Chapter 8
Wastewater & Stormwater Collection & Removal

- Sewerage is the process of
  - collection
  - transmission
  - treatment
  - disposal of waste water ← Receiving water body after proper treatment
- Sewer
  - the closed conduit in which sewage is transmitted
  - normally partially filled
- Sewage (sanitary, storm)
  - wastewater to be removed

- Comparative characteristics

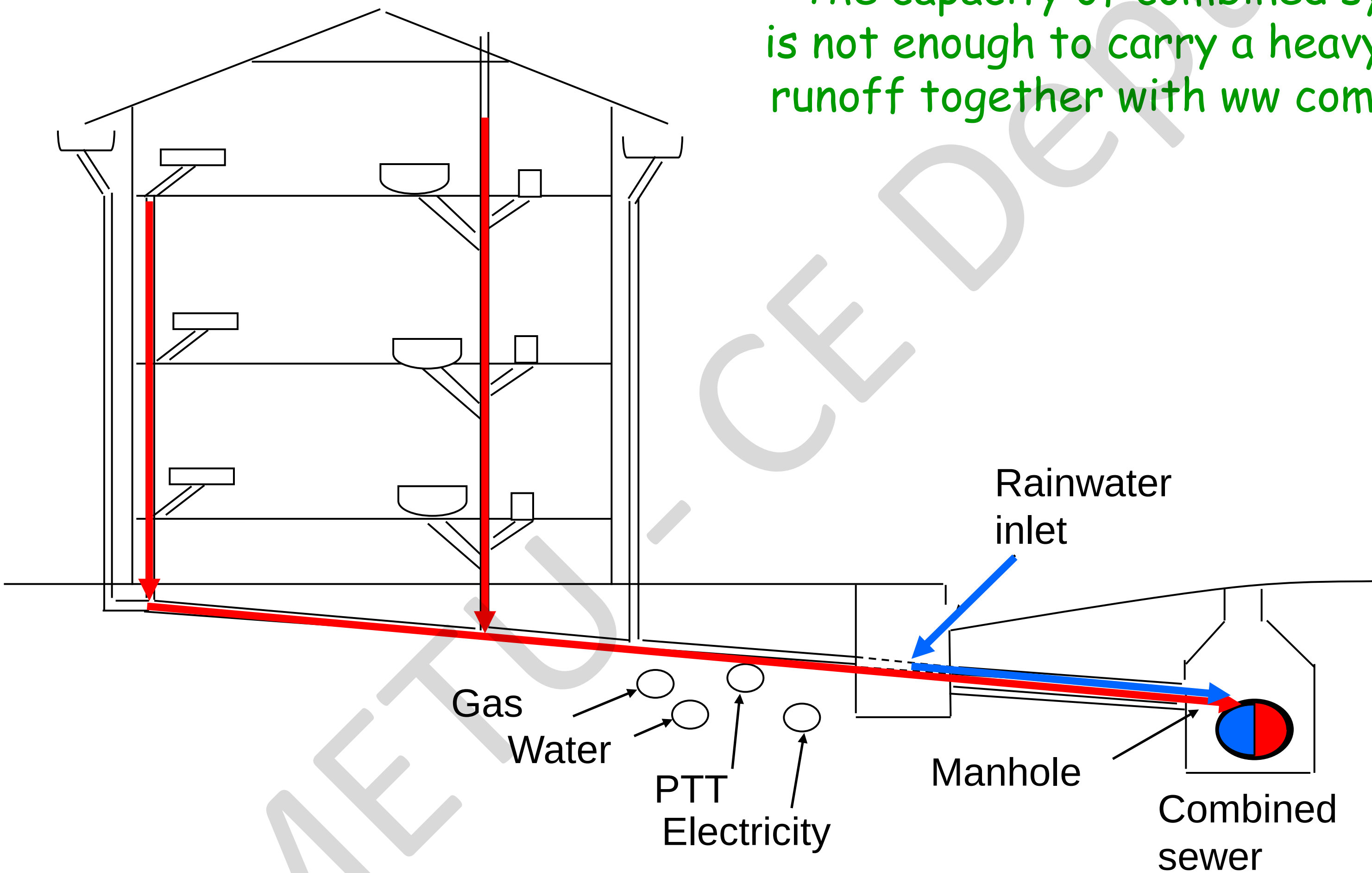
	Sewage	Municipal Water Supply
Change in discharge; Change in sewer size	Q and d increases in the direction of flow	Opposite
Type of flow	Gravity (partially filled)	Pressurized

- Pattern of network
- Reuse of wastewater

- Combined systems and seperate systems
  - Capacity problem
  - Cost
  - Feasibility during lifetime

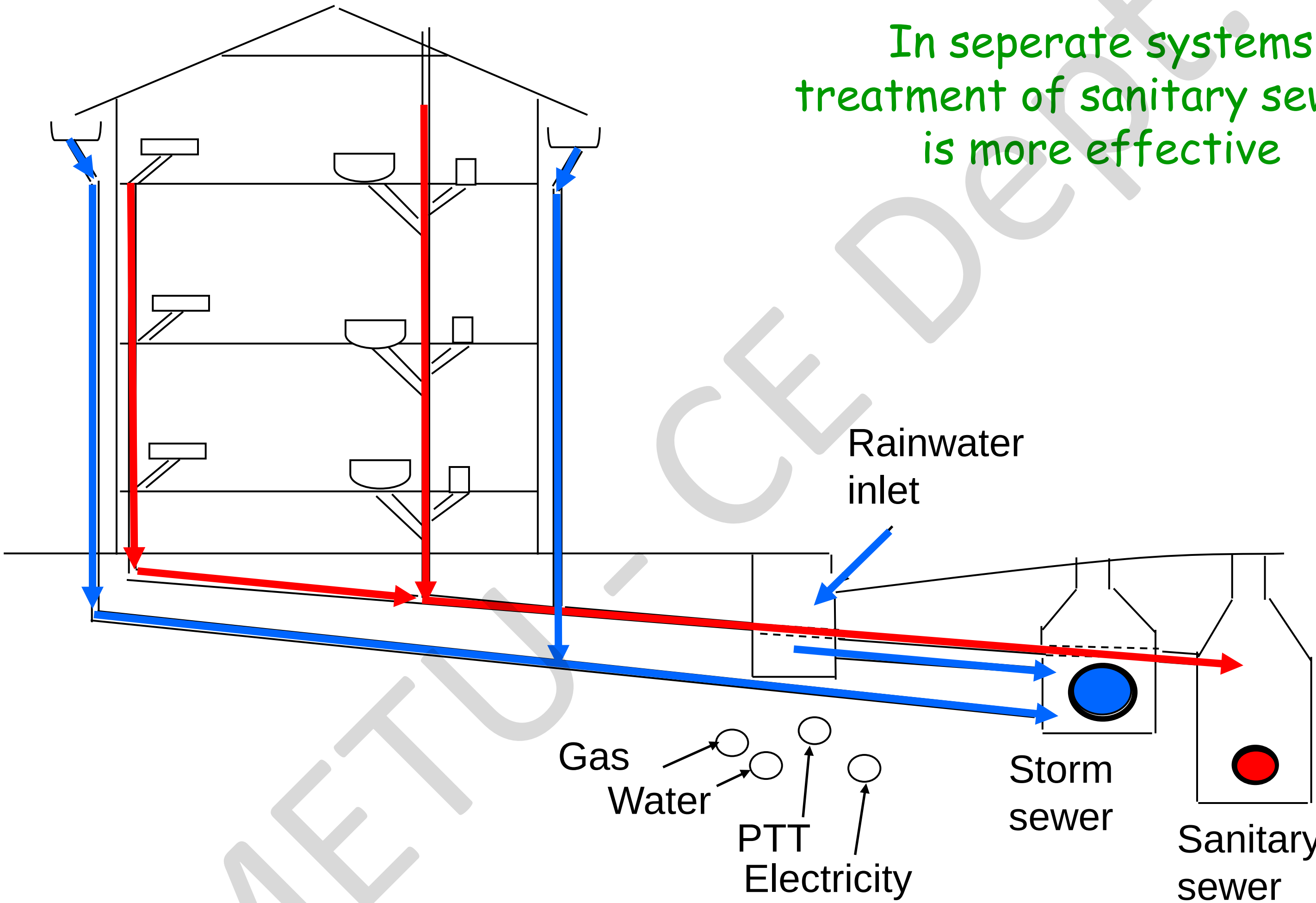
Storm water & sanitary ww from residential units or ww from public & industrial establishments are combined

