Sewer Processes and Design

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Introduction

- Sewer System
- Fundamental Hydrology for Sewer Design
- Fundamental Hydraulics for Sewer Design

- Sewer System

Sewer

What is sewer?

Sewer is an artificial conduit or system of conduits used to remove sewage and to provide drainage.

Sewage

Sewage is the mainly liquid waste containing some solids produced by humans which typically consists of

    -washing water
    -faeces
    -urine
    -laundry waste
    -other material from household and industry

History

In the 20th century developed world,

- Sewers are usually pipelines that begin with connecting pipes from buildings to one or more levels of larger underground horizontal mains, which terminate at sewage treatment facilities.
- Vertical pipes, called manhole, connect the mains to the surface.
- Sewers are generally gravity powered, though pump may be used if necessary.

Sewer Systems

- **STORM SEWER SYSTEM**
  [Storm Drains/Stormwater Drains/ Surface Water System]

- **SANITARY SEWER SYSTEM**
  [Foul Sewer]

I. Storm Sewer System

- STORM SEWER is designed to drain excess rainfall and groundwater from paved streets, parking lots, sidewalks, and roofs.
- STORM SEWERS vary in design from small residential dry wells to large municipal systems.
- STORM SEWERS are present on most motorways, freeways and other busy roads, as well as towns in areas which experience heavy rainfall, flooding and coastal towns which experience regular storms.

Ideally, STORM SEWERS should be separate from SANITARY SEWERS, though in some places the runoff from storm sewers is subjected to SEWAGE TREATMENT PLANT when there is sufficient capacity to spare.

Most drains have a single large exit at their point of discharge (often covered by a grating to prevent access by humans and exit by debris) into either a canal, river, lake, reservoir, ocean and spread out into smaller branches as they move up into their catchment area.

I. Storm Sewer System

Storm sewers may discharge into
     -individual dry wells.
     -man-made excavations (recharge basins).

Pipes characteristics
     -can come in many different shapes.
     -have many different features.
     -several different materials can also be used.

II. Sanitary Sewer System

- **Sanitary sewer** is a type of underground carriage system for transporting sewage from houses or industry to treatment or disposal.

- **Sanitary lines** generally consist of laterals, mains, and manholes (or other various forms of traps).
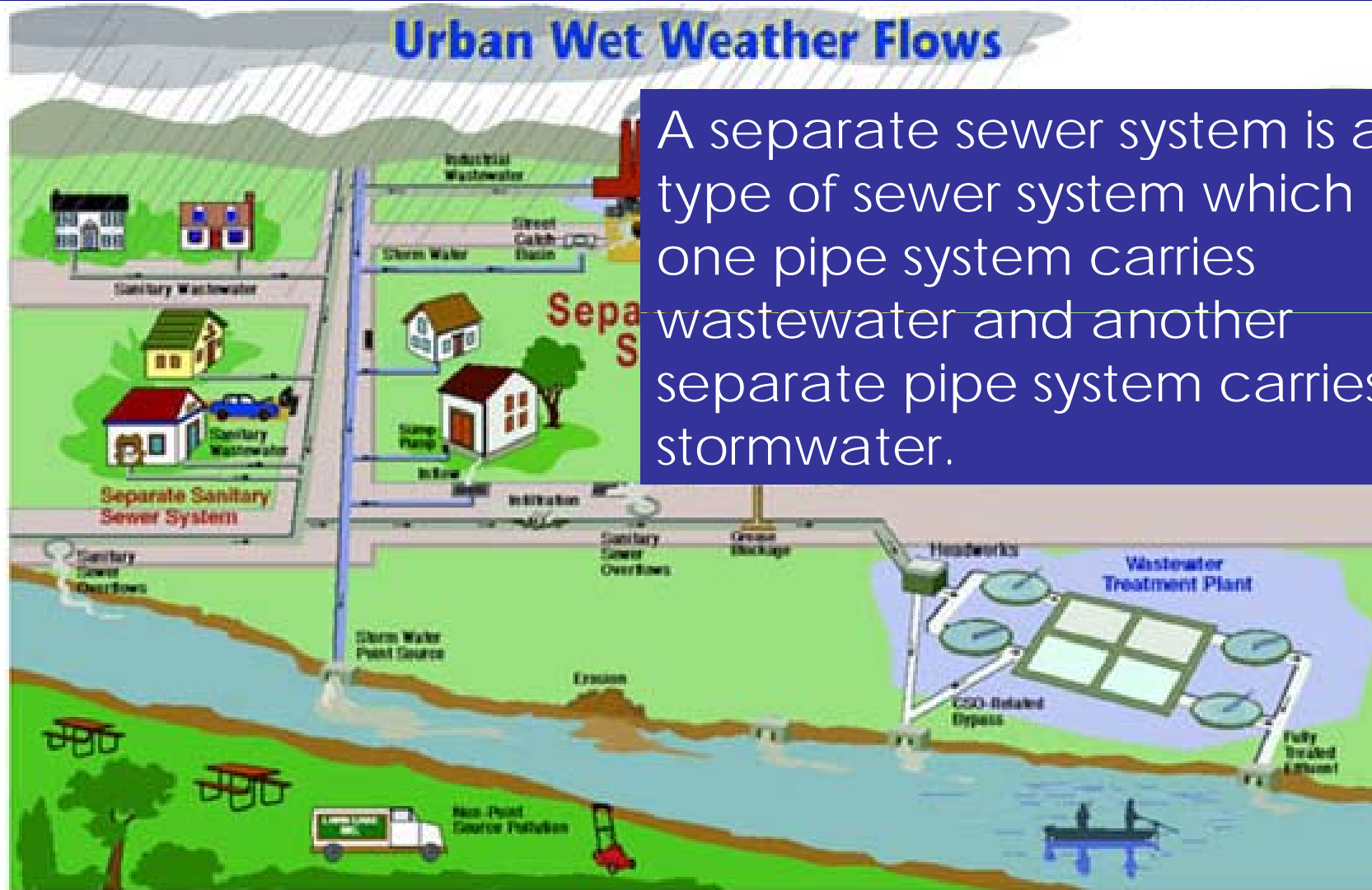
Types of Sewer System

