Chapter 7
Water Supply

- Municipal water supply systems
  - Water quantity and quality → selection of feasible sources

    ↓

    economic analysis

- Availability of water → indicator of degree of civilization

- Water can be obtained from:
  - rivers
  - lakes
  - groundwater

- Municipal water demand is composed of:
  - domestic + public +
  - commercial + industrial +
  - fire fighting + losses

Factors affecting water use:

- climate → more water is consumed in warmer climates
- characteristics of population → socio-economic status
- population size → per capita use is bigger in big cities due to greater industrial use, more parks, etc.
- life standards → US (500 L/cap/day) versus Turkey (100 L/cap/day)
- environmental concerns
  - water quality
  - sustainable development
  - use of flow reduction devices
  - reuse of waste water
- water rates and metering → cost of water ↑es consumption ↓es
- industry and commerce → 1 ton of paper consumes 250 m^3 water
- operating pressures

Design steps of municipal water supply systems:

1. Estimation of future population and total demand
2. Examination of sources of water supply ← quality & quantity
3. Examination of storage facilities
4. Design of storage and transmission facilities
   - dam(s)
   - municipal water supply systems
     - transmission lines
     - city network
5. Water treatment and quality control
6. Construction of the system
   - use of sound and proper material
   - minimization of water loss = f(type, age, operating pressure)
7. Establishment of operational organization

IŞIKLI
AKYAR
EGREKKAYA
ÇAMLIDERE
KURTBOGAZI
ÇUBUK-2
ÇUBUK-1
Ankara
BAYINDIR

- System should meet future demands

  Life time of the system ? = f(type of system, availability of techn., mat'l.s, econ. factors)

- Future demand (D) ⇔ good quality supply (S)

- Municipal Water Requirements:
  - domestic use (L/cap/day) – drinking and sanitary purposes
  - public use – schools, hospitals, parks
  - commercial and industrial uses – ex: textile, food
  - \+ use for fire fighting

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  municipal demand

- Future demand forecasting ⇒ population estimation

End of life time of project, t_n

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Projected population, P_n

- Factors to be considered in population estimation:
  - Topographic and climatic conditions
  - Socio-economic facilities available in the city
  - Past records of census results
  - Population growth rate & characteristics of community

$\left.\begin{array}{l}\text{Topographic and climatic conditions}\\ \text{Socio-economic facilities available in the city}\end{array}\right\}$ may impact migration

Population estimation methods

1- Arithmetic extrapolation

TURKEY

2- Geometric (logarithmic) extrapolation ← good for communities with large resources and power