The capacity of combined system is not enough to carry a heavy storm runoff together with ww component



a) Combined system

In seperate systems treatment of sanitary sewage is more effective

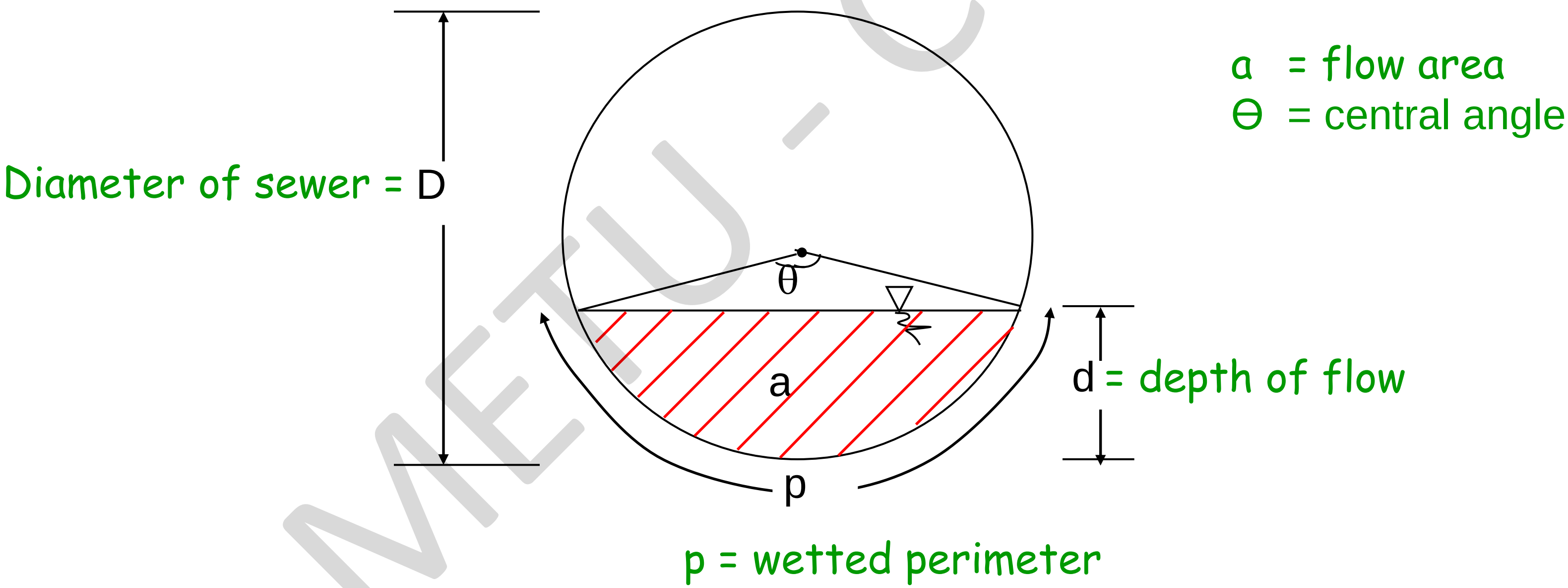


b) Seperate system

Flow in sewers

Sewers are designed as open channels, flowing partially full or at most just full

- mainly gravitational flow
- pumping may also be required if topographic conditions are not favorable
- circular cross-section



Hydraulic radius = a/p

Avr. x-sec. velocity

Friction slope

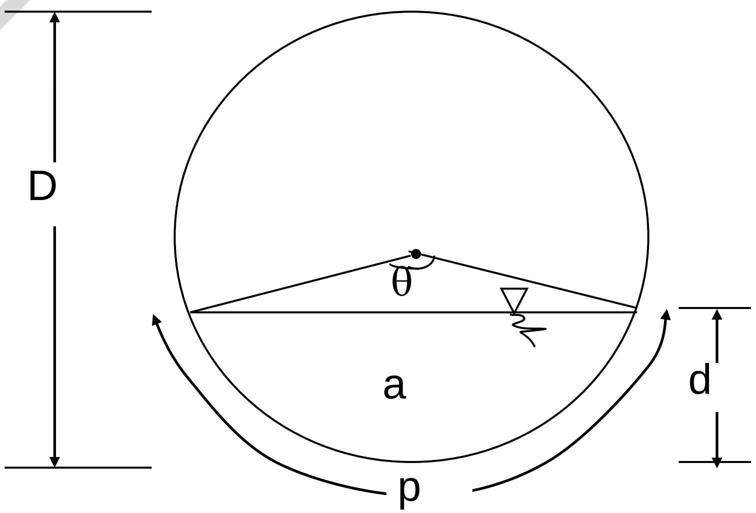
- partially filled parameters : d, a, p, r, u, q, sf, τ
- full-flow parameters : D, A, P, R, U, Q, Sf, τ

$$\cos\frac{\theta}{2} = 1 - \frac{2d}{D}$$

$$a = \frac{D^2}{8}\left(\theta - \sin\theta\right)$$

$$p = \frac{D\theta}{2}$$

$$r = \frac{D}{4}\left(1 - \frac{\sin\theta}{\theta}\right)$$



a = flow area
p = wetted perimeter
r = hydraulic radius

r = hydraulic radius
n = Manning's roughness coeff.
s_f = friction slope (equals slope of pipe for uniform flow)
S = pipe slope

From Manning's Eqn.

