\frac{\sqrt{L}}{S^{1/3}}$	Applicable to areas similar to airport conditions, see Table 6.12 for runoff coefficient C
Schaake et al. (1967)	$= \frac{0.503L^{0.24}}{S^{0.16}\alpha^{0.26}}$	α = percent imperviousness of area
Morgali and Linsley (1965)	$= 0.99\frac{n^{0.605}L^{0.593}}{i^{0.388}S^{0.38}}$	Works best for turbulent flow on homogeneous surface
Kinematic wave	$= \frac{0.93}{i^{0.4}}\left(\frac{nL}{\sqrt{S}}\right)^{0.6}$	Same as above
Yen and Chow (1983)	$= K_y\left(\frac{NL}{\sqrt{S}}\right)^{0.6}$	Modified from kinematic wave formula, see Table 6.19 for values of K_y and Table 6.18 for values of N

Rational method – Time of Concentration

- Inlet time
  - for small fully-sewered areas, some drainage authorities specify t_o as a constant typically ranging from 5 to 15 minutes
  - In more complex situations, it is recommended to use the kinematic wave formula

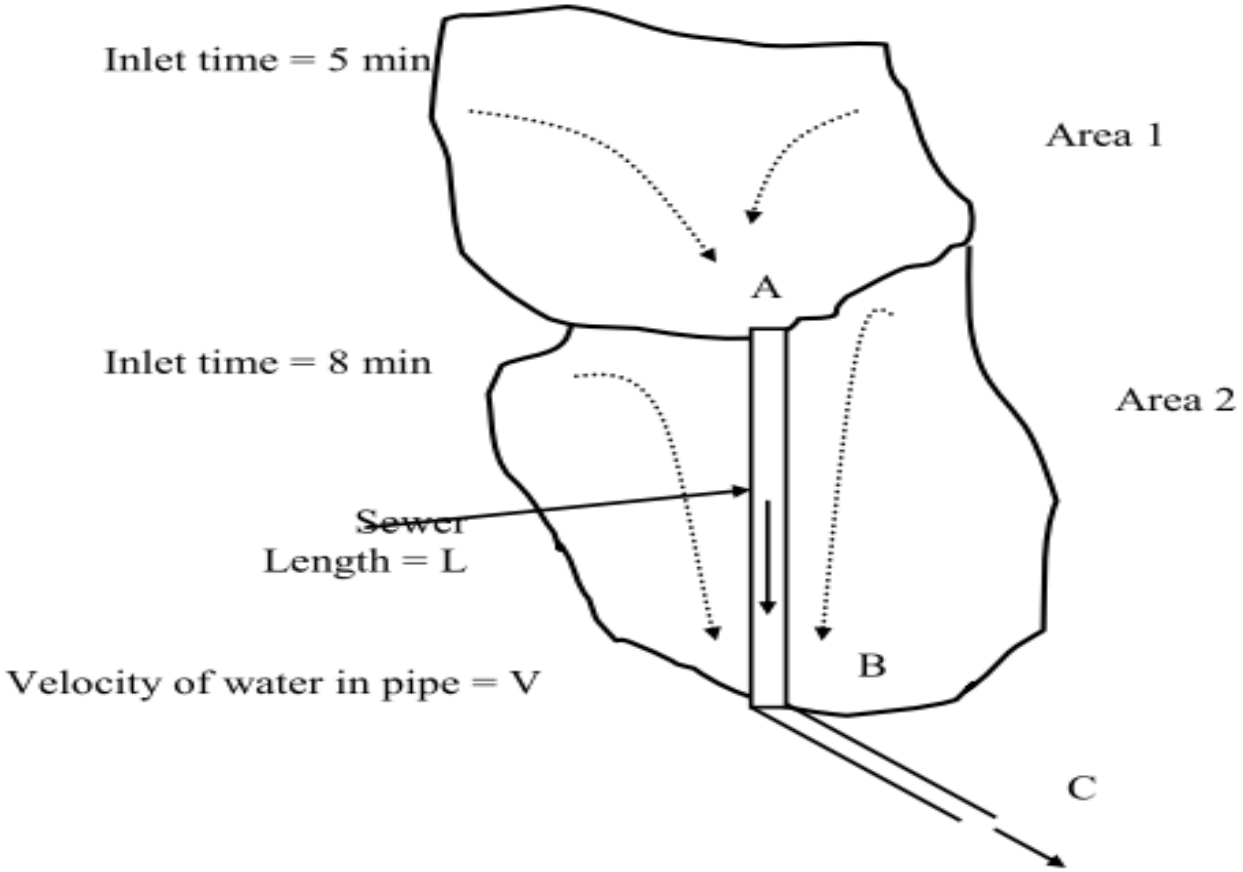
$$t_0 = 6.9 L^{0.6} n^{0.6} i^{-0.4} s^{-0.3}$$

where t_o is inlet time in minutes,
L is the travelled length (m),
n is the Manning's roughness coefficient,
i is the rain fall intensity (mm/hr), and
S is the slope of the catchment (m/m).

Estimation of tc

- tc = Flow time from the most remote point in the drainage area to the point in question.

  = Overland flow time (inlet flow time) + channel flow time.



Estimation of tc

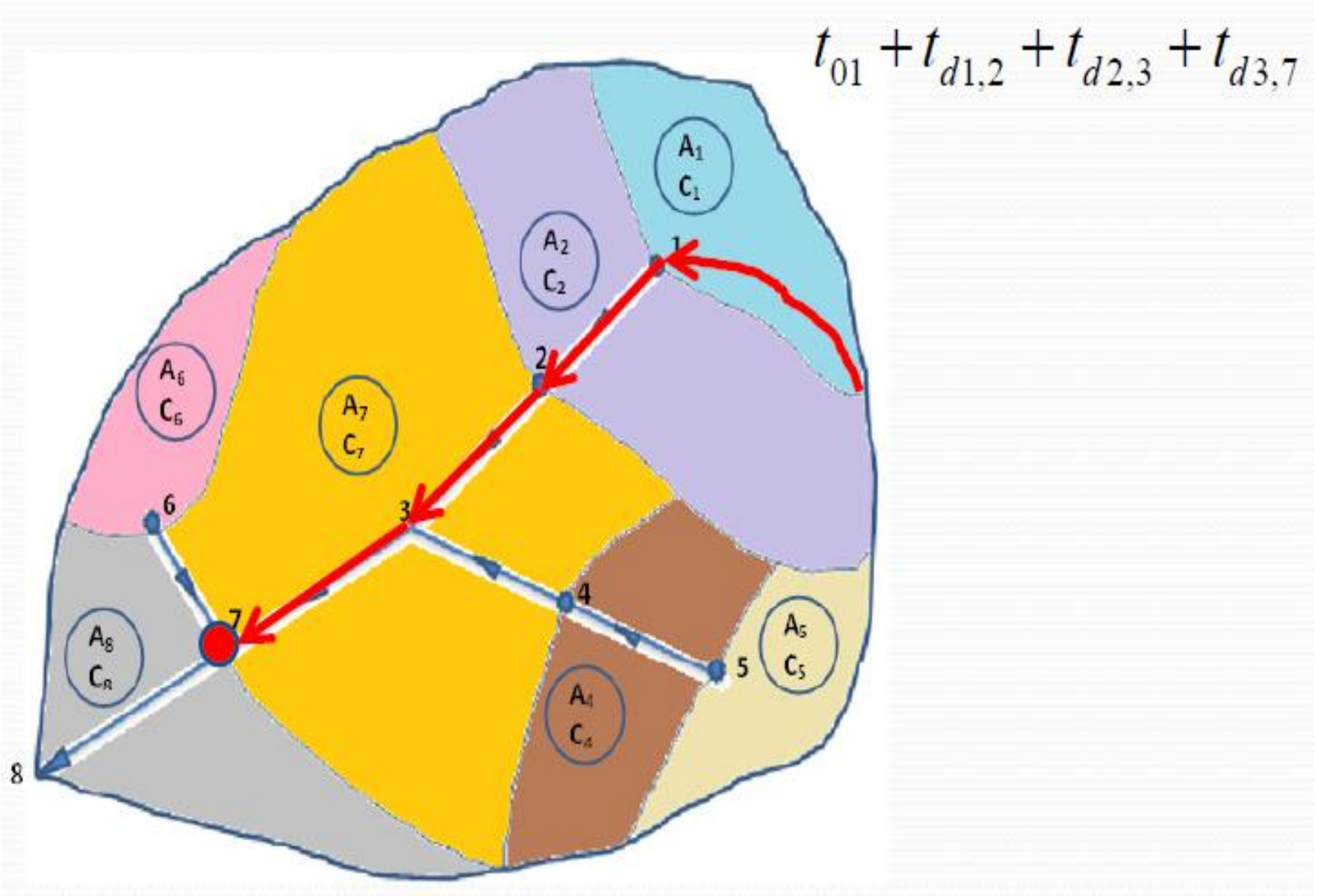
- If point of interest is A (i.e to find the flow in pipe AB) $t_c = 5$ min
- If the point of interest is B (to find the flow in pipe BC)