- SEPARATE SEWER SYSTEM

- COMBINED SEWER SYSTEM

Separate Sewer System

Urban Wet Weather Flows

A separate sewer system is a type of sewer system which one pipe system carries wastewater and another separate pipe system carries stormwater.
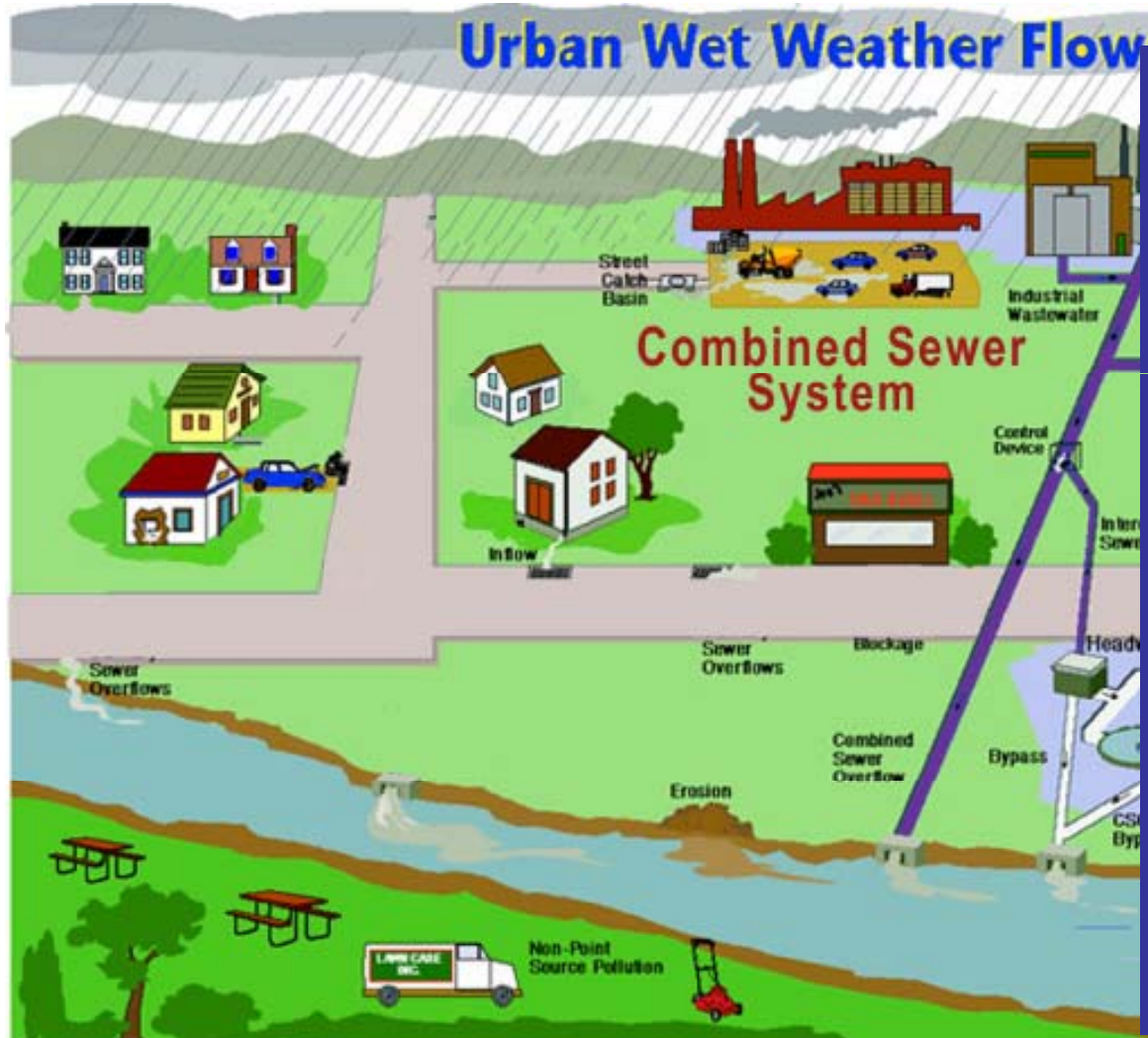
Separate Sanitary Sewer System

Separate Stormwater System

Combined Sewer System

Urban Wet Weather Flows

Combined Sewer System

Street Catch Basin

Industrial Wastewater

Control Device

Inter Sewer

Inflow

Sewer Overflows

Blockage

Head...

Sewer Overflows

Combined Sewer Overflow

Bypass

CS Byp

Erosion

Non-Point Source Pollution

Combined Sewer System

A combined sewer is a type of sewer system which provides partially separated channels for sanitary sewage and stormwater runoff. This allows the sanitary sewer system to provide backup capacity for the runoff sewer when runoff volumes are unusually high, but it is an antiquated system that is vulnerable to sanitary sewer overflow during peak rainfall events.
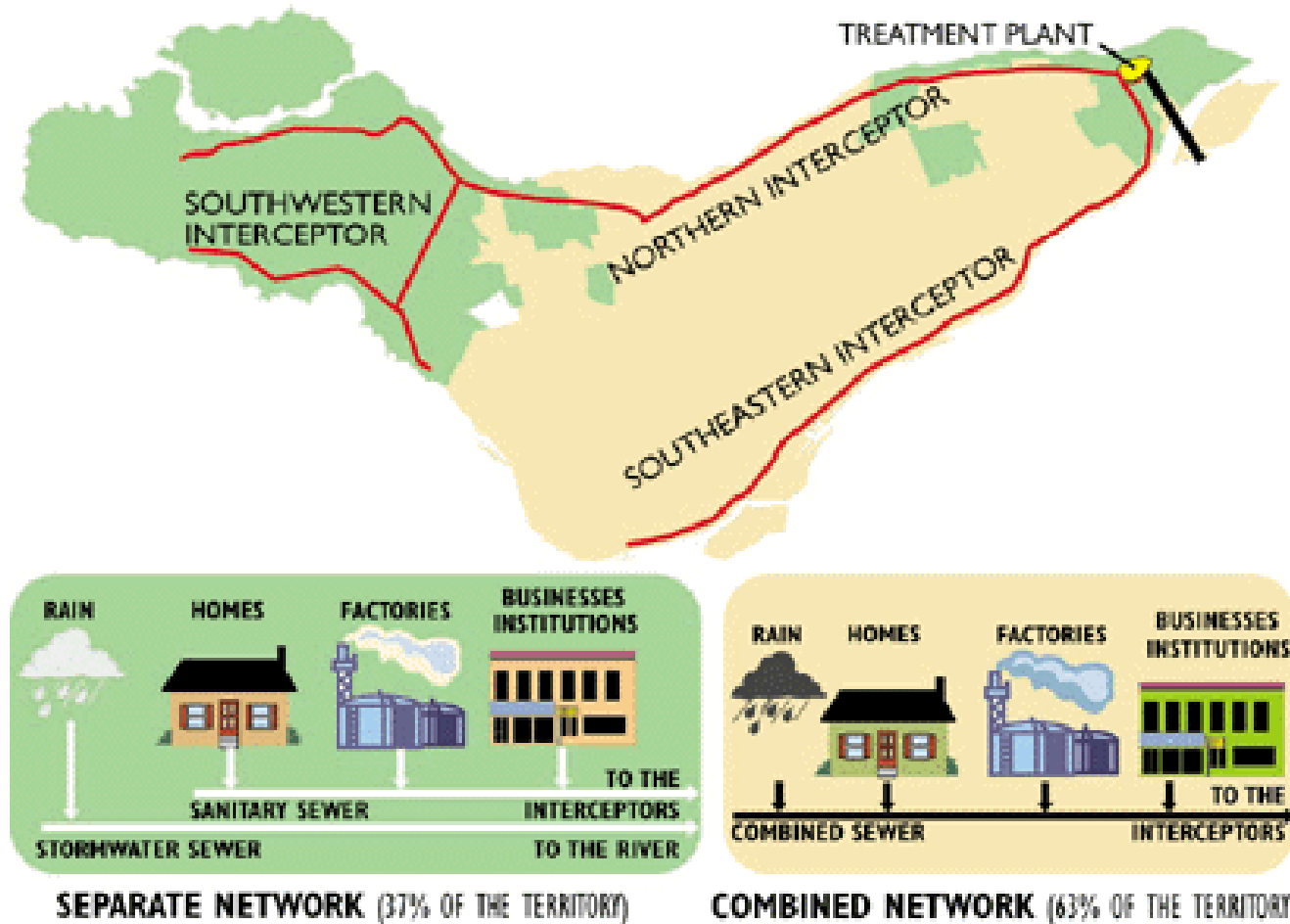
Photo : CUM

SEPARATE NETWORK (37% OF THE TERRITORY)

COMBINED NETWORK (63% OF THE TERRITORY)

Fundamental Hydrology for Sewer Design

Peak Flow Analysis

- Estimation of peak flow rates from small and mid-size watersheds is a common application of engineering hydrology.
- The UH procedures should be used when storage and runoff volume considerations influence the design (reservoirs or storm water detention ponds)
- Simpler approaches are justified when designing small hydraulic structures such as culverts or storm drainage systems.
- For these design problems, peak flows usually provide information to determine the appropriate pipe size.