$$u = \frac{1}{n} r^{2/3} \sqrt{s_f}$$

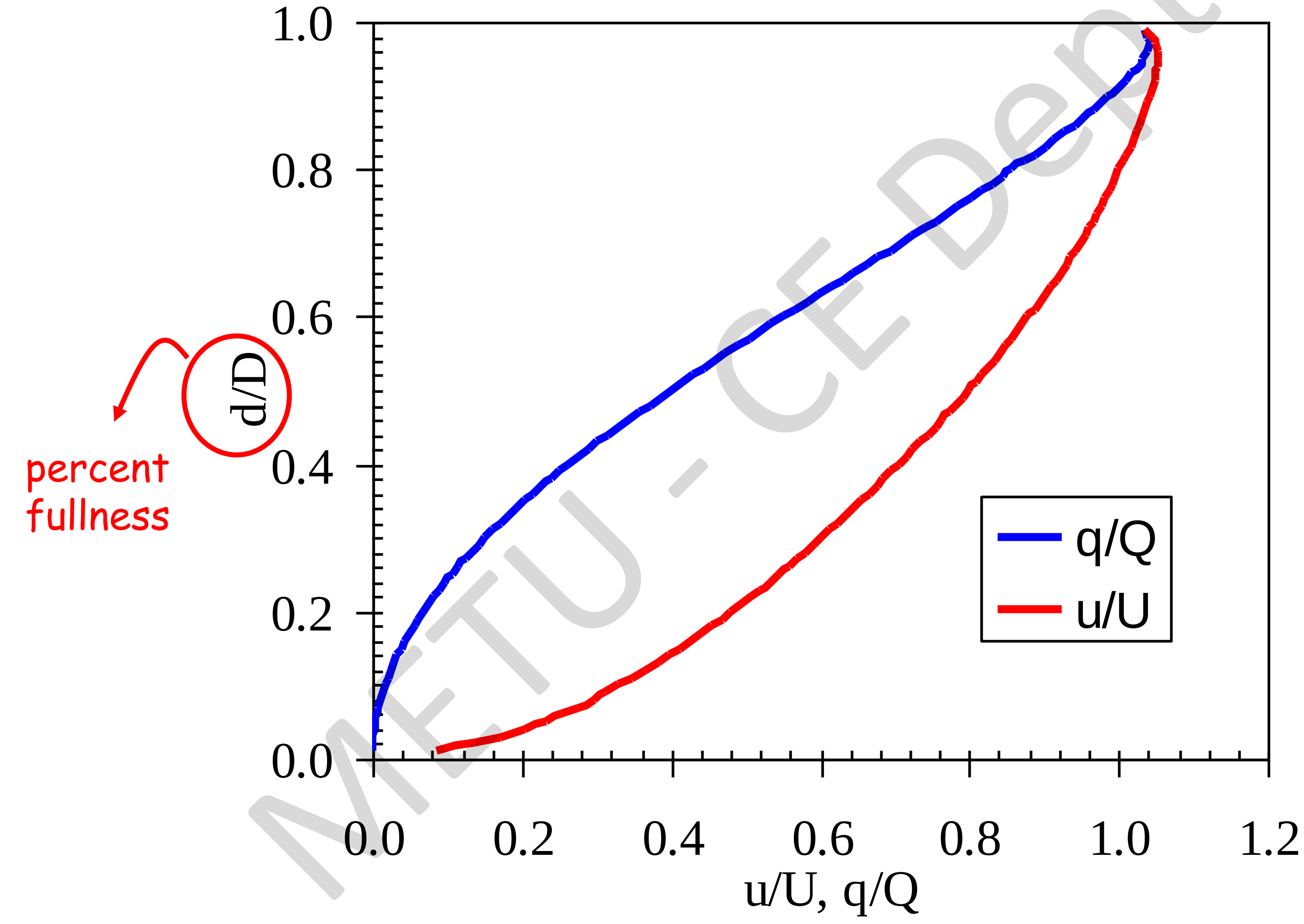
$$U = \frac{1}{N} R^{2/3} \sqrt{S}$$

dimensionless velocity →

$$\frac{u}{U} = \left(\frac{N}{n}\right)\left(\frac{r}{R}\right)^{2/3}$$

$$\frac{q}{Q} = \left(\frac{a}{A}\right)\left(\frac{N}{n}\right)\left(\frac{r}{R}\right)^{2/3}$$

ratios are called hydraulic elements of sewer


1.0
0.8
0.6
0.4
0.2
0.0
d/D
percent
fullness
0.0
0.2
0.4
0.6
0.8
1.0
1.2
u/U, q/Q
q/Q
u/U

Example 25: Given ϕ300 (D=300 mm), S=0.03. N=0.016 (variable) Maximum allowable velocity is 3 m/s. Determine,

- Full flow discharge and velocity
- Partially-filled discharge and velocity for 60% fullness
- Central angle and flow area for 30% fullness

$$Q_{full} = \frac{0.312}{N} D^{8/3}\sqrt{S} = \frac{0.312}{0.016}(0.3)^{8/3}\sqrt{0.03} = 0.136\,m^3/s$$

$$u_{full} = \frac{Q}{A} = \frac{4Q_{full}}{\pi D^2} = \frac{4*0.136}{\pi(0.3)^2} = 1.93\,\text{m/s} < 3\,\text{m/s, O.K.}$$

$$\text{For } \frac{d}{D} = 0.6 \qquad \frac{q}{Q} = 0.52, \frac{u}{U} = 0.88$$

$$q = 0.52*0.136 = 0.071\,m^3/s = 71\,\text{lt/s} \qquad u = 0.88*1.93 = 1.70\,m/s$$

$$\cos\frac{\theta}{2} = 1 - 2\frac{d}{D} = 1 - 2*0.3 = 0.4 \qquad \theta = 132° \qquad a = \frac{D^2}{8}(\theta - \sin\theta) = 0.0176\,m^2$$

Remarks on chart

- In practice, sanitary sewers are designed for:
  - d/D < 0.75
  - d/D > 0.50 under low flow conditions

- For small percent fullness values, i.e. d/D<0.5, greater slopes are needed to maintain the same self-cleansing effect as that of full sewer;

e.g. for d=0.20D, $S_{0.20D} \approx 2S$

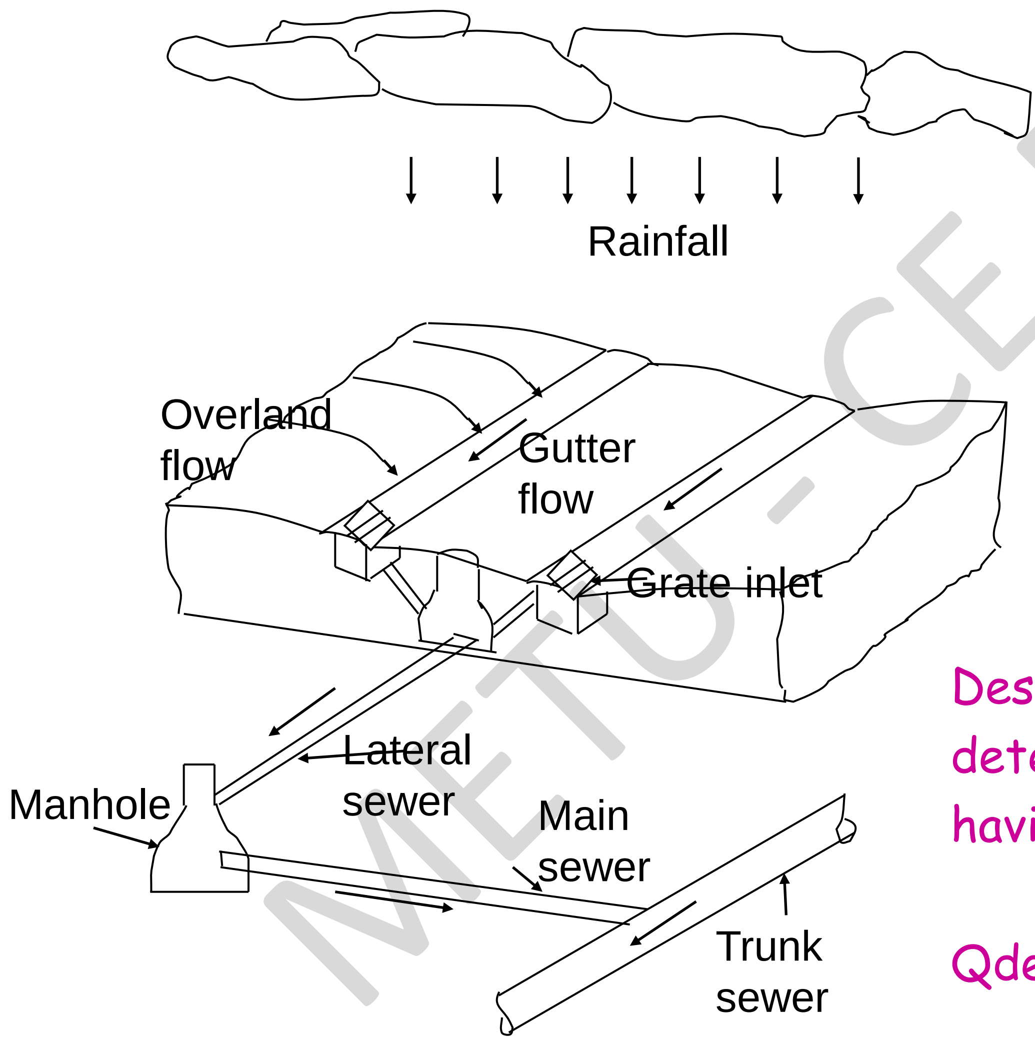
  - domestic sewage contains some solid material and storm runoff contains some sand, gravel and debris
  - if flow velocity is low, suspended material may settle down → hydraulic efficiency decreases
  - a minimum allowable velocity should be maintained for SELF-CLEANSING