  $t_c = [5 \text{ min} + L/V]$ or $t_c = 8$ min

  Choose the bigger t_c

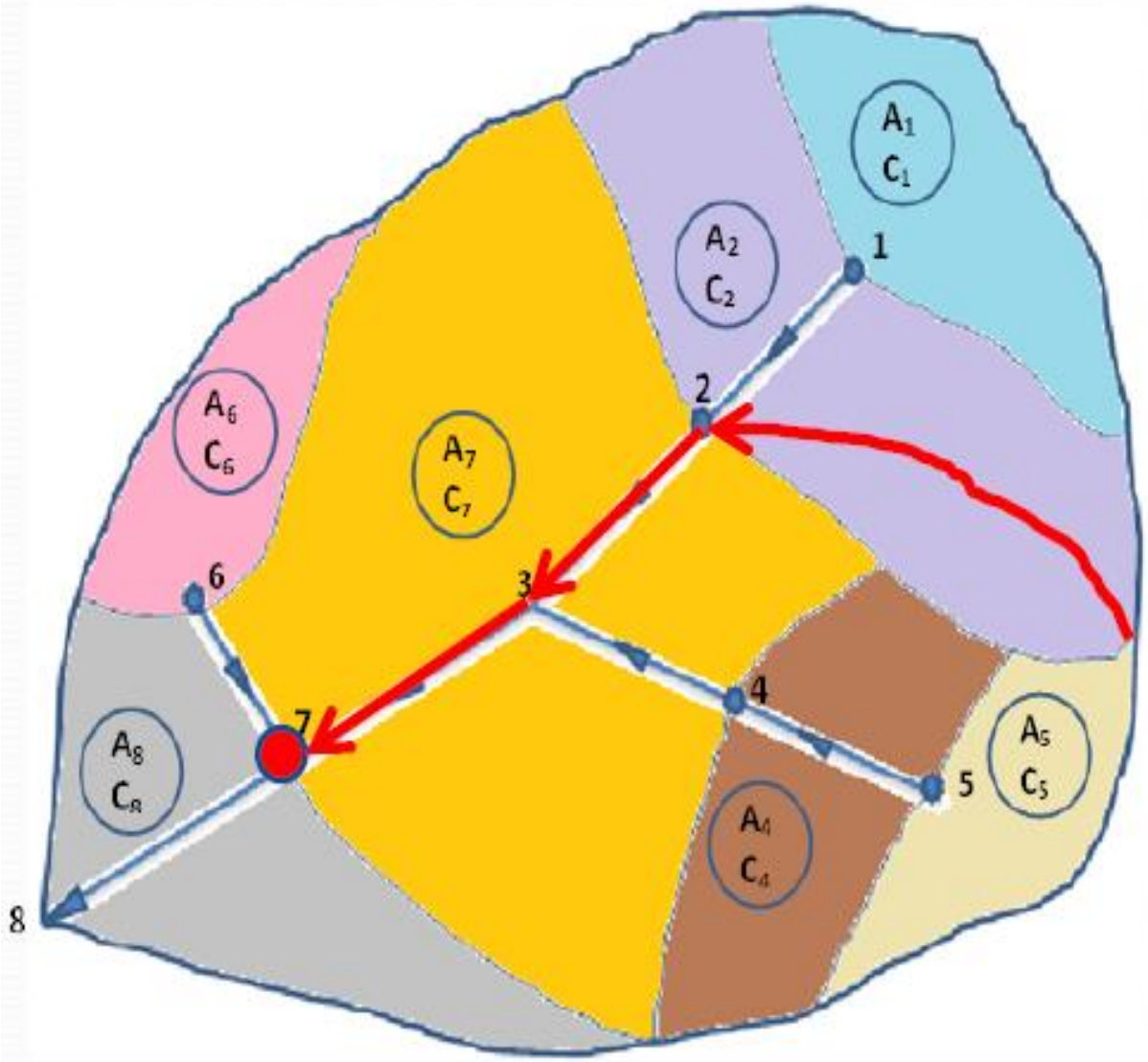
Rational method – Time of Concentration

$$t_{01} + t_{d1,2} + t_{d2,3} + t_{d3,7}$$



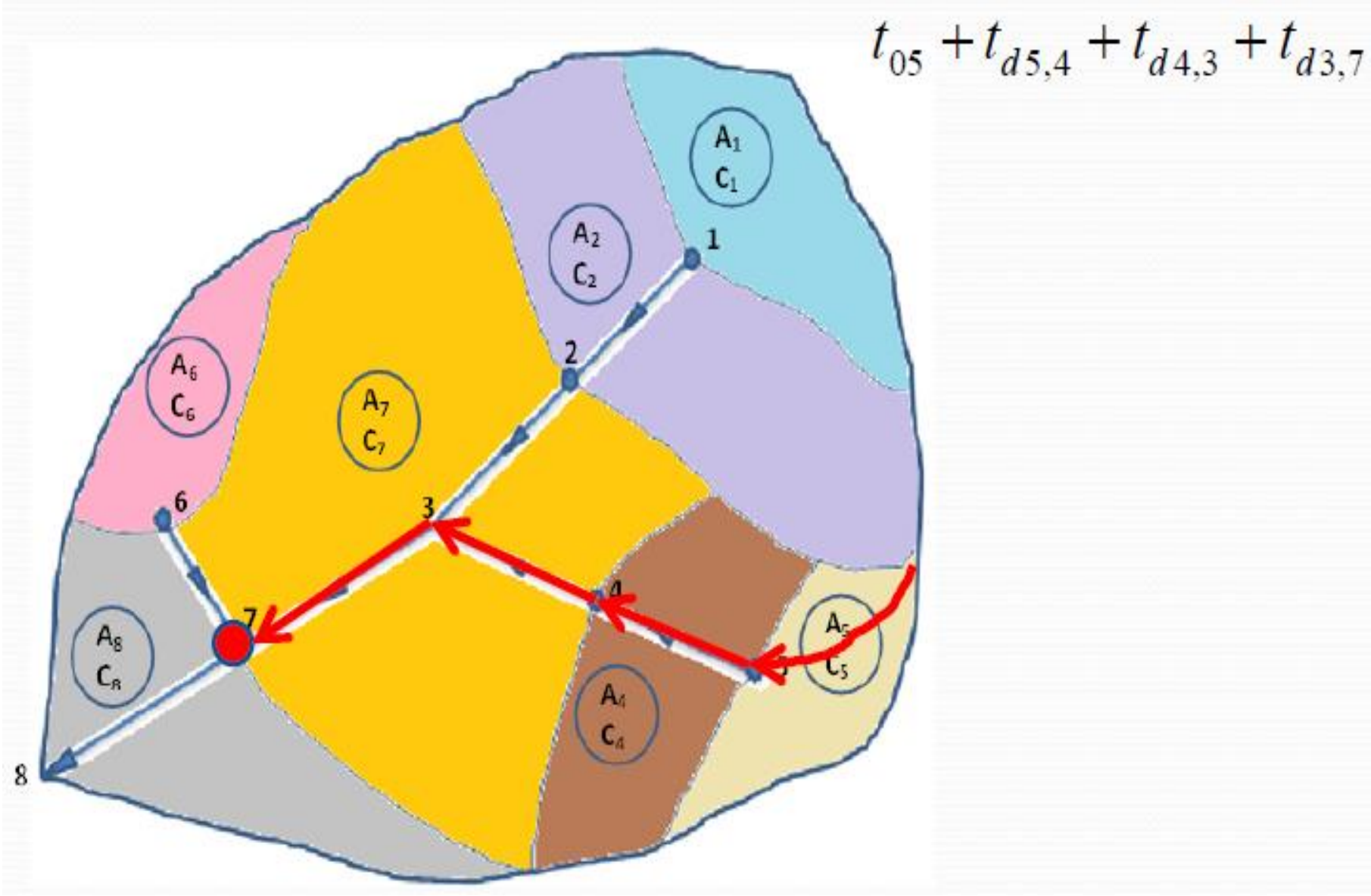
Rational method – Time of Concentration

$$t_{02} + t_{d\,2,3} + t_{d\,3,7}$$



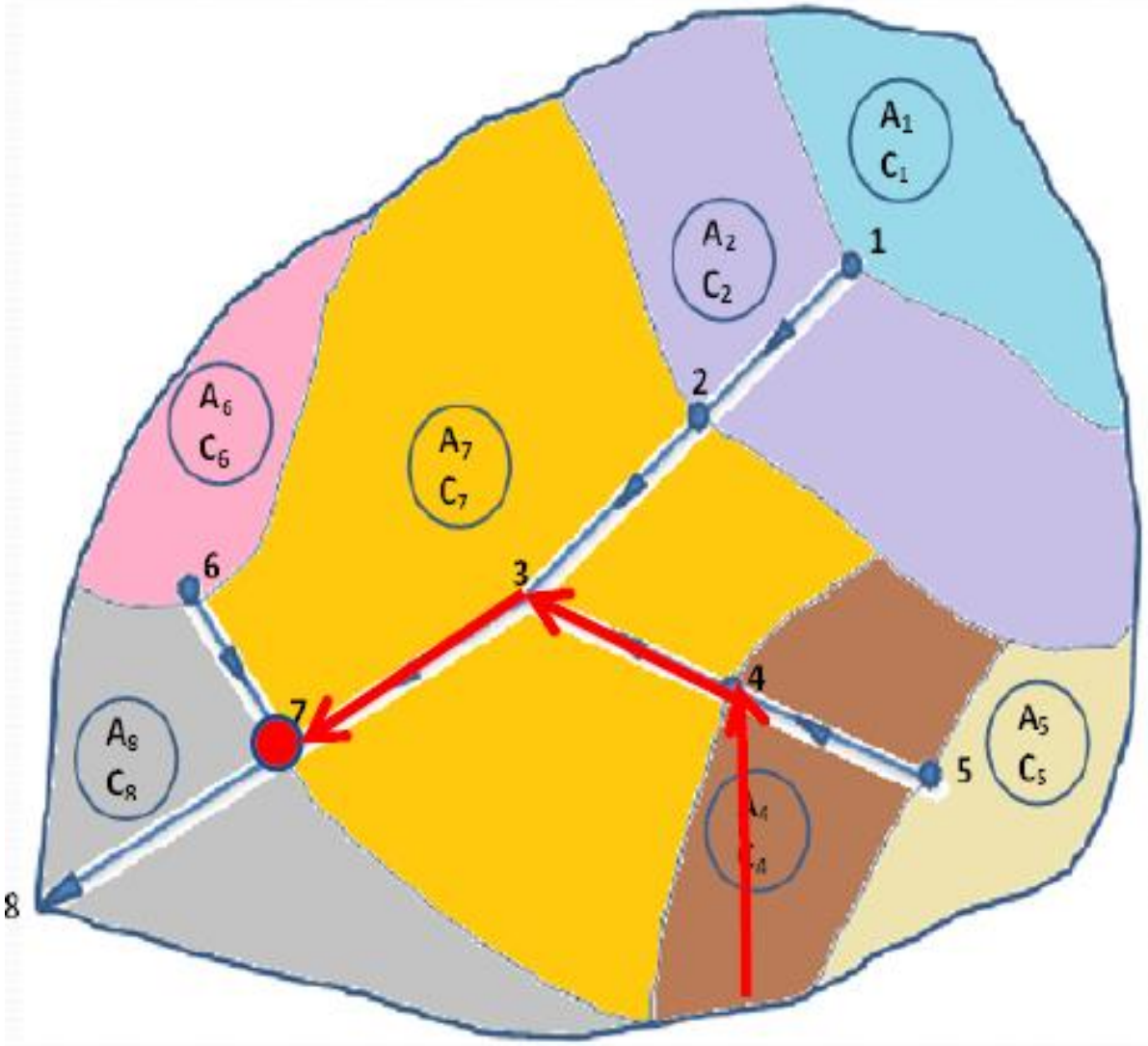
Rational method – Time of Concentration

$$t_{05} + t_{d5,4} + t_{d4,3} + t_{d3,7}$$



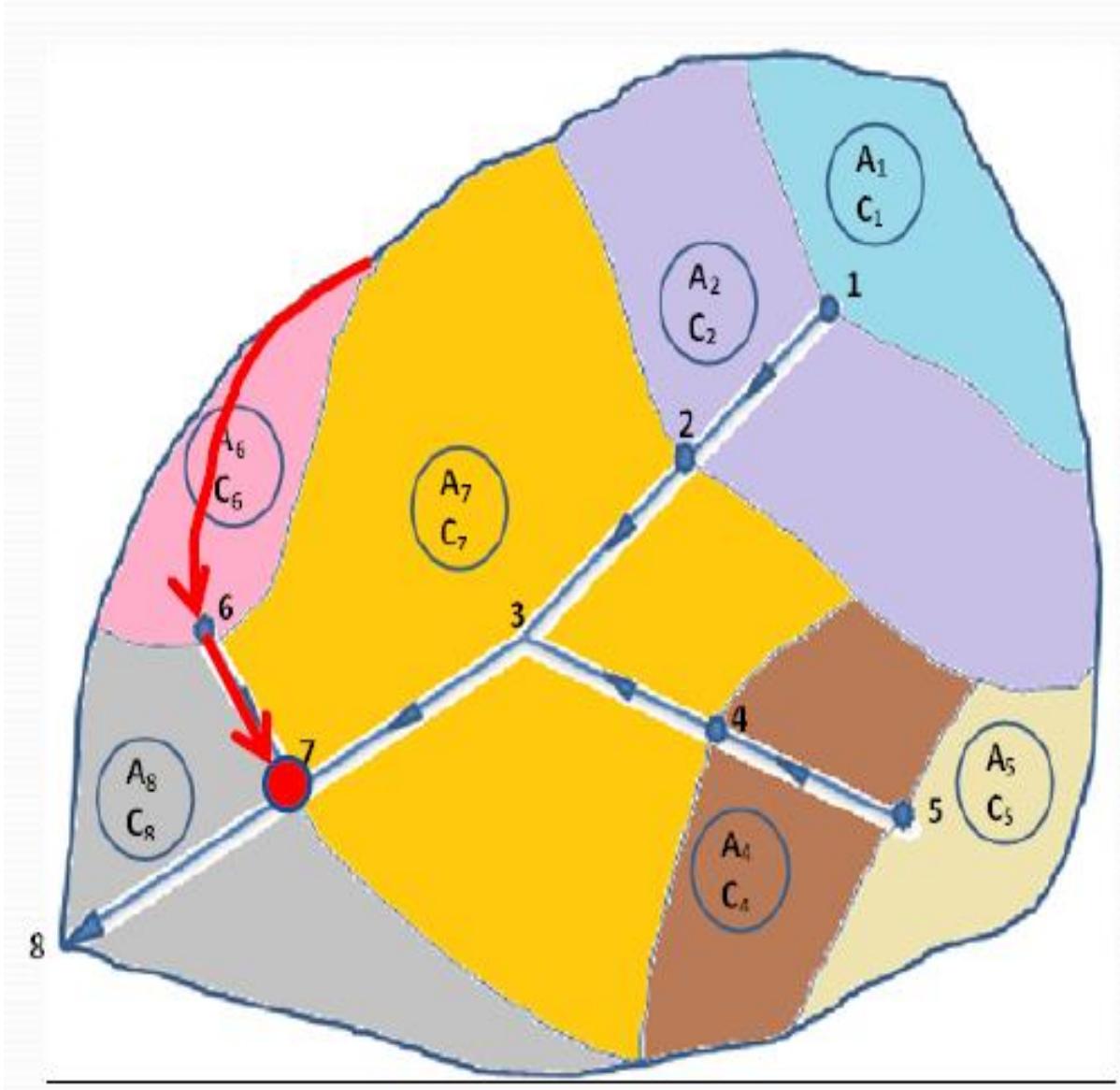
Rational method – Time of Concentration

$$t_{04} + t_{d4,3} + t_{d3,7}$$

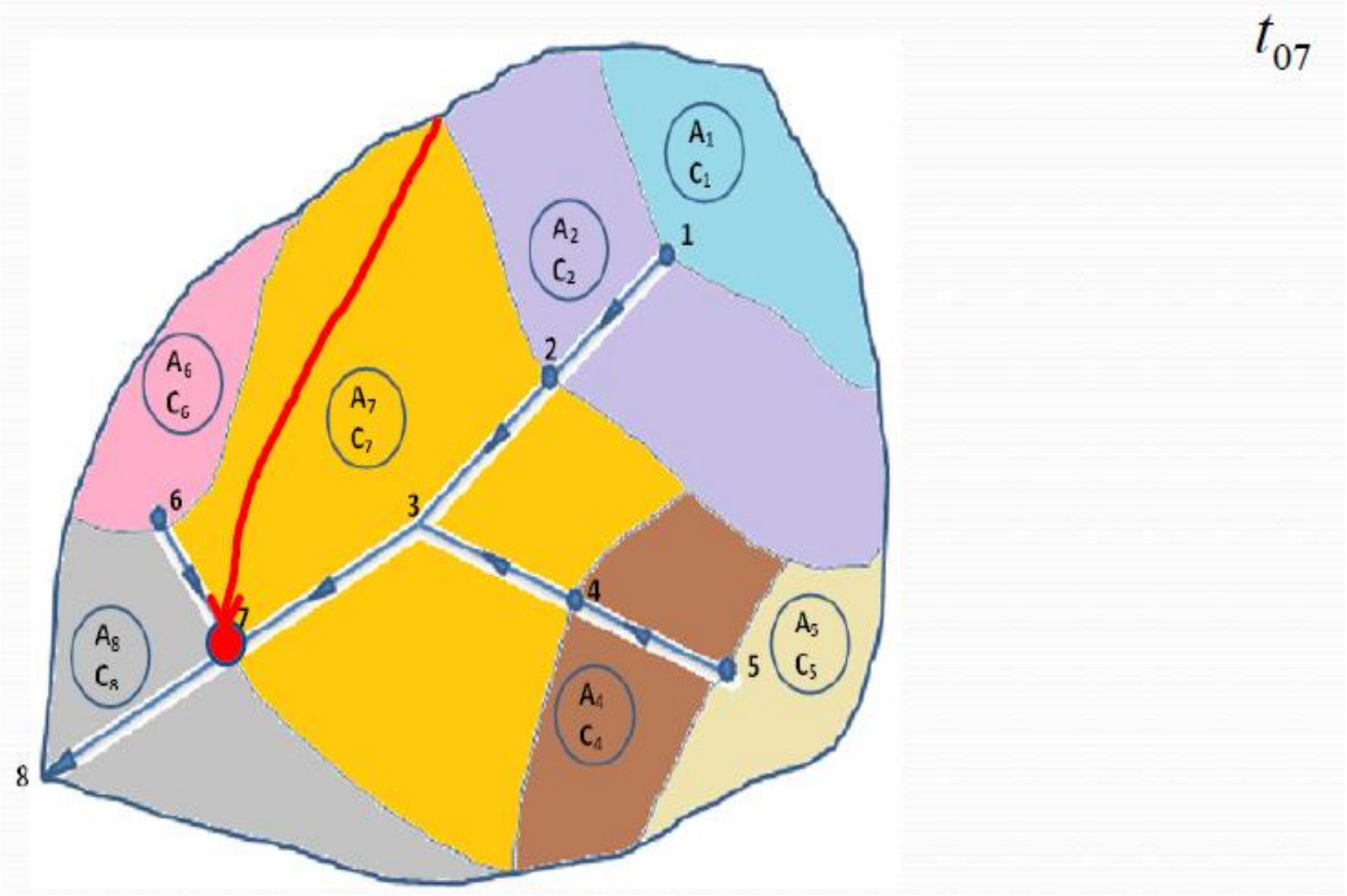


Rational method – Time of Concentration

$$t_{06} + t_{d6.7}$$



Rational method – Time of Concentration



Disturbance of flow, m
300
250
200
180
160
140
120
100
90
80
70
60
55
50
45
40
35
30
25
20
18
16
14
12
10
9
8
7
6
5
4
3
Character of ground