Simple Peak Flow Formulas

- **Fanning Formula**

$$Q = CA^{5/6}$$

Where   Q = peak flow (cfs)

              A = area (sq.mi.)

              C = constant (equal to 200 for Q=cfs)

- **Myers Formula**

$$Q = 100pA^{1/2}$$

Where   Q = max flow (cfs)

              p = Myers rating

              A = area (sq.mi.)

Simple Peak Flow Formulas

- For the above formulas, there is no attempt to consider rainfall amounts or intensities as parameter, or to relate the value of q to any probability or return period.

- They simply provide an upper limit of Q that would represent an extremely conservative design flow value.

Peak Flow from Gaged Data

- Most designs are based on a return period (highway culverts: 50 year return period)

- A frequency analysis using peak flows from gaged stream flow would provide desired peak flow.

- Drawbacks: gaged data may not exist, watershed may have changed land use, gaged data may not be at the location of design.

Rational Method

- Developed in 1800s in England as the first dimensionally correct equation.

- Used by 90% of engineers still today.

- Equation assumes that Q is a function of rainfall intensity applied uniformly over the watershed for a duration D.

- Equation also assumes that frequency of Q is equal to frequency of rainfall intensity.

- The proper rainfall duration is equal to the time of concentration.

Rational Method

- The equation is

$$Q = 1.008CIA$$

Where   Q = peak flow (cfs)
C = dimensionless coefficient
I = average rainfall intensity (in/hr)
A = catchment area (acre)
1.008 = unit conversion factor

The conversion factor is usually ignored.

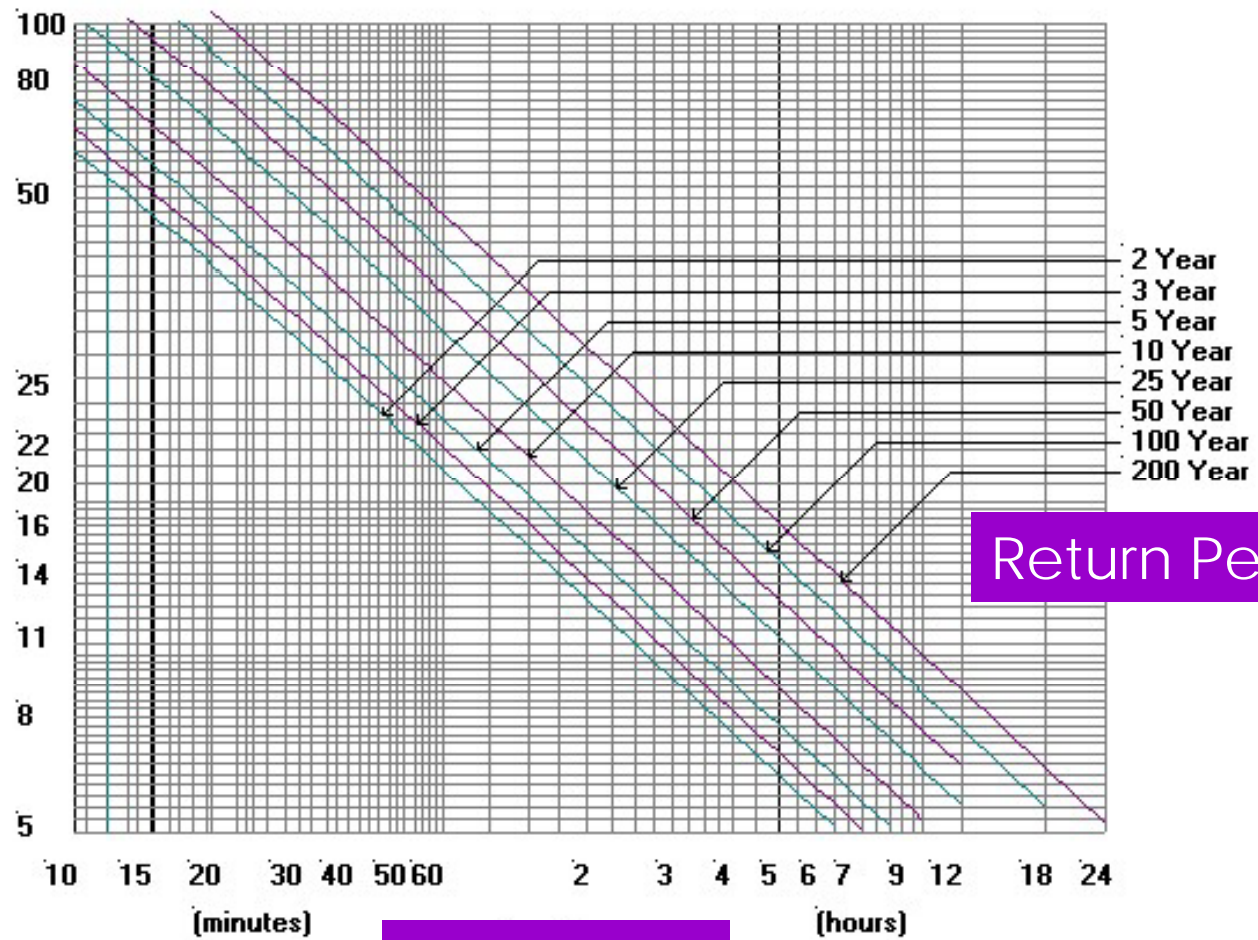# Rational Method

- What is needed?
    1) Time of concentration
    2) A set of rainfall intensity-duration-frequency curve (IDF curve)
    3) Drainage area size
    4) An estimate of the coefficient C

IDF Curve

Rational Method

- C is know as runoff coefficient and can be found for the different land uses

- If land use is mixed, you can calculate a composite C value as follows:

$$C = (C_A A_A + C_B A_B)/(A_A + A_B) \text{ or}$$
$$C = (\Sigma C_i A_i)/(A_i)$$