large slope → cost ↑ → smaller slopes

+

flushing systems

Design of storm sewer systems



as urbanization ↑es

⇩

capacity of combined sewer becomes insufficient

⇩

separate systems

Design discharge of a storm sewer is determined from a surface runoff having a high return period.

Qdes = f(rainfall, surface properties)

- System carries surface runoff with high T_r (return period)

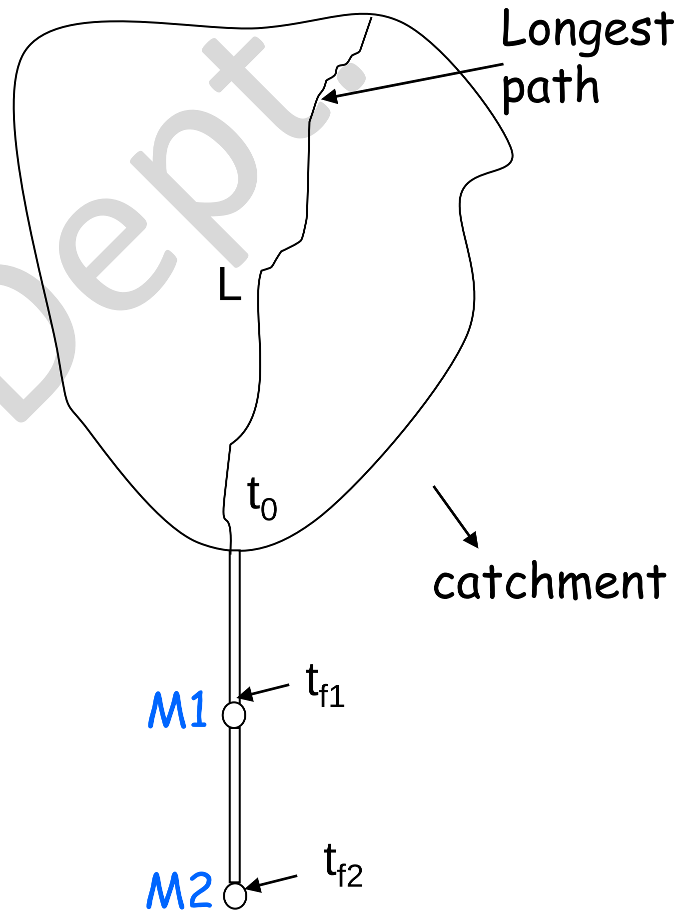
- Amount of storm sewage :
  - duration & intensity of rain
  - size of drainage area
  - surface characteristics of drainage area

- Rainfall / runoff relation → design storm runoff → hydrographs

- In case of lack of relevant information:
  - simple relations (eg. rational method)
  - synthetic unit hydrographs
  - geomorphologic synthetic unit hydrographs

$$t_c = t_0 + t_f$$

t_c = total time of concentration
t_0 = inlet time (time it takes from remotest pt to reach the sewer inlet)
t_f = flow time (time in the upstream sewer connected to the outer pt)



$$t_f = \sum_{i=1}^{n} \left(\frac{L_i}{u_i} \right)$$

L_i = length of the ith sewer along the flow path
u_i = velocity of the ith sewer along the flow path

Kinematic wave:

$$t_c = 6.99 \frac{(nL)^{0.6}}{i_e^{0.4} S_0^{0.3}}$$

n = Manning's roughness coeff. for the surface
t_c = time of concentration (min)
i_e = excess rainfall intensity (mm/hr)
L = flow length (m)

Turkish Bank of Provinces Codes

$0.5 \text{ m/s} \leq u \leq 4\text{-}5 \text{ m/s}$

$D_{min} = \phi 300$

Example 26 By investigating the topographical characteristics of the city, the flow directions in sewers are estimated as shown in Figure 1. The design criteria for both storm and sanitary sewer systems are given below:

- Manning's roughness coefficient, N_{full} is 0.016 for all pipes and is variable.
- Maximum allowable flow velocity, u_{max} is 4 m/s.
- Minimum allowable full flow velocity, u_{min} is 0.6 m/s.
- Street slopes are 0.01

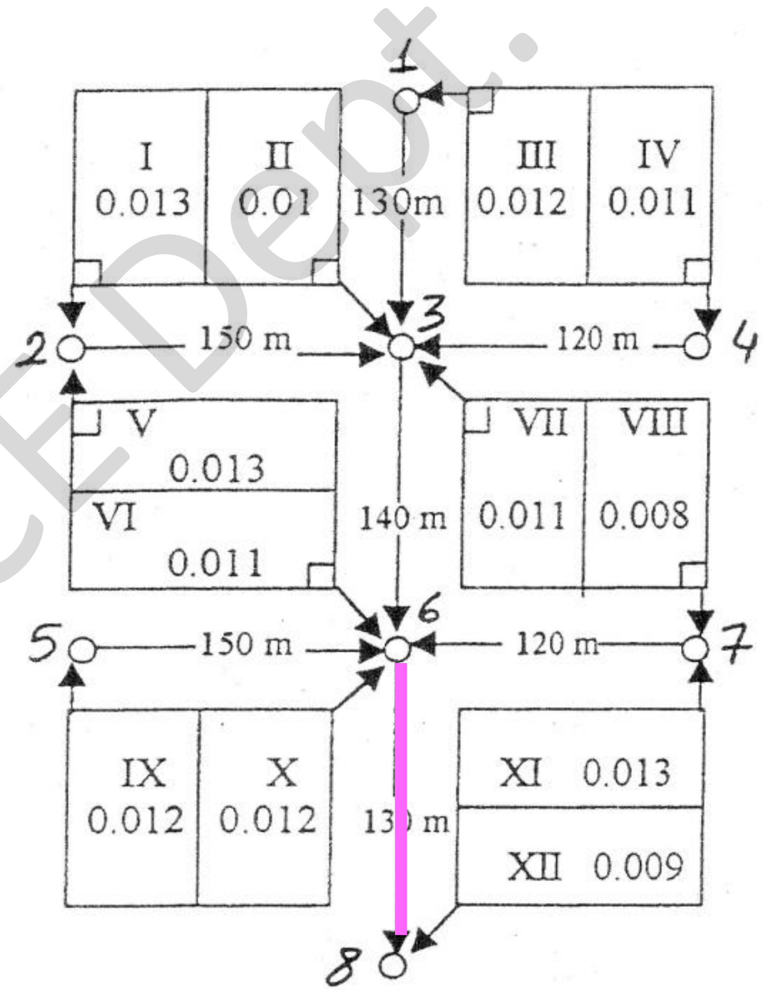


Figure 1. Layout of the system (areas in km^2).