Paved
Bare soil
Poor grass surface
Average grass surface
Dense grass
C = 0.95
C = 0.55
C = 0.44
C = 0.35
C = 0.28
Pivot line
Example
Percent slope
0.10
0.25
0.50
1.00
2.00
5.00
10.00
20.00
Inlet concentration time, min
35
30
25
20
15
10
9
8
7
6

Example 2

A sewer drains a single-family residential area (A= 10,000 m2) with C = 0.35. The distance from the most remote point is 60 m over ordinary grass with a slope of 4%. Determine the design flow. Assume the intensity for 10 year return period is 156 mm/h at the time of concentration.

Solution

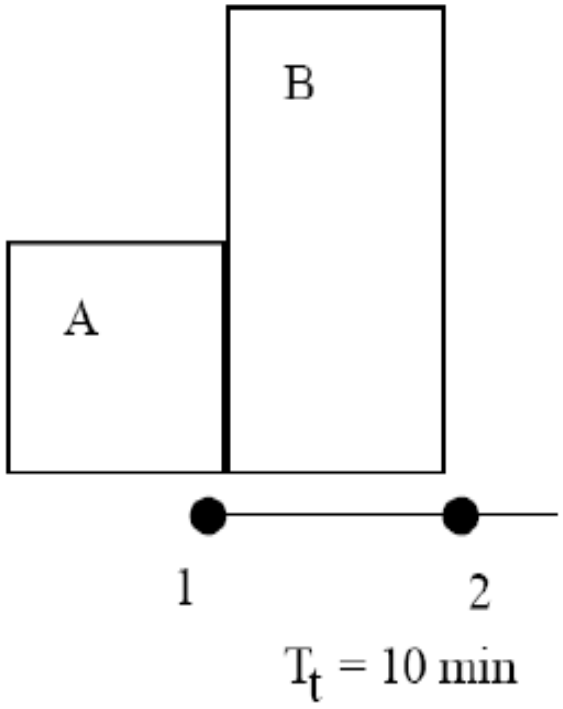
From Figure, inlet time = 15 min. = t c

i = 156 mm/h.

Q = C i A = 0.35 x 0.156 m/h x 10,000 m2 = 546 m3/h.

Example 3

- A storm sewer is proposed to drain a 12 hectares drainage area shown in the figure below. With given data in the table below determine the design discharge needed to convey 5-year peak discharge.