Where C_A, C_B = C values for land use A and B

A_A, A_B = areas of land use A and B
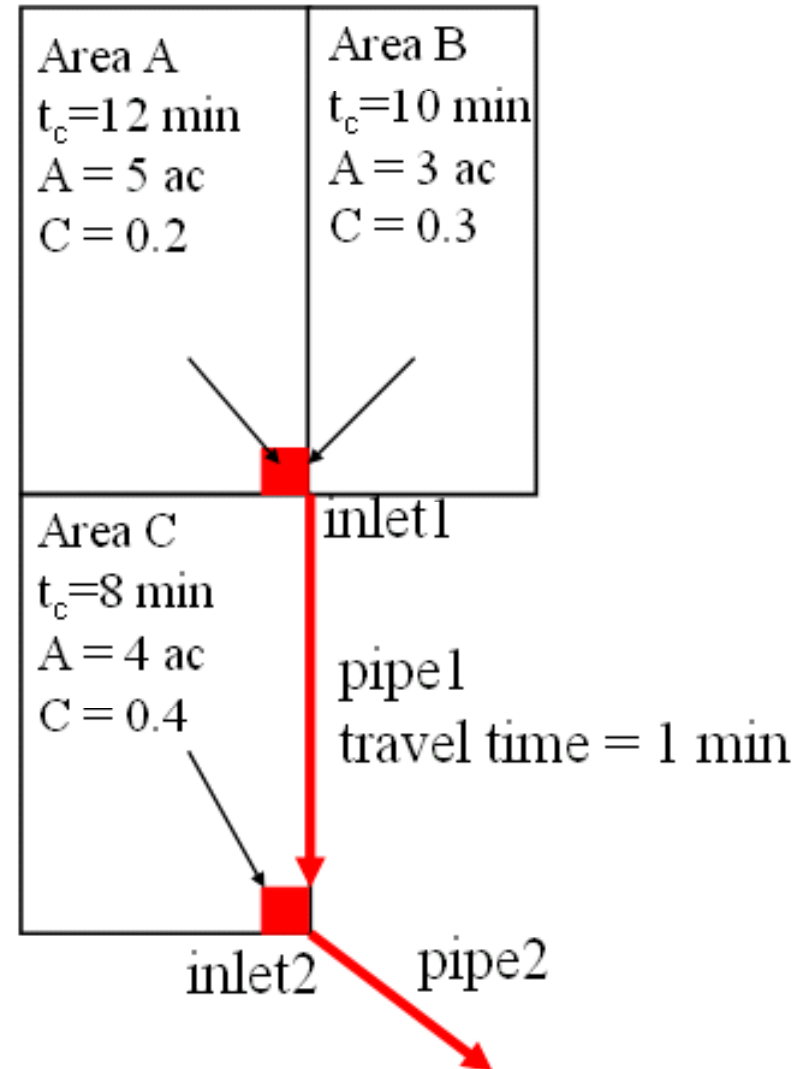
C_i, A_i = C and A for land use i

Example 1

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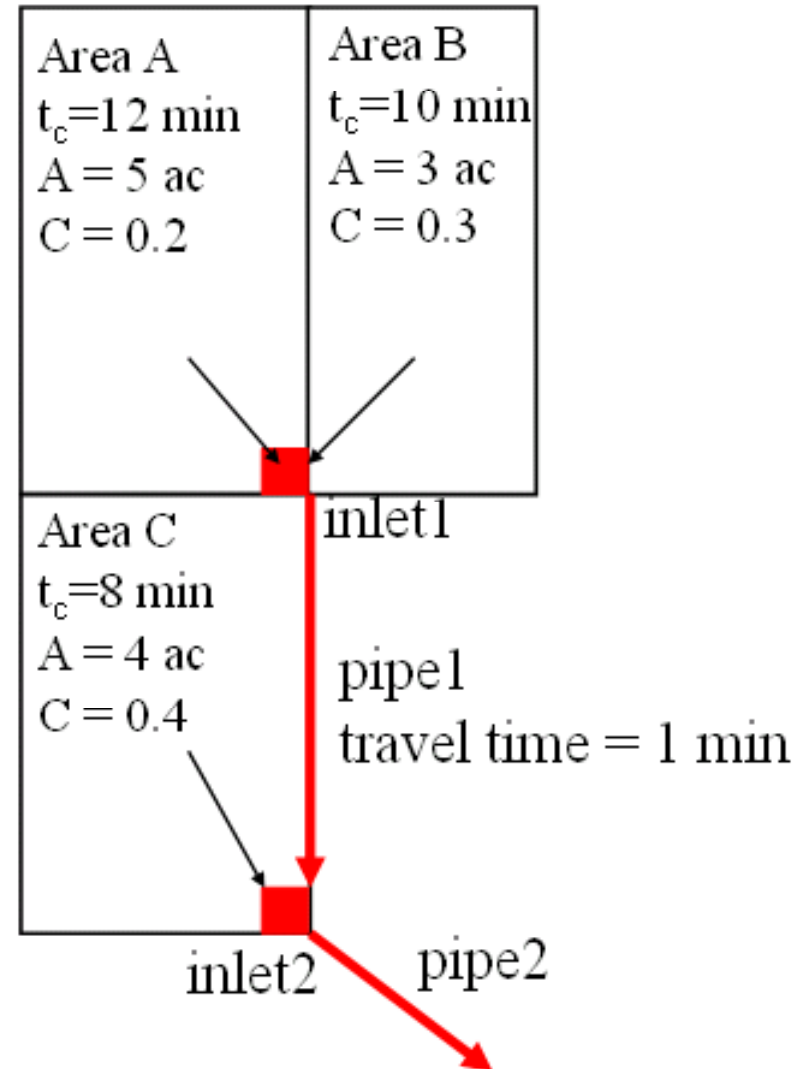
$$i = \frac{30}{(t+5)^{0.7}}$$