3- The Turkish Bank of Provinces method

4- Mathematical curve fitting method

5- Logistic S-curve method

6- Decreasing rate of increase method

7- Ratio and correlation method

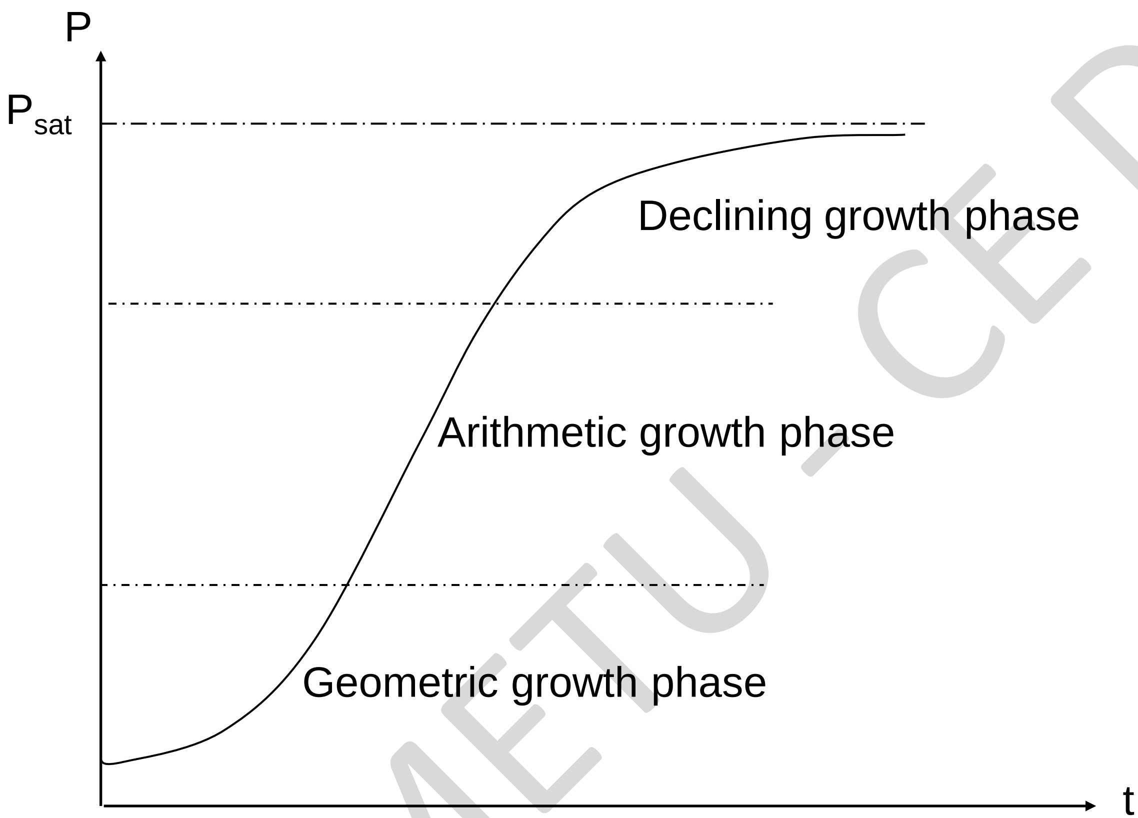
8- Component method

9- Employment forecasts

Before selecting the population projection method:

- examine previous census records
- socio-economic developments in the region

Population growth phases in settlements



Idealized Growth Pattern

since available resources & facilities are limited to support population growth beyond a certain value, the population growth follows a declining phase & the population tends to a saturation value, P_{sat}