Apply the rational method and use the rainfall intensity-duration-frequency curves given in Figure 3 for the storm sewer design. Consider the following data for the storm sewer system:

- Inlet times for all areas are 10 minutes.
- The flow time between two successive manholes is 2 minutes.
- T_r =25 years.
- Runoff coefficient, C for all areas are 0.7
- Pipe sizes are available for every 50 mm increments of diameter.
- Take D_{min} as φ300.

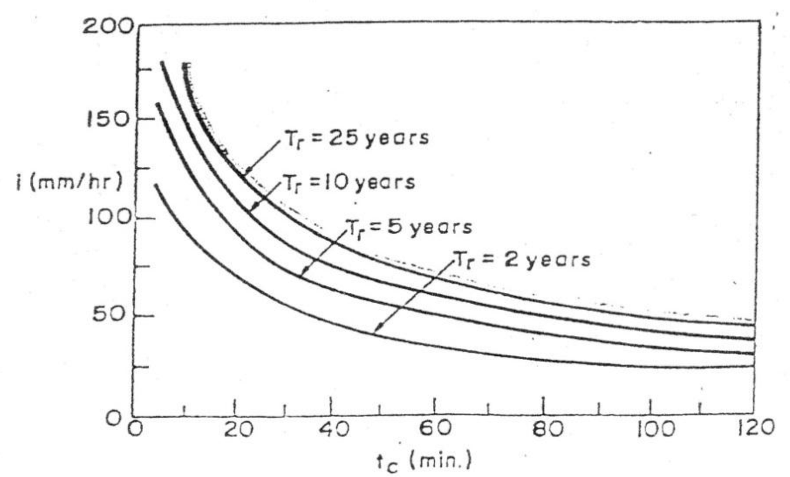


Figure 3. Rainfall intensity-duration-frequency curves.

Design of sewer, M6-M8: 3 possible paths are

Area no	C	A (km^2)	t_0 (min)	t_f (min)	t_c (min)
1	0.7	0.013	10	4	14
2	0.7	0.01	10	2	12
3	0.7	0.012	10	4	14
4	0.7	0.011	10	4	14
5	0.7	0.013	10	4	14
6	0.7	0.011	10	0	10
7	0.7	0.011	10	2	12
8	0.7	0.008	10	4	14
9	0.7	0.012	10	2	12
10	0.7	0.012	10	0	10
11	0.7	0.013	10	2	12

Path 1: Areas 6, 10
Path 2: Areas 6, 10, 2, 7, 9, 11
Path 3: Areas 6, 10, 2, 7, 9, 11, 1, 3, 4, 5, 8

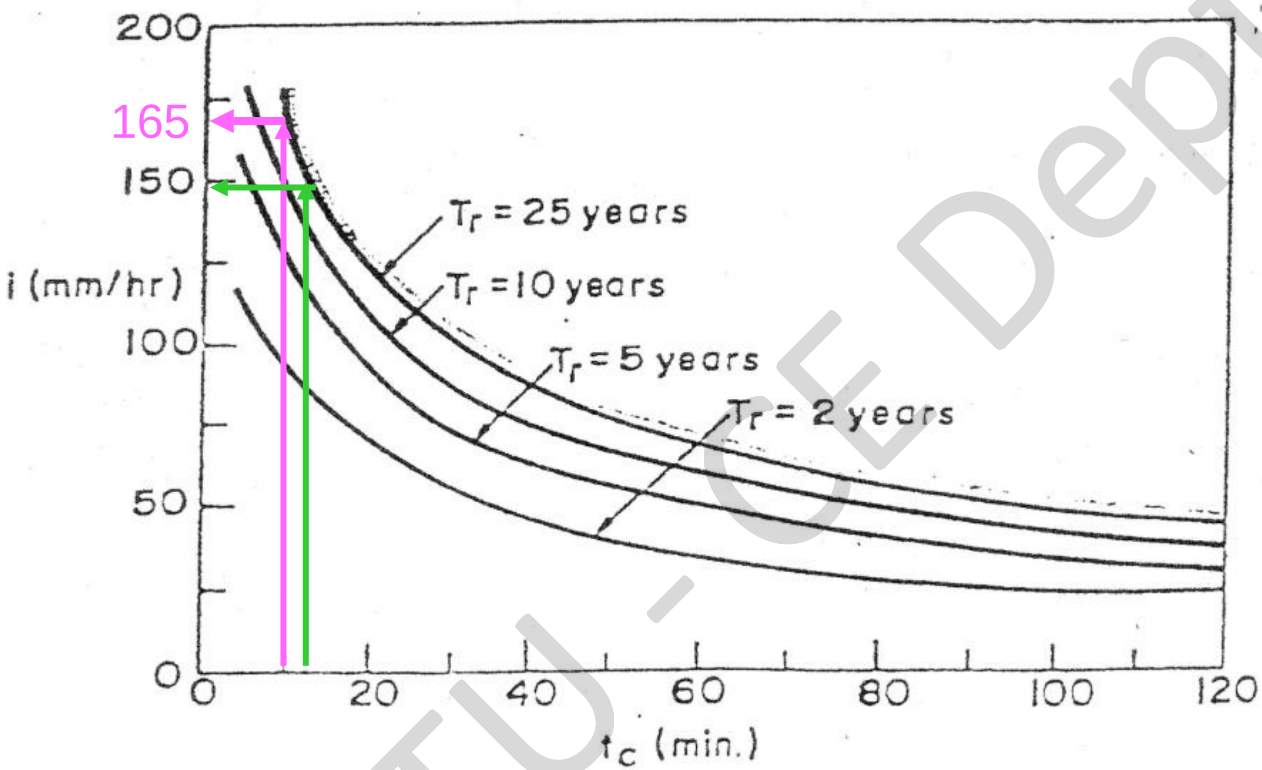


Figure 3. Rainfall intensity-duration-frequency curves.