Area A
t_c=12 min
A = 5 ac
C = 0.2

Area B
t_c=10 min
A = 3 ac
C = 0.3

inlet1

Area C
t_c=8 min
A = 4 ac
C = 0.4

pipe1
travel time = 1 min

inlet2   pipe2

Example 1

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

Area A
t_c=12 min
A = 5 ac
C = 0.2

Area B
t_c=10 min
A = 3 ac
C = 0.3

inlet1

Area C
t_c=8 min
A = 4 ac
C = 0.4

pipe1
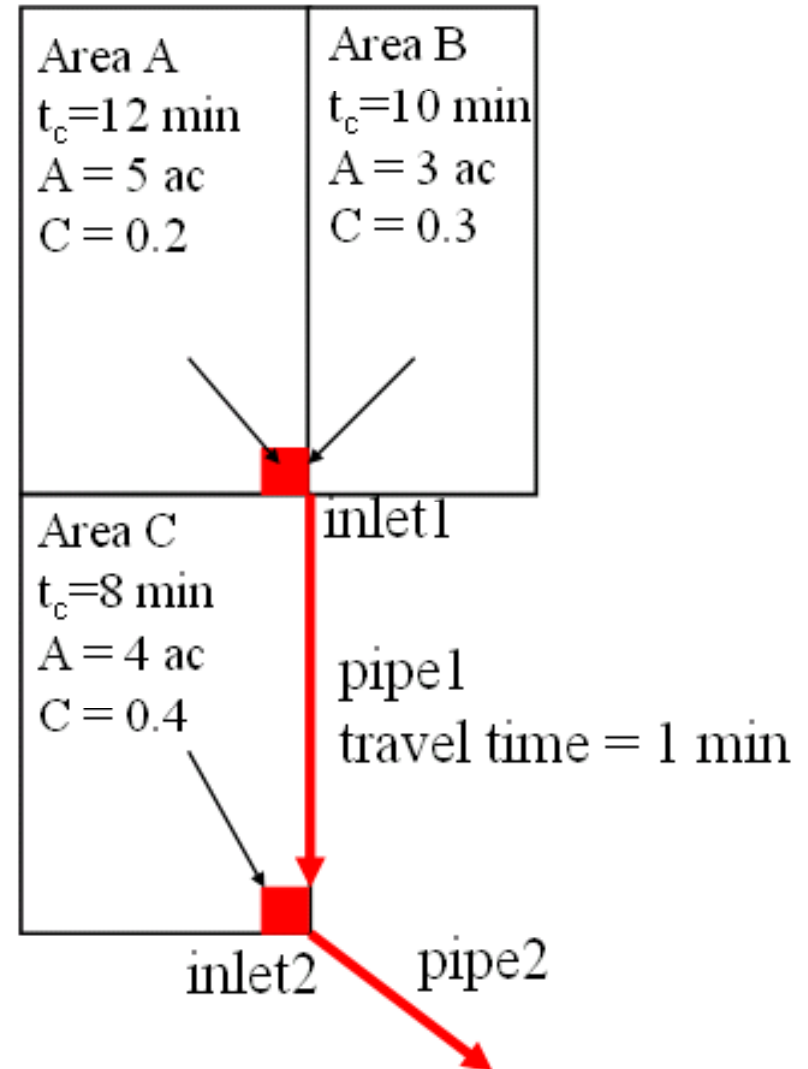travel time = 1 min

inlet2   pipe2

Example 1

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

Area A
t_c=12 min
A = 5 ac
C = 0.2

Area B
t_c=10 min
A = 3 ac
C = 0.3

inlet1

Area C
t_c=8 min
A = 4 ac
C = 0.4

pipe1
travel time = 1 min

inlet2   pipe2

Example 1

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.
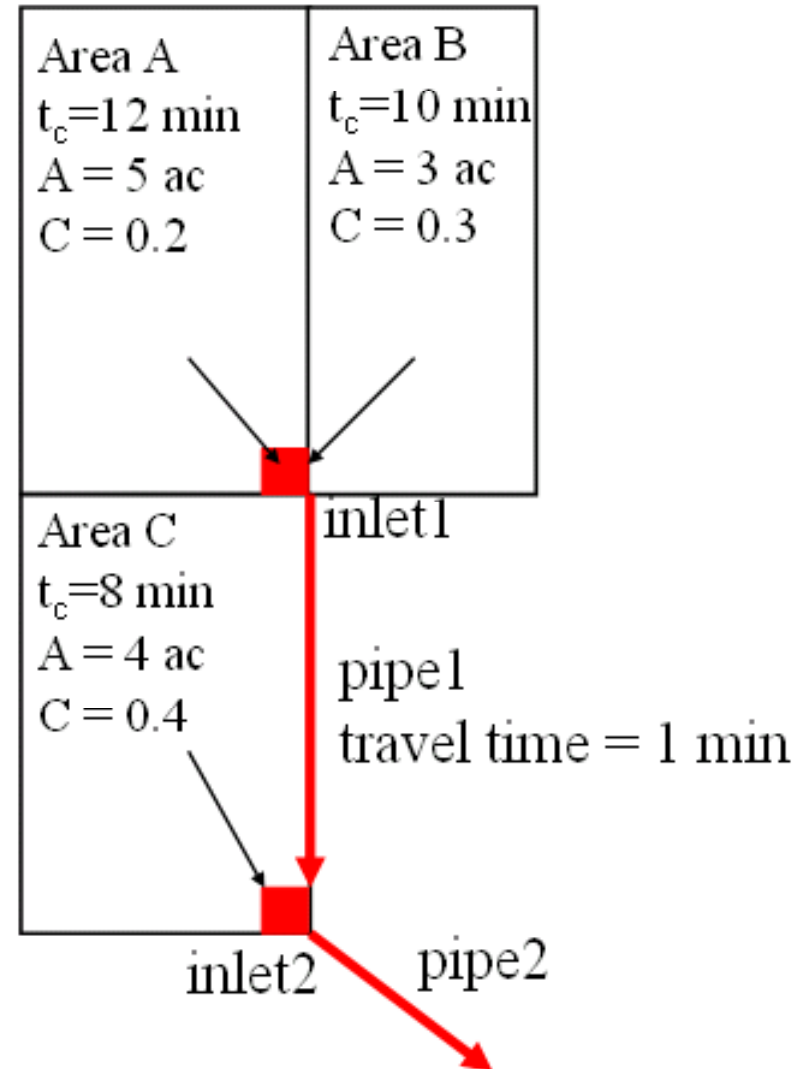
Area A
t_c=12 min
A = 5 ac
C = 0.2

Area B
t_c=10 min
A = 3 ac
C = 0.3

inlet1

Area C
t_c=8 min
A = 4 ac
C = 0.4

pipe1
travel time = 1 min

inlet2   pipe2

Fundamental Hydraulic for Sewer Design

PRESSURE FLOW

Is a flow condition in which the fluid moves through a closed conduit as a result of source of energy, generally external to the conduit proper, such as the energy supplied by a pump or an external pressure head.

GRAVITY FLOW

Is a flow condition in which flow takes place due to the energy within the conduit and flowing fluid, namely, the force of gravity.

Although gravity flow can take place in any pipe of conduit, pressure flow can exist only in a closed conduit, flowing full.

Open Channel

TYPE OF OPEN CHANNEL

- Most open channel flow occur in drainage structures and facilities.

- Various forms of open channel types such as man-made ditch, natural stream, sewer etc.

- In case flow sewer system, open channel flow conditions exist, even though the flow takes place in a pipe.

Open Channel

- In connection with the sewer, the flow take place in a pipe, the flow condition is nevertheless still of the open channel since the water surface is unconfined/ open to the atmosphere. Only after the flow in a channel reached the point where the pipe cross section is 100% full are pressure-flow conditions reached.

Open Channel

- Ditches and canals usually take on the form of trapezoidal channels.

- Side slopes of the channels are usually chosen to be compatible with the soil conditions and/or the lining of the channel wall.

Open Channel Flow

The open channel flow can be:

1) STEADY AND UNIFORM FLOW
   The capacity of the flow and its velocity remain constant throughout the length of the channel reach.

   Such flow are theoretical and are seldom encountered in practice, but many sewers and other drainage structures are designed on the assumption that steady uniform flow prevails.

The open channel flow can be:

2) UNSTEADY FLOW
    The capacity of the flow varies along the length
    of the channel reach.

The open channel flow can be:

3) NONUNIFORM FLOW
   The velocity flow varies along the reach due to changes in
   -cross section
   -channel slope
   -roughness coefficient
   -physical channel changes.

   These flows are often encountered and require consideration in case of large sewers, ditches, and natural streams.

Open Channel Flow

- Many of the flow formulas were derived from observation and study of open channel flow conditions.

- The most commonly used formula is the Manning formula because of its wide acceptance.

- Manning's flow formula takes on 3 forms

Open Channel Flow

$$V = \frac{R^{2/3} x S^{1/2}}{n}$$

$$Q = \frac{A x R^{2/3} x S^{1/2}}{n}$$

$$s = KQ^2$$

A = cross-sectional area of the flow
       in the channel (sq.m.)

R = hydraulic radius (cross sectional
       area/wetted perimeter) (m)

v = velocity of flow (m/s)

Q = capacity of flow (cms)

s = slope of the hydraulic radient

K = a geometric proportionality
       coefficient

n = roughness coefficient

Robert Manning, in 1885

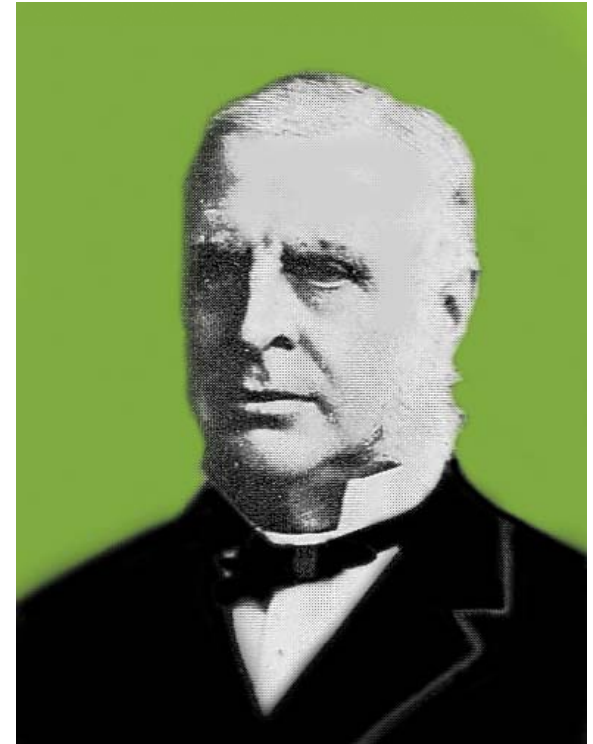Developed Manning formula used for open channel flow conditions.

$$v = \frac{1}{n}R^{2/3}S^{1/2}$$

v = velocity of flow, m/s
R = hydraulic radius, m
S = slope of the energy gradient
n = a roughness coefficient

Open Channel Flow

- Values of the n coefficient to be used with the Manning formula
    - -vary greatly
    - -are dependent upon the materials and conditions of the channel walls and bottom together with the prevailing flow conditions.