Site	Area (ha)	C	Inlet time (min)
A	4	0.8	10
B	8	0.5	30

i = 2700/(t + 15), for 5-year intensity
Where I in mm/hr and t in min

Solution

- **Upstream Area (Manhole 1):**

A = 4 ha
C = 0.8
tc = 10 min
i = 2700/(10+15) = 108 mm/hr
Qp = CiA/360 = (0.8)(108)(4)/360 = 0.96 m3/sec

- **Downstream Area (Manhole 2):**

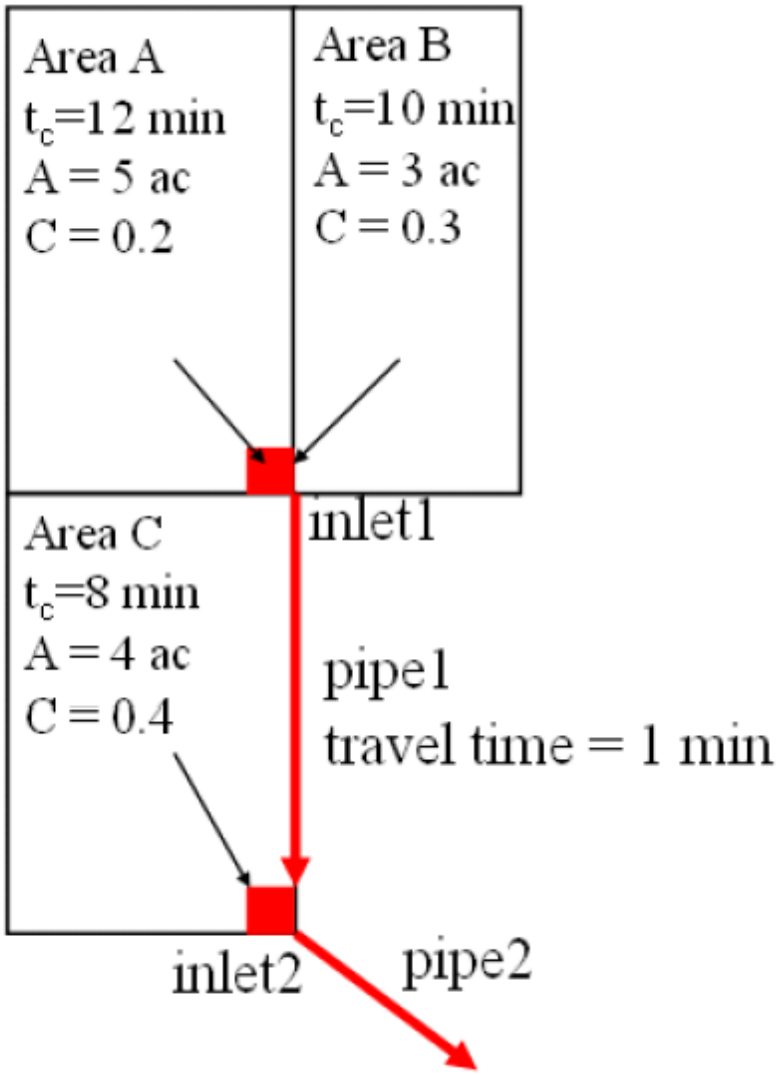
A = 4 +8 = 12 ha
C = (0.8 x 4 + 0.5 x 8)/ 12 = 0.6
Time from A – 1 – 2 : 10 + 10 = 20 min
Time from B – 2 : 30 min (**max)**
tc = 30 min
i = 2700/(30+15) = 60 mm/hr
Qp = CiA/360 = (0.6)(60)(12)/360 = 1.2 m3/sec

Example 4

A storm drain system consisting of two inlets and pipe is to be designed using rational method. A schematic of the system is shown. Determine the peak flow rates to be used in sizing the two pipes and inlets.