Path 1: t_c=10 minutes (i = 165 mm/hr)

Area no	C	A (km^2)	t_0 (min)	t_f (min)	Q (m^3/s)
6	0.7	0.011	10	0	0.353
10	0.7	0.012	10	0	0.385
				sum	0.738

$$Q_p = \frac{CiA}{3.6}$$

Path 2: t_c=12 minutes (i = 147 mm/hr)

Area no	C	A (km^2)	t_0 (min)	t_f (min)	Q (m^3/s)
6	0.7	0.011	10	0	0.314
10	0.7	0.012	10	0	0.343
2	0.7	0.01	10	2	0.286
7	0.7	0.011	10	2	0.314
8	0.7	0.008	10	2	0.229
11	0.7	0.013	10	2	0.372
9	0.7	0.012	10	2	0.343
				sum	2.20

Path 3: t_c=12 minutes (i = 137 mm/hr)

Area no	C	A (km^2)	t_0 (min)	t_f (min)	Q (m^3/s)
6	0.7	0.011	10	0	0.293
10	0.7	0.012	10	0	0.320
2	0.7	0.01	10	2	0.266
7	0.7	0.011	10	2	0.293
8	0.7	0.008	10	2	0.213
11	0.7	0.013	10	2	0.346
9	0.7	0.012	10	2	0.320
3	0.7	0.012	10	4	0.320
1	0.7	0.013	10	4	0.346
4	0.7	0.011	10	4	0.293
5	0.7	0.013	10	4	0.346
				Sum	3.357

$$Q_p = \frac{CiA}{3.6}$$

Max. discharge occurs for Path 3 so use 3.357 m^3/s as design discharge

$$Q = \frac{0.312}{N} D^{8/3} \sqrt{S_0}$$

$$3.357 = \frac{0.312}{0.016} D^{8/3} \sqrt{0.01}$$

$$D = 1.226 \ m$$

$$D = 1226 \ mm$$

$$take \ D = 1250 \ mm$$

$$Q_{full} = \frac{0.312}{0.016} (1.25)^{8/3} \sqrt{0.01} = 3.536 \ m^3 / s$$

$$\frac{Q_{des}}{Q_{full}} = \frac{3.357}{3.536} = 0.95$$

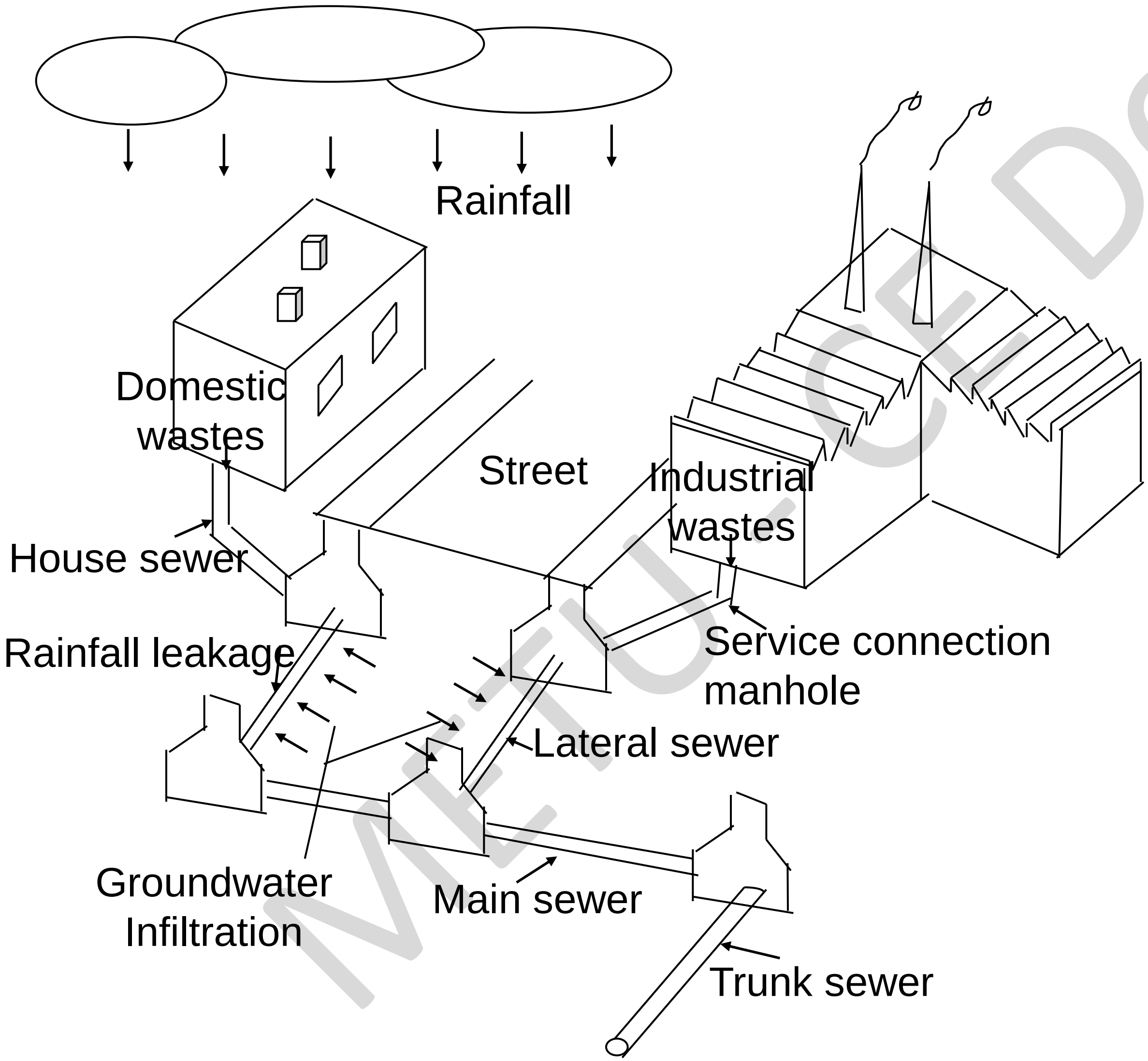
From Figure 8.3

$$\frac{u_{des}}{u_{full}} = 1.04$$

OK!

$$u_{des} = 1.04 (u_{full}) = 1.04 \left(\frac{3.536}{\pi \frac{1.25^2}{4}} \right) = 3 \ m/s$$

Design of sanitary sewer systems:



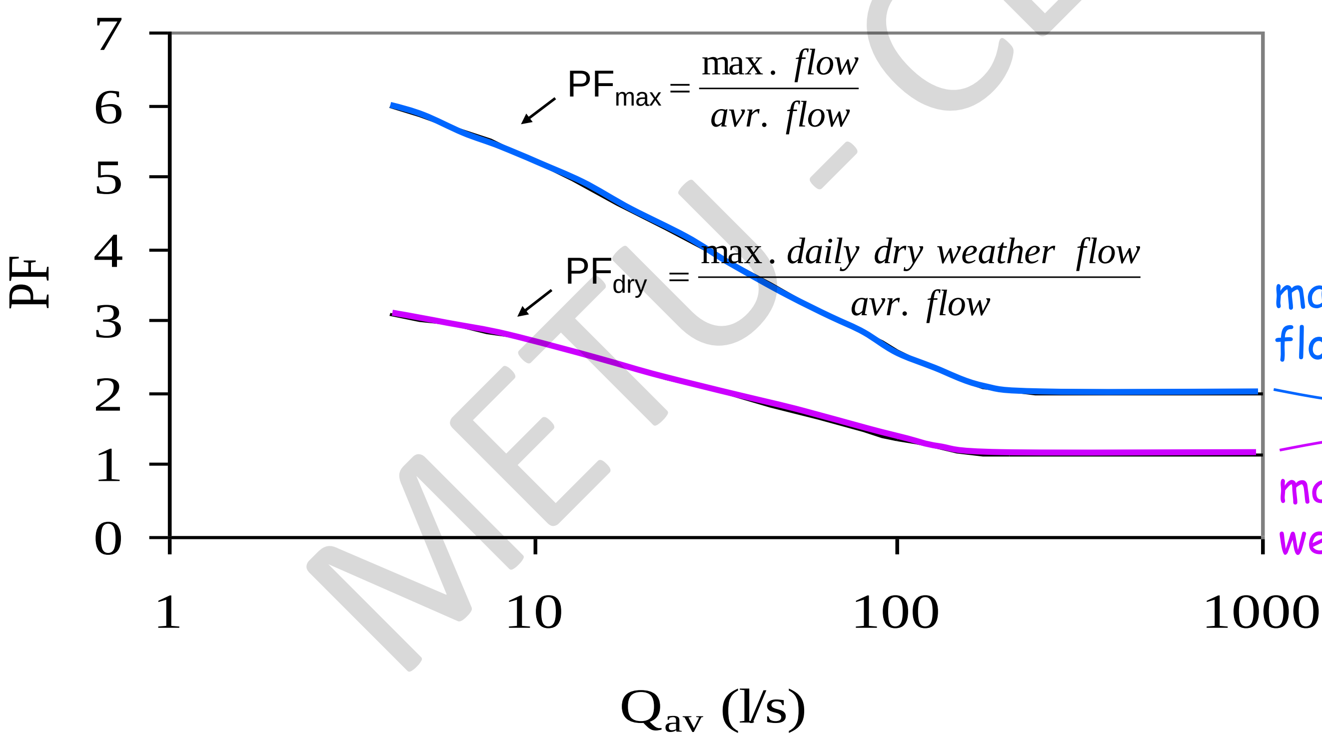
sanitary sewage
&
industrial wates
are
collected & removed
by
sanitary sewer systems