- The velocity and capacity of flow are inversely related to the value of n, that is, higher values of n produce lower values of v and Q.

Open Channel Flow

Values of Manning's Roughness Coefficient, n

| Nature of Surface	Manning's n Range
Concrete pipe	0.011–0.013
Corrugated metal pipe	0.019–0.030
Vitrified clay pipe	0.012–0.014
Steel pipe	0.009–0.011
Monolithic concrete	0.012–0.017
Cement rubble	0.017–0.025
Brick	0.014–0.017
Laminated treated wood	0.015–0.017
Open channels:	
Lined with concrete	0.013–0.022
Earth, clean, after weathering	0.018–0.020
Earth, with grass and some weeds	0.025–0.030
Excavated in rock, smooth	0.035–0.040
Excavated in rock, jagged and irregular	0.040–0.045
Natural stream channels:	
No boulders or brush	0.028–0.033
Dense growth of weeds	0.035–0.050
Bottom of cobbles with large boulders	0.050–0.070

Source: Design Charts for Open-Channel Flow, U.S. Department of Transportation, Federal Highway Administration, Hydraulic Design Series No. 3 (Washington, DC; U.S. Government Printing Office, 1961).

Example 2

A concrete channel (n=0.013), rectangular in shape and 1.25 m wide, must carry water at a uniform rate of flow of 2000 L/s and a depth of 0.75 n.

Determine the required channel bottom slope for this channel.
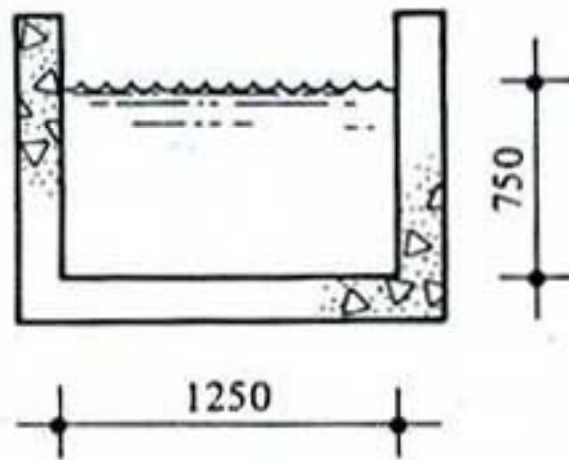
$$Q = \frac{A \times R^{2/3} \times S^{1/2}}{n}$$

Example 2

Solution $A = 1.25 \times 0.75 = 0.938 \text{ m}^2$

$P = 0.75 + 1.25 + 0.75 = 2.75 \text{ m}$

$R = A/P = 0.938/2.75 = 0.341 \text{ m}$

Therefore, $S = [(nQ)/(AR)^{2/3})]^2$

$= [(0.013 \times 2.0)/(0.938 \times 0.341)^{2/3}]$

$= 0.003$

So, $S_o = 0.003$

Example 3

A 500 mm asbestos cement sewer pipe (n=0.012) has been installed with an invert slopes of 0.008.

Determine the capacity of flow when this pipe is flowing half full. Assume the flow is uniform.

<u>Solution</u> $A = \pi d^2/(4\times2) = \pi(0.5)^2/8 = 0.098$ m^2
$R = 0.5/4 = 0.125$ m
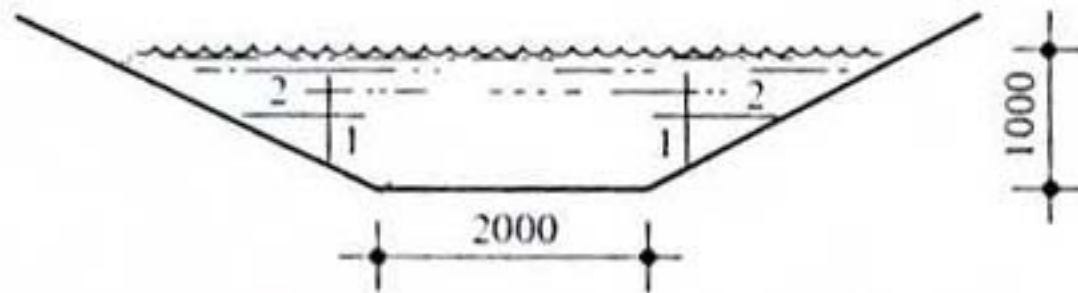$Q = [0.098\times0.125^{2/3}\times0.008^{1/2}]/0.012$
$= 0.183$ cms
$= 183$ L/s

$$Q = \frac{A\times R^{2/3}\times S^{1/2}}{n}$$

Example 4

For the trapezoidal channel shown in figure, determine the slope of the channel if the capacity of flow has to be 4500 L/s. Assume uniform flow and n=0.025

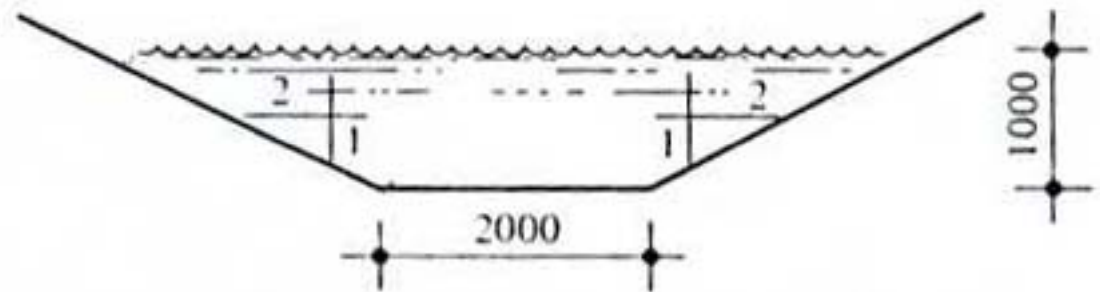# Example 4

Solution   Top width   = 2.0+2(2x1.0) = 6.0 m

A   =[(2.0+6.0)/2]x1.0

    = 4.0 m^2

P   = 2.0+2xsqrt(1.0^2+2.0^2)

    = 6.47 m

R   = 4.0/6.47

    = 0.62 m

S   =[(0.025x4.5)/(4.0x0.62$^{2/3}$)]^2

    = 0.0015

The Hazen-Williams formula has be developed specially for use with water and has been generally accepted as the formula used for pipe flow problems.