Rainfall intensity (in/hr) as a function of t is:

$$i = \frac{30}{(t+5)^{0.7}}$$

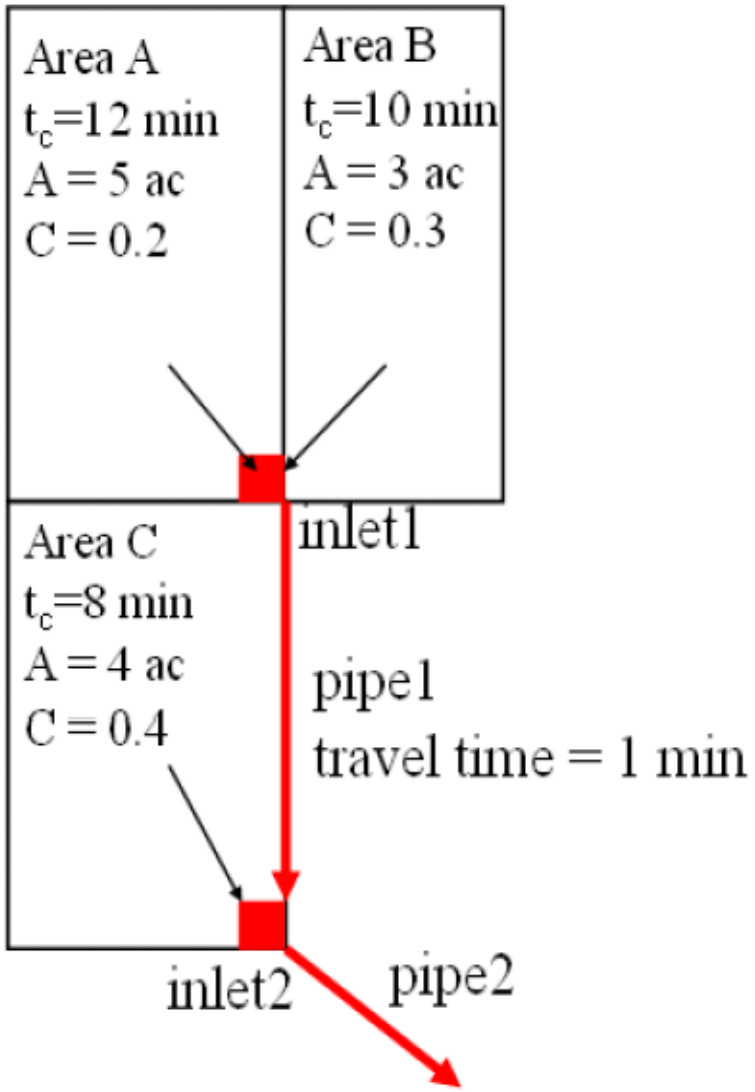


Solution

Size Inlet 1 and pipe 1:

Area A and B contribute
Take largest tc = 12 min

A = 5+3 = 8 acre
*C = (5*0.2+3*0.3)/8 = 0.24*
I = 30/(12+5)$^{0.7}$ = 4.13 in/hr
*Q = CIA = 0.24*4.13*8 = 7.9 cfs*



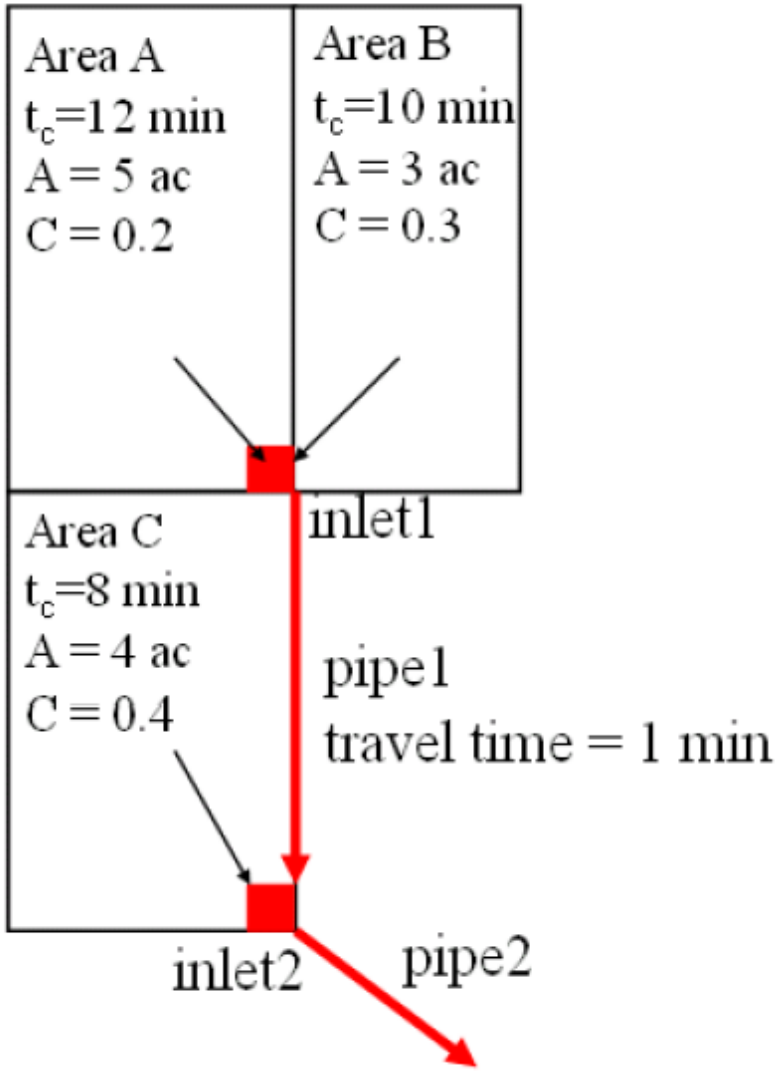
1 acre = 0.4047 ha = 4047 m^2 = 43560 ft^2

Solution

Size Inlet 2:

Flow from area C contributes
Take tc = 8 min

A = 4 acre
C = 0.4
I = 30/(8+5)$^{0.7}$ = 4.98 in/hr
*Q = CIA = 0.4*4.98*4 = 8.0 cfs*

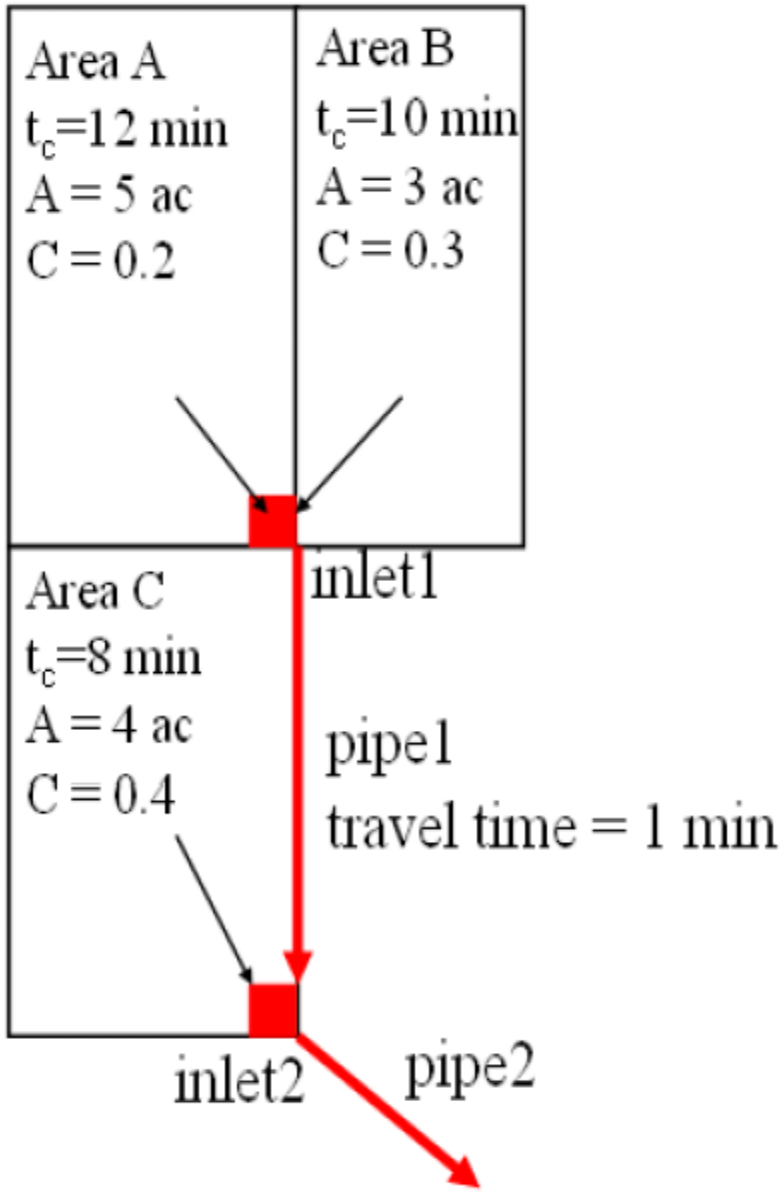


Solution

Size pipe 2:

Flow from all areas
Take tc = 12+1 = 13 min

A = 5+4+3 = 12 acre
*C = (5*0.2+4*0.4+3*0.3)/12*
= 0.29
I = 30/(13+5)$^{0.7}$ = 3.97 in/hr
*Q = CIA = 0.29*3.97*12 = 13.8 cfs*