Q_{av} ≈ 70-130 % of avr. daily water consumption

Proper design
↓
elimination of accumulation

- System carries sanitary sewage and industrial wastes
- Q_{av} : (70 - 130) % of D_{ad} → average daily consumption
- Consider future projection for D_{ad} → per capita water use at the end of the lifetime of the project
- There exist fluctuations in wastewater flows since it is a function of daily water consumption.

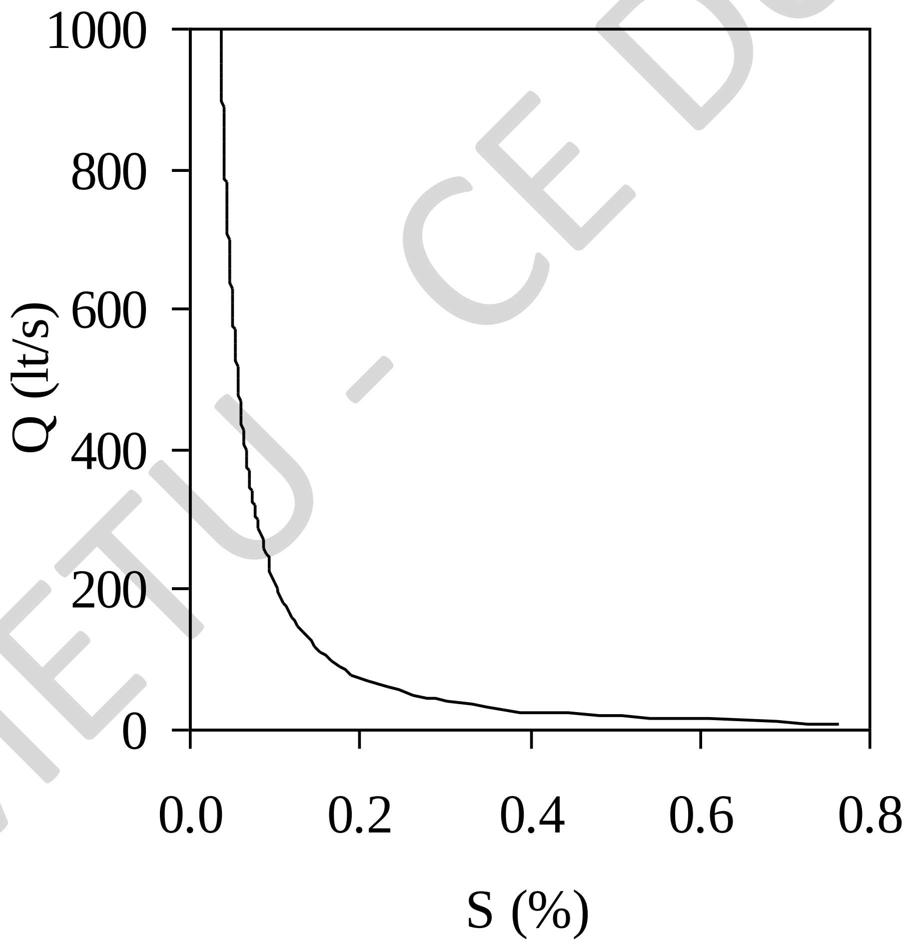
partially filled sewer provide a degree of equalization



max. possible variation of ww flow over the design period

max. daily variation of dry weather flow

Minimum required full flow velocity ($u_{full,min}$) for self-cleansing may be taken as 0.6 m/s. The slopes necesary for the minimum full velocity of 0.6 m/s under N=0.016 is given in the figure below:



- Codes of Turkish Bank of Provinces:
  - u_{max}= 2.5 - 3.0 m/s
  - $D_{min}=\phi 200$

storm water may also leak from manholes & improper connections of the storm water collection system

high gw table may cause leakage into the system

- Design flow:
  - $Q_{des}= Q_{av}*(PF)_{max}$ + GW infiltration + Some portion of rainfall
- If the percent fullness under design flow conditions exceeds 0.75 or the design velocity exceeds the maximum allowable value → increase the diameter
- Check the system performance under smaller flows !
- Dry weather flow:
  - $Q_{low} = Q_{av}* (PF)_{dry}$ + GW infiltration

Example 27

For the sanitary sewer system, the following data are given:

- $Q_{average}$ = 165.625 lt/s
- 70% of the average daily demand returns to the sanitary sewer system.
- Groundwater infiltration is 0.4 lt/s/ha.
- Rainfall contribution is 0.5 lt/s/ha.
- Minimum depth of flow is 2 cm.
- Pipe sizes are available for every 50 mm increments of diameter. Take D_{min} as φ200.

Area no	A (ha)	Gw infiltration (L/s)	Rain (L/s)
1	1.3 × 0.4 =	0.52	0.65
2	1.0 × 0.5	0.4	0.5
3	1.2	0.48	0.6
4	1.1	0.44	0.55
5	1.3	0.52	0.65
6	1.1	0.44	0.55
7	1.1	0.44	0.55
8	0.8	0.32	0.4
9	1.2	0.48	0.6
10	1.2	0.48	0.6
11	1.3	0.52	0.65
	SUM	5.04	6.3

Q_{ave} = 165.625 L/s × 0.7 = 115.94 L/s

$$Q_{des} = PF_{\max} \times Q_{ave} + \text{Gw inf.} + \text{Rainfall}$$
$$Q_{low} = PF_{dry} \times Q_{ave} + \text{Gw inf.}$$
$$\text{From Fig.8.6} \Rightarrow PF_{\max} = 2.6$$
$$PF_{dry} = 1.6$$
$$Q_{des} = 2.6 \times 115.94 + 5.04 + 6.3 = 312.78 \ L/s$$
$$Q_{low} = 1.6 \times 115.94 + 5.04 = 190.54 \ L/s$$

From Fig.8.7 $\Rightarrow$ min. slope for 0.6 m/s is 0.09%

$S_{6-8} = 0.01 \Rightarrow$ thus we can use 0.01

By using MANNING'S EQN

$$0.31278 = \frac{0.312}{0.016} D^{8/3} \sqrt{0.01} \Rightarrow D = 0.503 \ m$$

$$select \ D = 550 \ mm$$

$$Q_{full} = 0.396 \ m^3/s \qquad u_{full} = 1.67 \ m/s$$

$$\frac{Q_{des}}{Q_{full}} = 0.79 \text{ From Fig. 8.3} \Rightarrow \frac{d}{D} = 0.75, \ \frac{u_{des}}{u_{full}} = 0.98$$

$u_{des} = 1.64 \ m/s \longrightarrow$ OK!