$$v = 0.849CR^{0.63}S^{0.54}$$

v = velocity of flow, m/s
R = hydraulic radius, m
S = slope of the energy gradient
C = a roughness coefficient

$$Q = 0.849CAR^{0.63}S^{0.54}$$

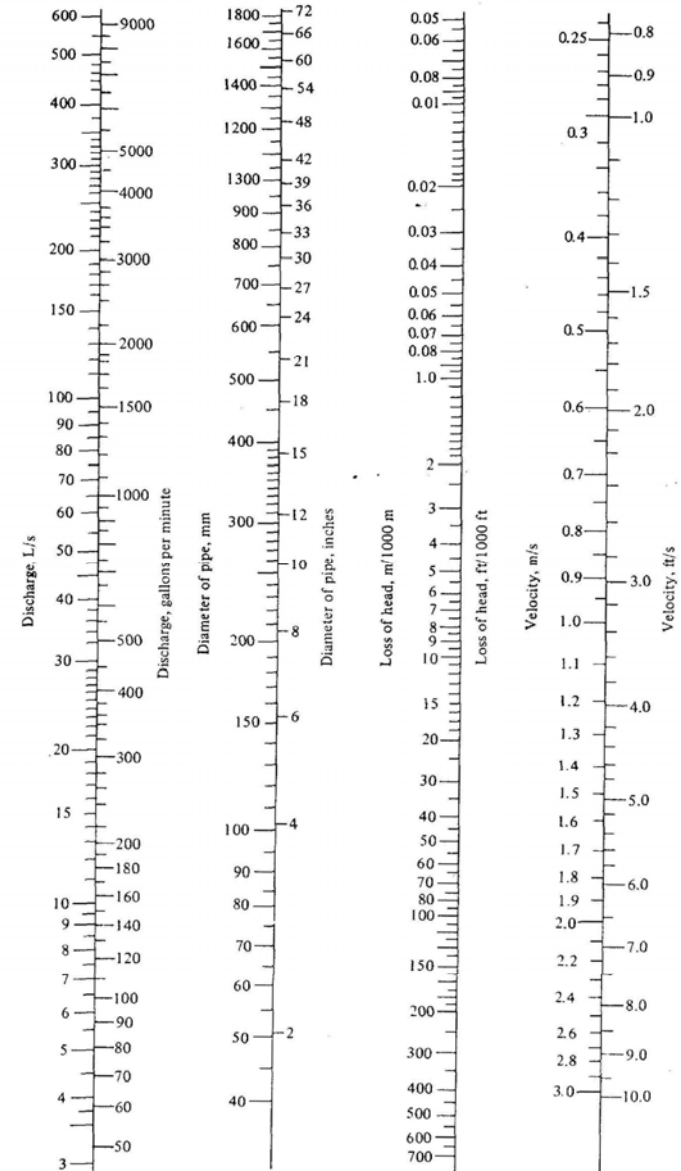| Pipe Material	C	n
Asbestos Cement	130–140	0.011–0.015
Cast Iron		
Plain	90–100	0.014–0.016
Cement-lined	100–130	0.012–0.015
Concrete		
New	120–130	0.011–0.015
Old	100–120	0.012–0.014
Plastic	140–150	0.009–0.010

Values of C in the Hazen-William Formula and of n in the Manning Formula.

Hazen-Williams Formula

- **Graphical Solutions (Nomograph)**

Hazen-Williams Formula
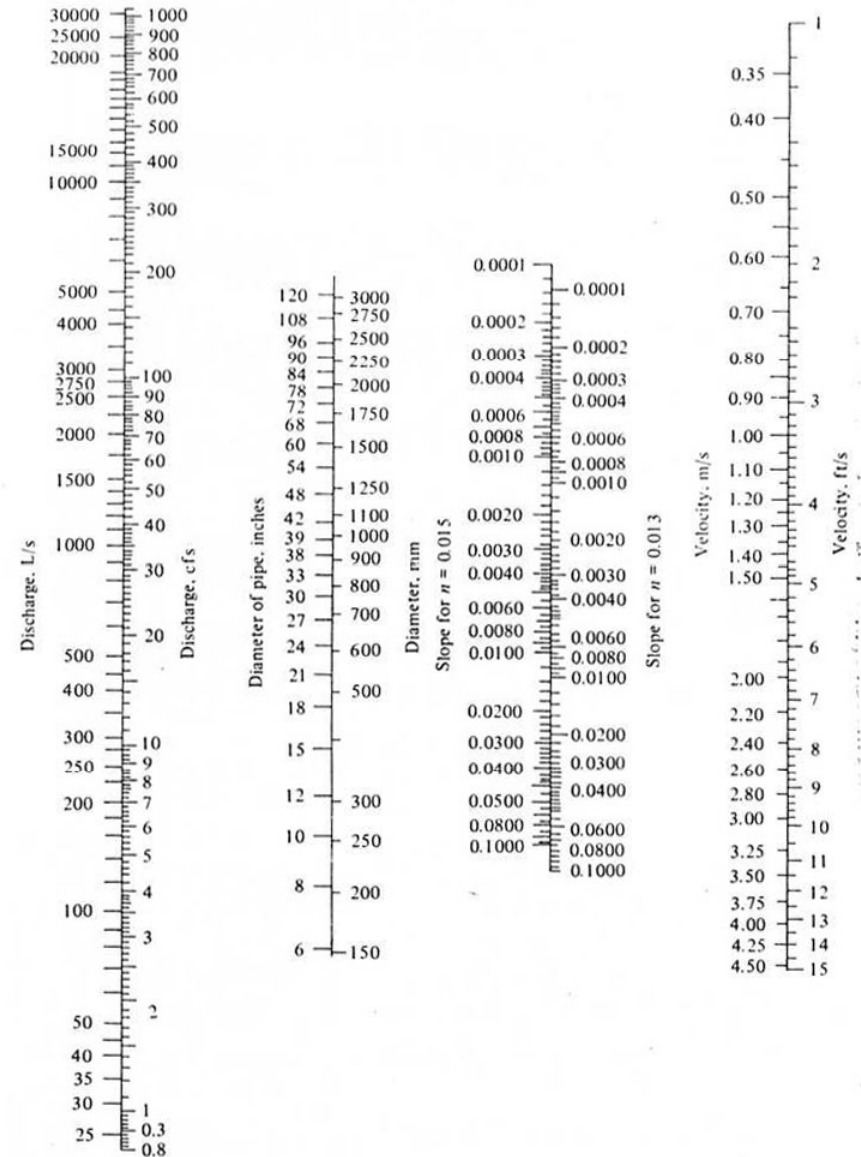
- **Mathematical Solutions**

Graphical Solutions (Nomograph)