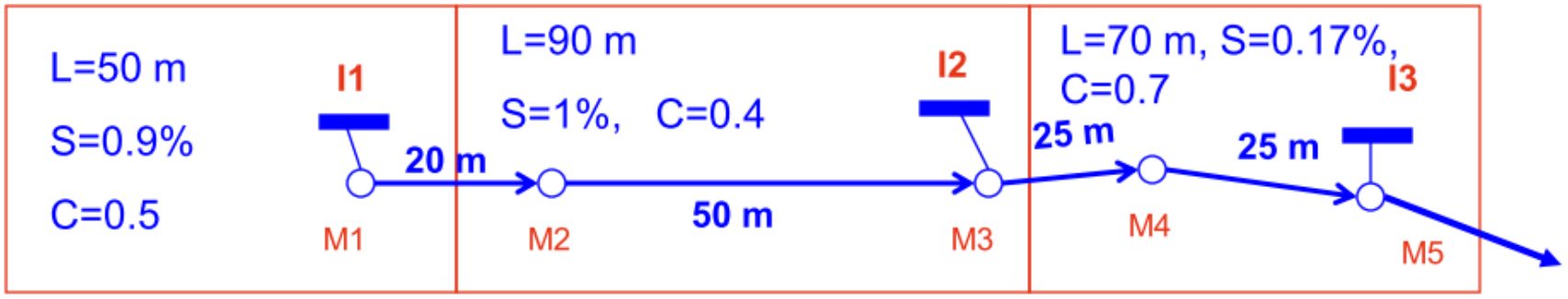


**Note how tc is taken as the largest value (12 min) plus travel trough pipe1.*

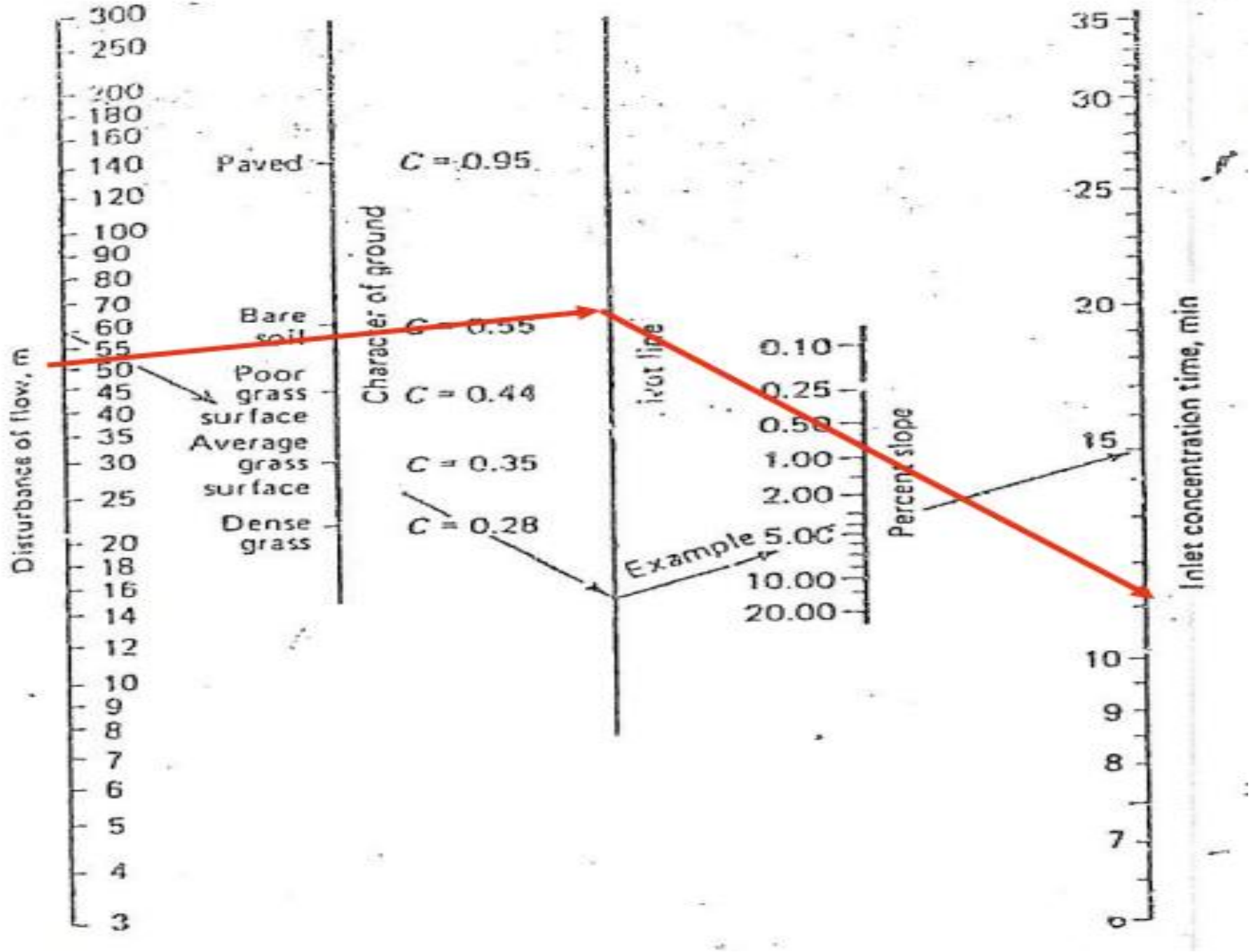
Example 5

- A storm water line is used to collect storm water from three catchment areas (A1, A2, and A3) as shown on the figure. Find the storm water quantities at the three inlets (I 1, I 2, I 3). Assume the velocity in the pipes as 1 m/s.

  Take a return period of 5 years



A1= 2 ha A2= 3 ha A3= 4 ha

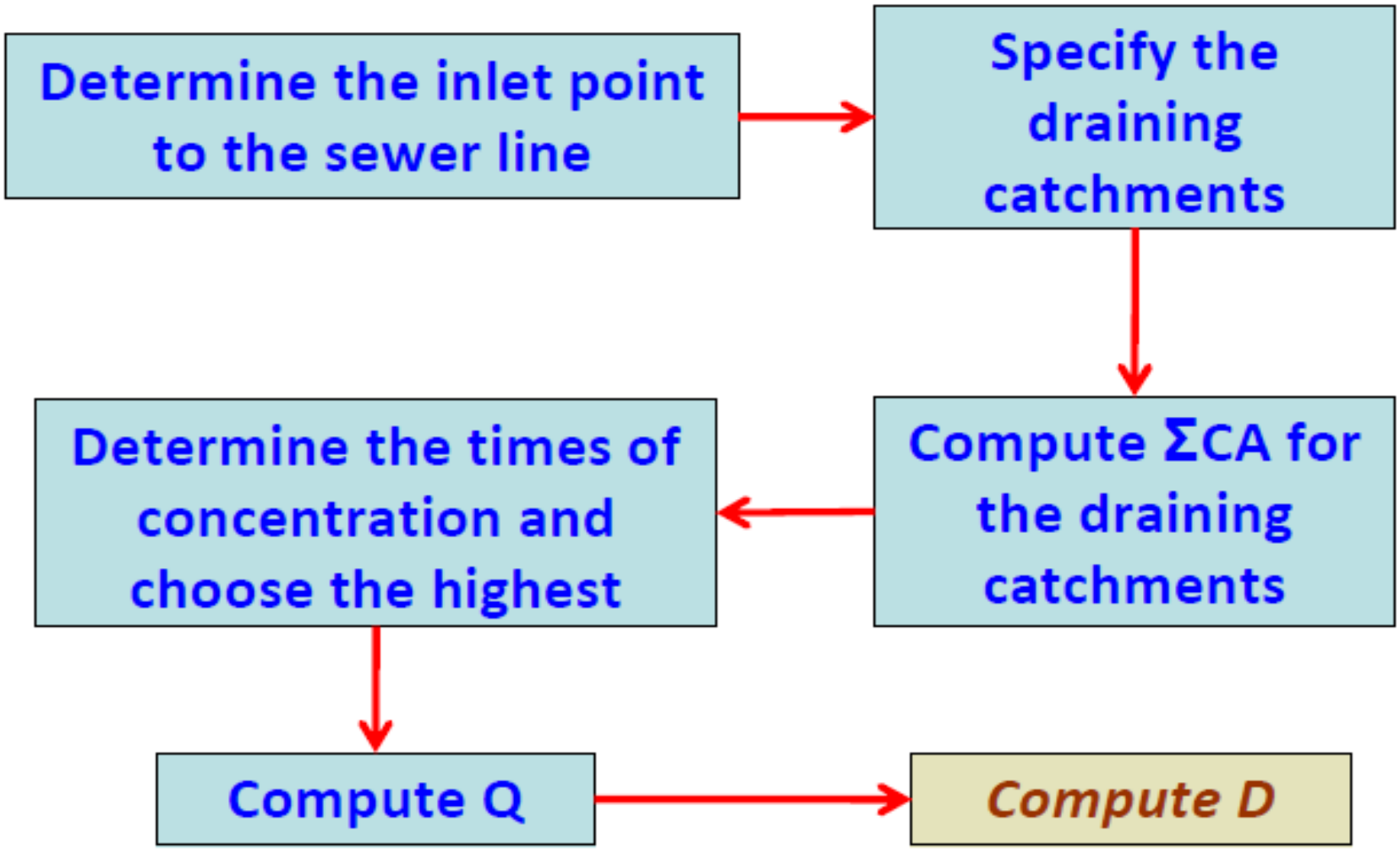

Disturbance of flow, m
300
250
200
180
160
140
120
100
90
80
70
60
55
50
45
40
35
30
25
20
18
16
14
12
10
9
8
7
6
5
4
3
Character of ground
Paved
C = 0.95
Bare soil
C = 0.55
Poor grass surface
C = 0.44
Average grass surface
C = 0.35
Dense grass
C = 0.28
Example
Percent slope
0.10
0.25
0.50
1.00
2.00
5.00
10.00
20.00
Inlet concentration time, min
35
30
25
20
15
10
9
8
7
6