Arithmetic Extrapolation Method

Rate of population growth is constant

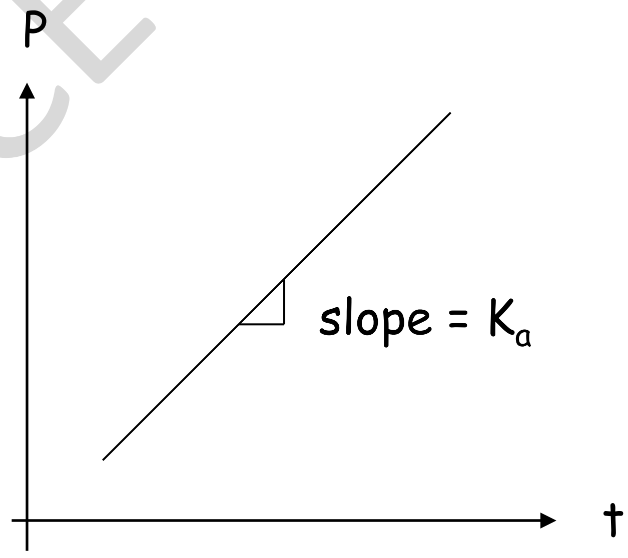
$$\frac{dP}{dt} = K_a$$

constant

$$K_a = \frac{P_2 - P_1}{t_2 - t_1}$$

$$P_n = P_2 + K_a(t_n - t_2)$$

projected population

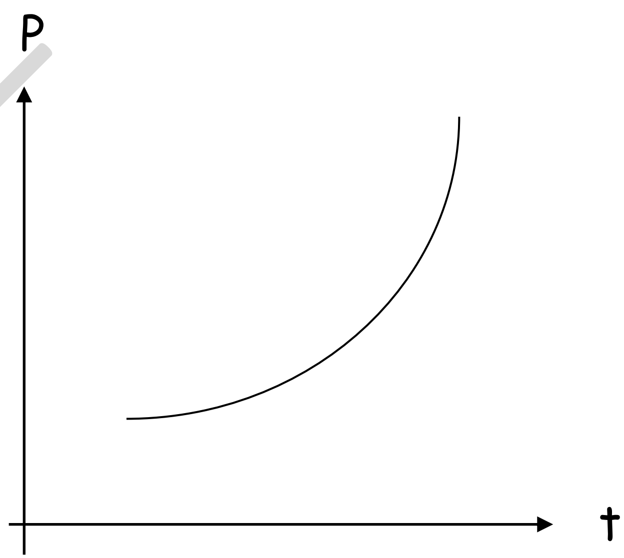


Geometric Extrapolation Method

$$\frac{dP}{dt} = K_g P$$

rate of change of population is assumed to be proportional to the population

$$K_g = \frac{lnP_2 - lnP_1}{t_2 - t_1}$$



$$\int_{P_2}^{P_n} \frac{dP}{P} = K_g \int_{t_2}^{t_n} dt$$

$$lnP_n = lnP_2 + K_g (t_n - t_2)$$

Turkish Bank of Provinces Method

$$P_n = P_2\left(1+\frac{k}{100}\right)^{35+n}$$

lifetime of the project

$$k = \left(\sqrt[t_2-t_1]{\frac{P_2}{P_1}} - 1\right) * 100$$

P_n = population at the end of the life time of the project

k = growth rate factor

n = number of years between the last census and beginning of project

k=3 if k $\geq$3

k=1 if k $\leq$ 1

k is as it is if 1 < k < 3

<u>Next step</u>: estimate average total demand corresponding to the projection year