Diameter Nominal mm	in.	Actual, mm	Area, m²	C 80	90	100	110	120	130	140	150	K'
100	4	102	0.0081	219.1	176.1	144.9	121.5	103.4	89.14	77.71	68.39	733 800
150	6	152	0.0182	30.40	24.45	20.11	16.86	14.35	12.37	10.79	9.492	101 800
200	8	203	0.0324	7.489	6.022	4.954	4.153	3.535	3.048	2.657	2.338	25 080
250	10	254	0.0507	2.526	2.031	1.671	1.401	1.192	1.028	0.8961	0.7887	8459
300	12	305	0.0730	0.1039	0.8358	0.6876	0.5764	0.4906	0.4230	0.3688	0.3245	3481
400	15	381	0.1141	0.3506	0.2819	0.2319	0.1944	0.1655	0.1427	0.1244	0.1095	1174
450	18	457	0.1642	0.1443	0.1160	0.0954	0.0800	0.0681	0.0587	0.0512	0.0450	483.0
550	21	533	0.2235	0.0681	0.0548	0.0450	0.0378	0.0321	0.0277	0.0242	0.0213	228.0
600	24	610	0.2029	0.0355	0.0286	0.0235	0.0197	0.0168	0.0145	0.0126	0.0111	119.0
700	27	686	0.3695	0.0200	0.0161	0.0132	0.0111	9.450	8.149	7.104	6.252	67.03
750	30	762	0.4562	0.0120	9.638	7.929	6.646	5.657	4.878	4.252	3.742	40.12
850	33	838	0.5520	7.535	6.059	4.985	4.178	3.556	3.066	2.673	2.353	25.22
900	36	914	0.6570	4.932	3.966	3.263	2.735	2.328	2.007	1.750	1.540	16.51
1000	39	991	0.7710	3.340	2.685	2.209	1.852	1.576	1.359	1.185	1.043	11.18
1050	42	1067	0.8942	2.328	1.872	1.540	1.291	1.099	0.9474	0.8259	0.7268	7.792
1200	48	1219	1.1679	1.215	0.9768	0.8037	0.6737	0.5743	0.4944	0.4310	0.3793	4.066
1400	54	1372	1.4782	0.6846	0.5504	0.4529	0.3796	0.3231	0.2786	0.2419	0.2137	2.291
1500	60	1524	1.8249	0.4098	0.3295	0.2711	0.2272	0.1934	0.1668	0.1454	0.1279	1.371

Note: Values in italics are $K \times 10^3$.

$$s = K \times Q^{1.852} = K' \left(\frac{Q}{C}\right)^{1.852} \quad \text{where } Q \text{ is in m}^3/\text{s}.$$

Mathematical Solutions

Diameter Nominal mm	Nominal in.	Actual, mm	Area, m²	n 0.009	0.010	0.012	0.013	0.015	0.018	0.020	0.024	K'
100	4	102	0.0081	164.9	203.6	293.2	344.1	458.1	659.7	814.4	1173.0	2 038 000
150	6	152	0.0182	18.97	23.42	33.73	39.58	52.70	75.89	93.69	134.9	234 400
200	8	203	0.0324	4.090	5.050	7.272	8.534	11.36	16.36	20.20	29.09	50 540
250	10	254	0.0507	1.244	1.536	2.212	2.596	3.456	4.977	6.145	8.848	15 370
300	12	305	0.0730	0.4706	0.5809	0.8366	0.9818	1.307	1.882	2.324	3.346	5814
400	15	381	0.1141	0.1431	0.1767	0.2545	0.2987	0.3976	0.5726	0.7069	0.1018	1769
450	18	457	0.1642	0.0541	0.0668	0.0962	0.1129	0.1504	0.2165	0.2673	0.3850	668.9
550	21	533	0.2235	0.0238	0.0294	0.0423	0.0496	0.0661	0.0952	0.1175	0.1692	294.0
600	24	610	0.2920	0.0117	0.0144	0.0208	0.0244	0.0324	0.0467	0.0576	0.0830	144.2
700	27	686	0.3695	6.228	7.688	0.0111	0.0130	0.0173	0.0249	0.0308	0.0443	76.94
750	30	762	0.4562	3.550	4.383	6.312	7.408	9.862	0.0142	0.0175	0.0252	43.87
850	33	838	0.5520	2.136	2.637	3.797	4.456	5.932	8.542	0.0106	0.0152	26.39
900	36	914	0.6570	1.343	1.658	2.387	2.801	3.730	5.371	6.631	9.548	15.59
1000	39	991	0.7710	0.8761	1.082	1.558	1.828	2.434	3.505	4.327	6.230	10.83
1050	42	1067	0.8942	0.5901	0.7285	1.049	1.231	1.639	2.360	2.914	4.196	7.291
1200	48	1219	1.1679	0.2895	0.3574	0.5147	0.6040	0.8041	1.158	1.430	2.059	3.577
1400	54	1372	1.4782	0.1545	0.1907	0.2746	0.3223	0.4291	0.6178	0.7628	1.098	1.908
1500	60	1524	1.8249	0.0881	0.1087	0.1566	0.1837	0.2446	0.3522	0.4349	0.6262	1.088
1700	66	1676	2.2081	0.0530	0.0654	0.0942	0.1105	0.1471	0.2119	0.2616	0.3767	0.6545
1800	72	1829	2.6278	0.0333	0.0411	0.0592	0.0695	0.0925	0.1332	0.1645	0.2368	0.4115
2150	84	2134	3.5768	0.0146	0.0181	0.0260	0.0305	0.0407	0.0586	0.0723	0.1041	0.1808
2450	96	2438	4.6717	0.0072	0.0089	0.0128	0.0150	0.0200	0.0287	0.0355	0.0511	0.0887
2750	108	2743	5.9126	0.0038	0.0047	0.0068	0.0080	0.0106	0.0153	0.0189	0.0272	0.0473

Note: Values in italics are $K \times 10^3$.

$$s = K \times Q^2 = K' \left(\frac{Q}{C}\right)^{1/2}$$ where Q is in m³/s.

Example 5

A cast-iron water pipe, 400 mm in diameter, carries water at a rate of 0.125 cms. Determine, by means of the Hazen-Williams formula. The slope of the hydraulic gradient of this pipe and the velocity of flow.

Solution   1. Graphical solution

Use the nomograph, line up the known value, d=381, the actual diameter of a nominal 400-m pipe, and Q−0.125, and find

S = 0.0045 m/m

v = 1.09 m/s

Example 5

Solution   2. Mathematical solution

From table, for d = 400 and C = 100, find K = 0.232 and A = 0.114. Hence

$$s = 0.232 \times 0.125^{1.85} = 0.005 \text{ m/m}$$

and $v = Q/A = 0.125/0.114 = 1.09$ m/s

Example 6

An asbestos cement water pipe (C=140) with a diameter of 300 mm has a slope of the hydraulic gradient of 0.0025 m/m. Determine, using the Hazen-Williams formula, the capacity of the pipe and the velocity of flow.

Solution   1. Graphical solution

          Use the nomograph, with d=305 mm, the actual diameter of a 300-mm pipe, and s=0.0025, find Q = 0.048 cms and v = 0.66 m/s

          However, it must be remembered that the nomograph, as indicated was constructed for C=100, whereas pipe in question has a C=140. Consequently, the value of Q and v need to be corrected.

Example 6

Solution   2. Mathematical solution

From table, for d=300 and C=140, find K=0.369 and A=0.730. Hence

$$Q = (0.0025/0.369)^{0.54} = 0.067 \text{ cms}$$

$$v = 0.067/0.730 = 0.92 \text{ m/s}$$

Example 7

A concrete pipe, 400 mm in diameter, carries water a rate of 125 L/s. Determine by means of the Manning formula the slope of the hydraulic gradient of this pipe and the velocity of flow. Assume n=0.013.

Solution   <u>1. Graphical solution</u>

      Use the nomograph, line up the known values of d=381 mm, the actual diameter of a 400 mm pipe, and Q = 125 L/s and find for n=0.013

        S = 0.0047 m/m

        v = 1.09 m/s

Example 7

Solution   2. Mathematical solution

From table, for d=400 mm and n=0.013, find K=0.2994 and A=0.114. Hence,

$S = 0.299 \times 0.125^2 = 0.0047$ m/m

$v = 0.125/0.114 = 1.10$ m/s

Summary

Hazen-Williams formula
Manning formula

In fact, these formulas:
- are developed for use with the flow of water.
- are applicable to incompressible fluids with a relative density of 1.0.

Common practice,
- Hazen-Williams formula exclusively for applications to pipe flow.
- Manning formula for gravity flow.