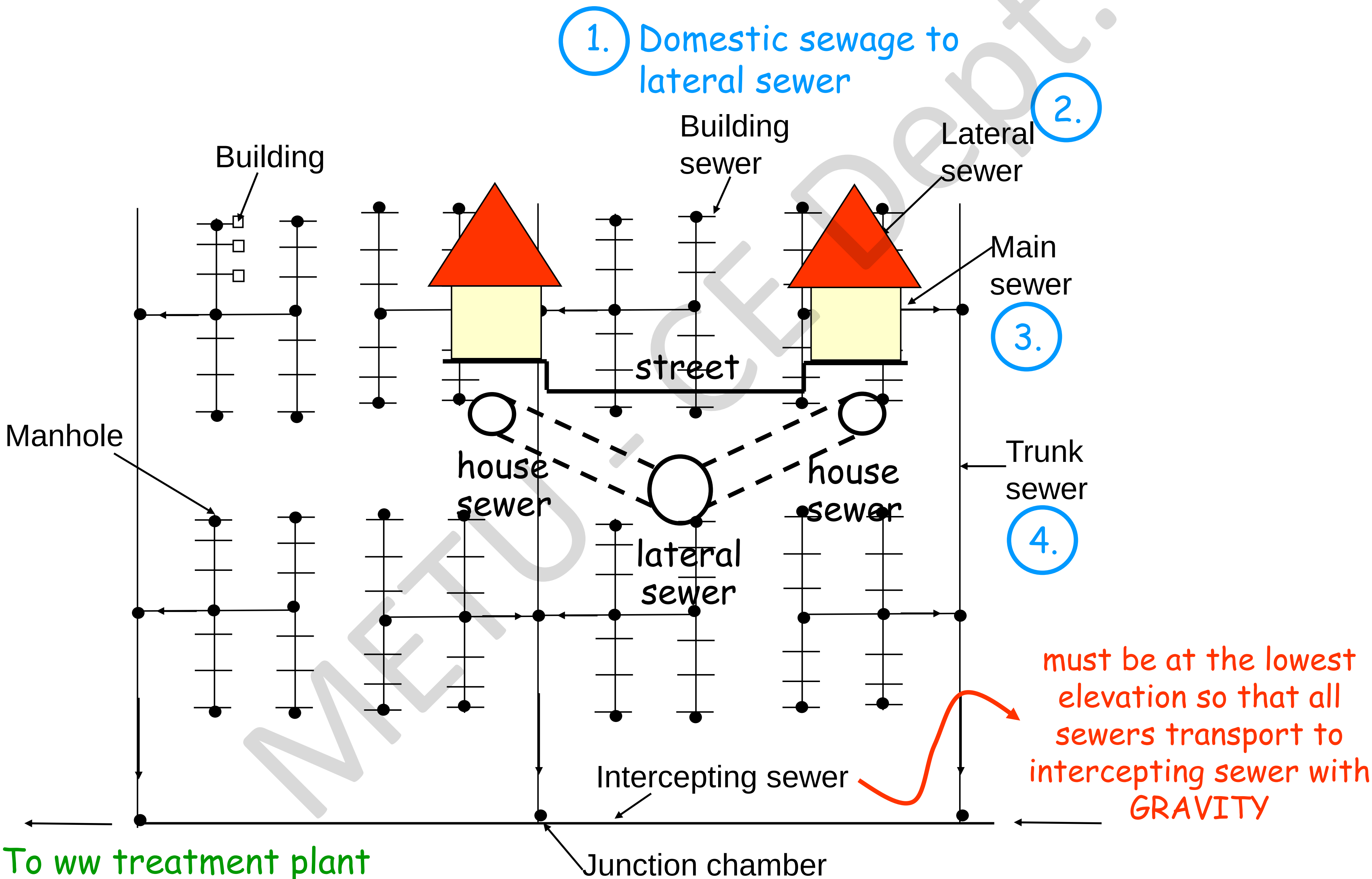
$\frac{Q_{low}}{Q_{full}} = \frac{190.54}{396} = 0.48 \text{ From Fig. 8.3} \Rightarrow \frac{d}{D} = 0.54 \longrightarrow$ OK!

Constructional Details of Sewers:

Lay-out of the system ?

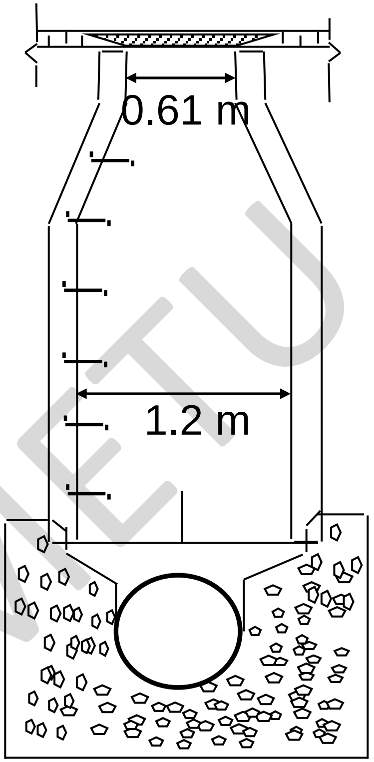
- Underground surveys are required to detect:
  - location of existing sewers,
  - water and gas mains
  - electrical and telephone cables, etc
- Excavate trenches and place sewers deep enough
  - to protect them against
    - breakage
    - traffic load
    - freezing
  - to permit them to drain the lowest basements
- Common values for sewer depth:
  - 1.0 m below the basement floor or
  - about 3.0 m below the top of building foundations

Typical layout of a wastewater collection system



- Manholes are placed
  - where there is a change in diameter or slope &
  - at street junctions

- The codes of the Turkish Bank of Provinces:
  Maximum spacing between two manholes is 150 m



Changes → for small diameters every 50 meters

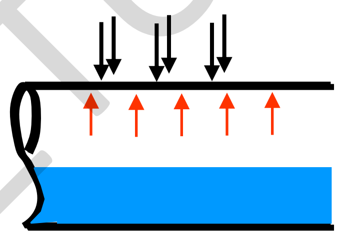
Manhole→ enlarged compartments used for inspection & cleaning purposes

Sewer materials:

selection of material is governed by the quality and quantity of sewage
&
the stresses applied

- plain concrete
- reinforced concrete
- asbestos cement
- cast iron or corrugated steel

- Selection of a specific type depends on:
  - quantity of sewage
  - stresses applied



- For water supply → pressurized flow → internal pressure
- For wastewater collection → gravity flow → no internal pressure
- Internal pressure → some of the traffic & soil load is taken by internal pressure
- No internal pressure → traffic & soil load more critical

Sewage disposal