120
100
80
60
40
20
0
Intensity (mm/hr)
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
180
Duration (min)
1 in 20 yrs
1 in 5 yrs
1 in 2 yrs

Solution

Inlet Code	Area Code	C	Time of Concentration (minutes)			I mm/h	Q m^3/s
			T_{inlet}	T_{travel}	T_C		
I 1	A1	0.50	11.90	-----	11.90	74	0.21
I 2	A1& A2: *A1+pipe *A2	C_{com} = 0.44 For: A1,A2	11.9 15	70/60=1.17	13.10 15	66	0.40
I 3	A1+ A2+ A3: *A1+pipe *A2+pipe *A3	C_{com} = 0.56 For: A1,A2 A3	11.9 15 15.5	120/60=2 50/60=0.83 -----	13.9 15.83 15.5	64	0.90

General Procedure for Determining the Diameter of the Storm Sewer lines



Example 6

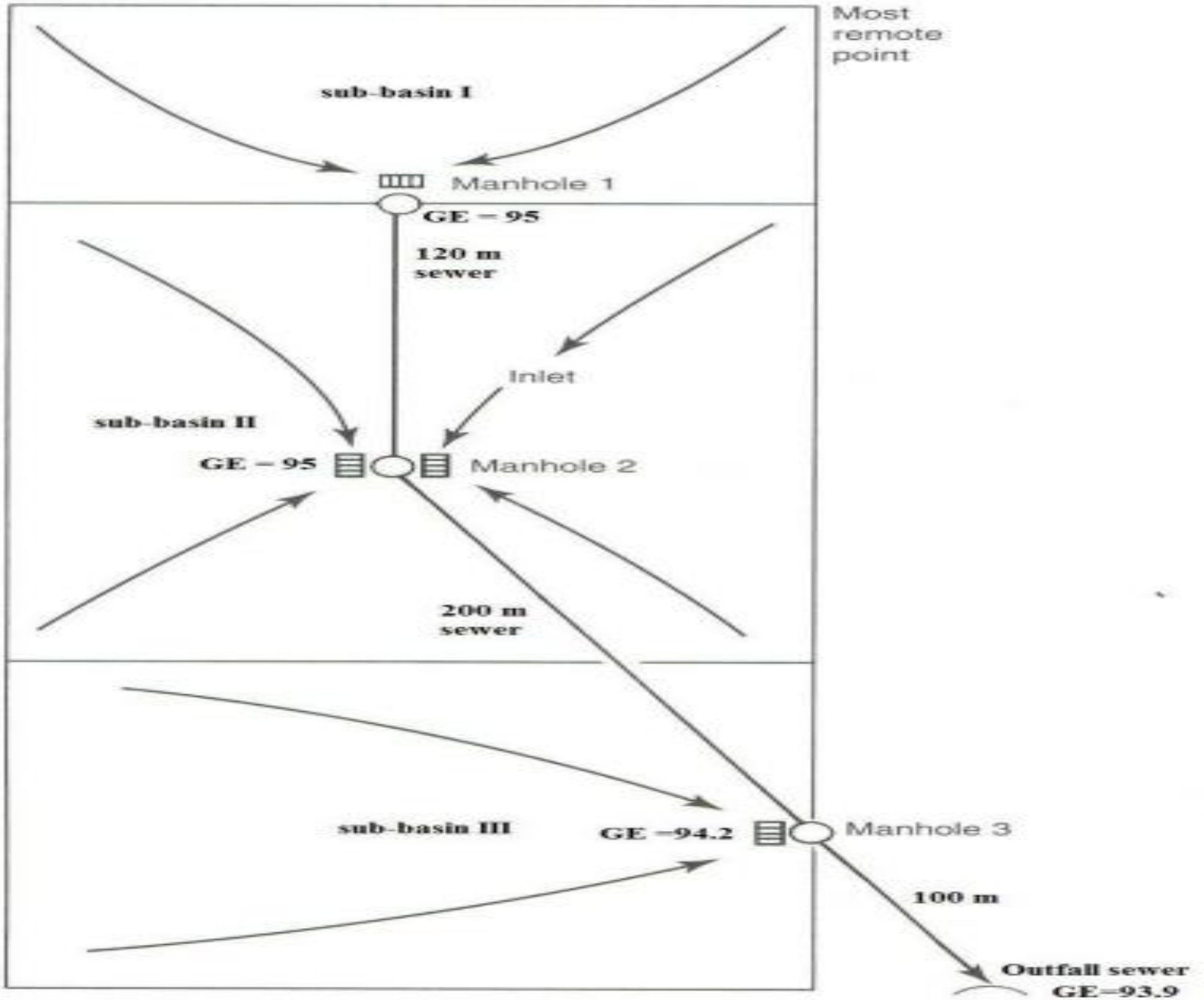
- Design the stormwater drainage system for the areas shown in the following figure. Draw a neat profile along the route of MH 3-MH 2-MH 1. On the profile show all pipe sizes, slopes, and ground and invert elevations.

  The rainfall intensity (mm/h) for the area can be found from the following equation:

  $$i = 1200/(t + 45)$$, where t is the rainfall duration (min)

  The minimum allowable scouring velocity required to avoid the deposition of solids is 0.75 m/s and the maximum is 3 m/s. The minimum depth of the sewer below the street must be 1.5 m and coefficient of roughness, n = 0.013 is applicable. Assume n variable with depth.

Sub-basin	Drainage Area A (m^2)	Runoff Coefficient C	Inlet time (minutes)
I	7000	0.60	5.00
II	16000	0.50	12.00
III	12000	0.80	8.00


Most
remote
point
sub-basin I
Manhole 1
GE – 95
120 m
sewer
Inlet
sub-basin II
GE – 95
Manhole 2
200 m
sewer
sub-basin III
GE –94.2
Manhole 3
100 m
Outfall sewer
GE–93.9