Average total demands

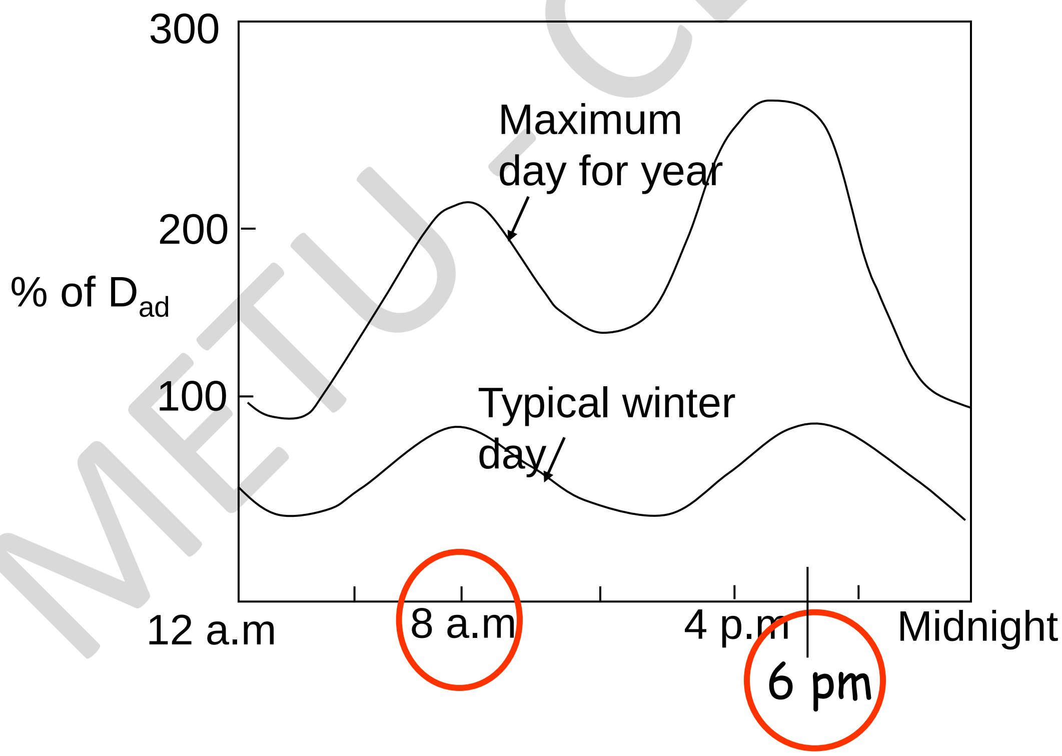
daily average demand

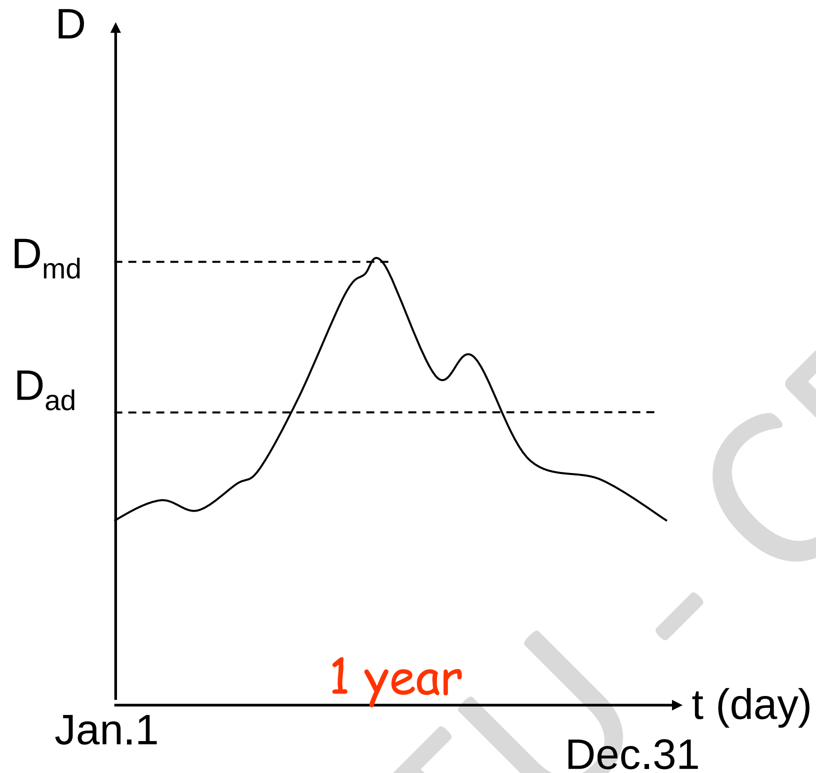
P_n	D_{ad} (lt/cap/day)	D_{ad} (lt/s)
3000	60	2.1
50000	120	69.4
100000	170	196.8
500000	230	1330.0
1000000	280	3240.0
2000000	330	7640.0
3000000	370	12850.0