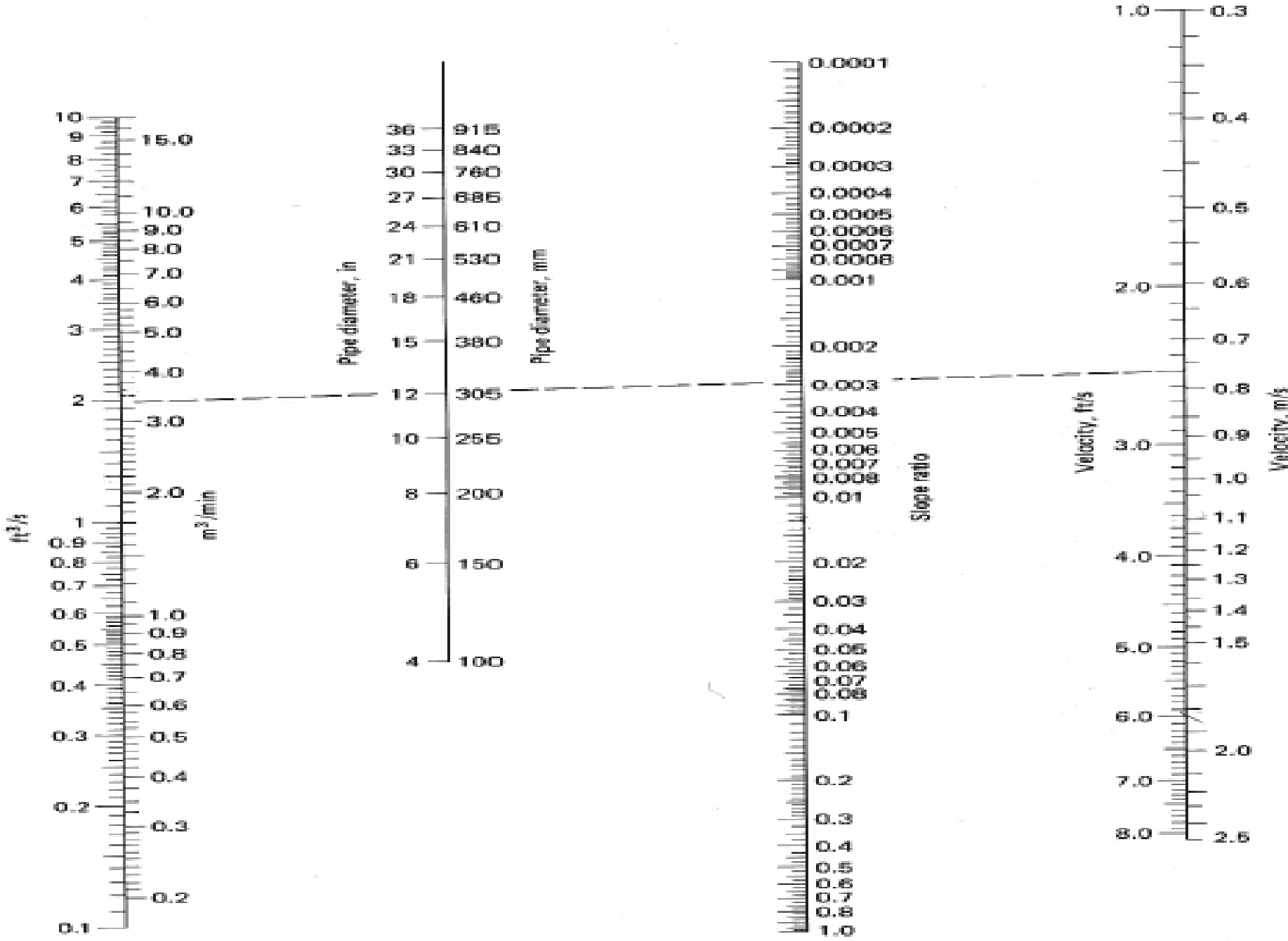


FIGURE 16-2
Nomogram for solution of Manning's equation for circular pipes flowing full ($n = 0.013$).

Solution

- **Line 1 (MH1-MH2) (collects storm water from sub-basin I)**

$A = 7000\ m^2,\ t_c = 5\ min$

$i = 1200 / (t + 45) = 24\ mm/h$

$q = C\ i\ A = 0.6 \times (24 / 1000 \times 60) \times 7000 = 1.68\ m^3/min$

Ground elevations: 95 and 95 m

From nomograph at $Q = 1.68\ m^3/min$ and $V_{min} = 0.75\ m/s \rightarrow D = 200 - 255\ mm$

At $D = 255\ mm$ and $S = 0.004 \rightarrow Q = 2.4\ m^3/min$ and $V = 0.8\ m/s$

$q/Q = 1.68/2.4 = 0.70 \rightarrow v/V = 0.95 \rightarrow v = 0.95\ (0.80) = 0.76\ m/s > 0.75\ m/s$ (OK)

Invert level at the upper end = 95 – 1.5 – 0.255 = 93.245m

Invert level at the lower end = 93.245 – 0.004 x 120 = 92.765 m

- **Line 2 (MH2-MH3)** (collects storm water from sub-basin II and sub-basin I)

Area contributing flow to line 2 = 7,000 + 16,000 = 23,000 m^2

t_c = max. of :

[12 min]

[5 + (120 m / 0.76 m/s x 60 s/min)] = [5 + 2.63] = [7.63 min]

i = 1200 / (12 +45) = 21.05 mm/h

Ceff = (0.50 x 16000+0.6x7000)/23000 = 0.53

q = C i A = 0.53 x 21.05/(1000x60) x 23,000 = 4.28 m^3/min

Ground elevations: 95 m and 94.2 m

S= (95-494.2)/200 = 0.004

From nomograph at Q = 4.30 m^3/min and S =0.004 → D = 350 – 380 mm

At D = 380 mm and S = 0.004 → Q = 7.0 m^3/min and V = 0.92 m/s

q/Q = 4.28/7.0 = 0.62 → v/V = 0.9 → v = 0.9(0.92)=0.83 m/s > 0.75 m/s (OK)

Invert at upper end = (92.765 + 0.255) – 0.380 = 92.64 m

Invert at lower end = 92.64 – (0.004 x 200) = 91.84 m

- **Line 3 (MH3 – outfall)**

Area contributing flow to line 3 = 7,000 + 16000 + 12,000 = 35,000 ^{m2}

t_c = max. of :

[5 + (120/0.76x60)+(200/0.83x60)] = [5 + 6.65] = [11.65 min]

12 + (200/0.83x60)= 16.02 min

8 min

i = 1200 / (16.01 +45) = 19.67 mm/h

Ceff = (0.60 x 7000+0.50 x 16000+.8x13000)/35000 = 0.646

q = C i A = 0.646 x (19.67/1000x60) x 35,000 = 7.41 m^3/min

Ground elevations: 94.2 m and 93.9 m

S = (94.2 – 93.9)/100 = 0.003

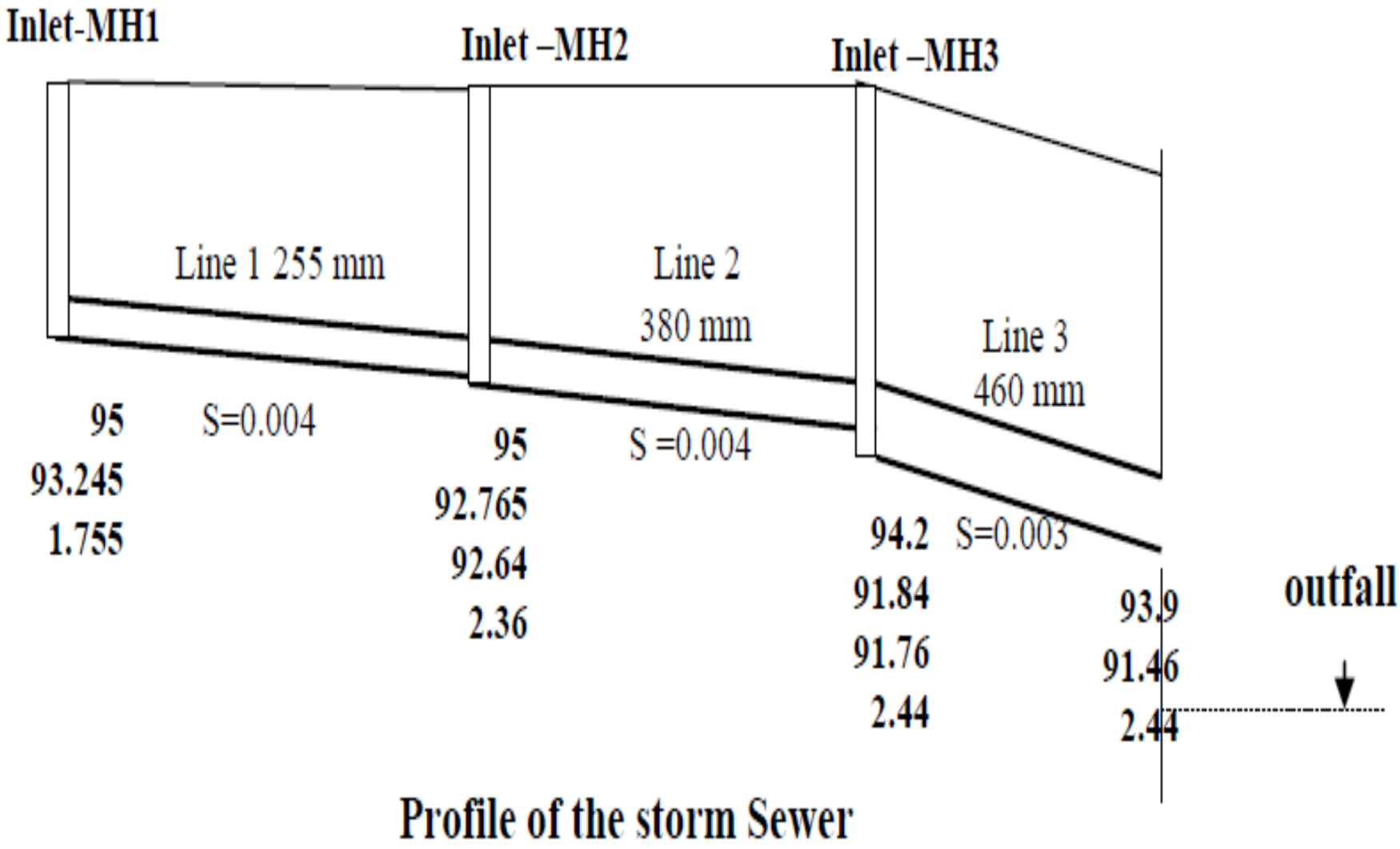
From nomograph, at S = 0.003 and Q = 7.41 m^3/min → D = 380 – 460 mm.

At D = 460 mm and S =0.003 → Q = 9.5 m^3/min and V = 1.0 m/s

q/Q = 7.41/9.5 = 0.78 → v/V = 0.98 → v = 0.98 m/s > 0.75 (OK)

Invert level at the upper end = (91.84 + 0.38) – 0.46 = 91.76 m

Invert level at the lower end = 91.76 – 0.003 x 100 = 91.46 m



Profile of the storm Sewer