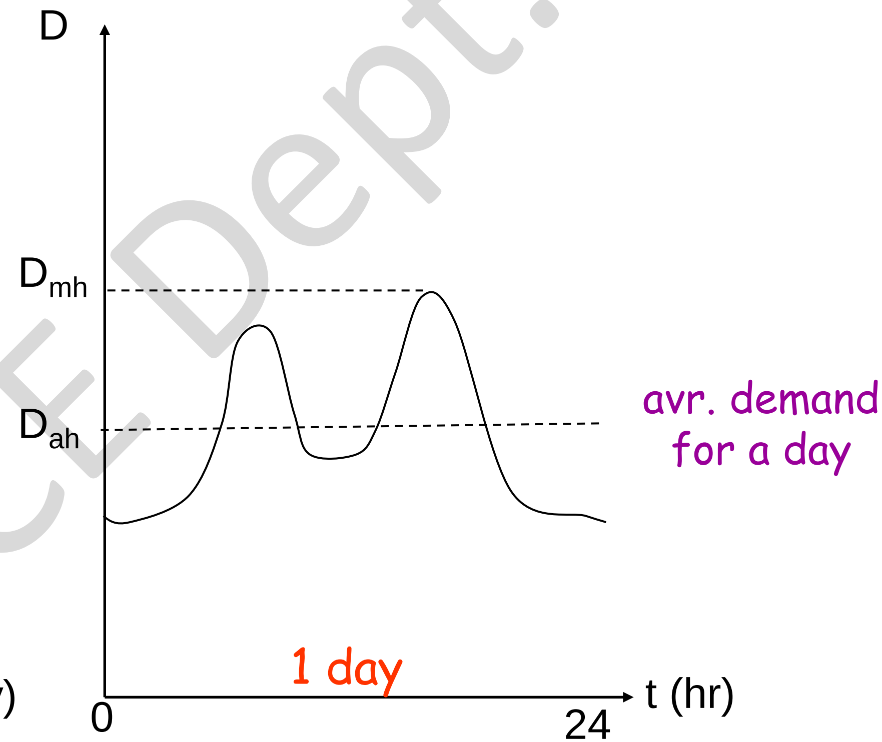
$$\frac{60\ L}{cap.day} \times 3000\ cap \times \frac{1\ day}{24\ hr} \times \frac{1\ hr}{60\ min} \times \frac{1\ min}{60\ \sec} = 2.1\ L/\sec$$

Hourly, daily, monthly fluctuations in water use depend on:

- climatic conditions
- size of the urban area
- socio-economical structure of community







$$(P.F.)_{day} = \frac{D_{md}}{D_{ad}}$$

$$(P.F.)_{hour} = \frac{D_{mh}}{D_{ah}}$$

$(P.F.)_{day}$ = daily peak factor
D_{md} = maximum daily demand
D_{ad} = average daily demand

$(P.F.)_{hour}$ = hourly peak factor
D_{mh} = maximum hourly demand
D_{ah} = average hourly demand

Elements of municipal water supply systems

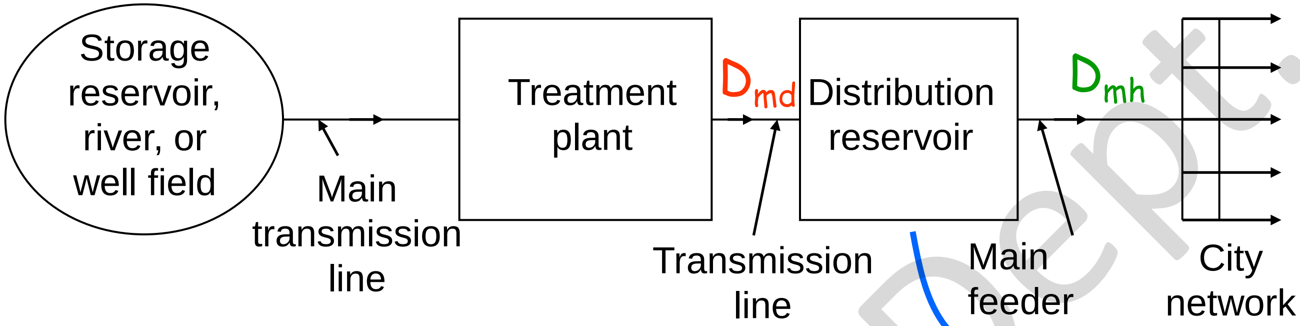
Water is conveyed from a source(s):

- storage reservoir(s)
- river(s)
- fresh water lake(s)
- groundwater
- sea

to community mainly in closed conduits because of:

- The requirement of pressurized flow
- Less likelihood of pollution

- Use of closed conduits:
  - requirement for pressurized flow
  - environmental concerns
- Necessary energy for flow:
  - Gravity ← when source is located substantially above the level of the city
  - pumping
  - gravity + pumping ← In Ankara there are over 60 pumping stations & distribution reservoirs
- Selection of suitable conduits and routes:
  - topography
  - available materials
  - economy



Transmission line is designed to carry

$$D_{md} = D_{ad} * (P.F)_{day}$$

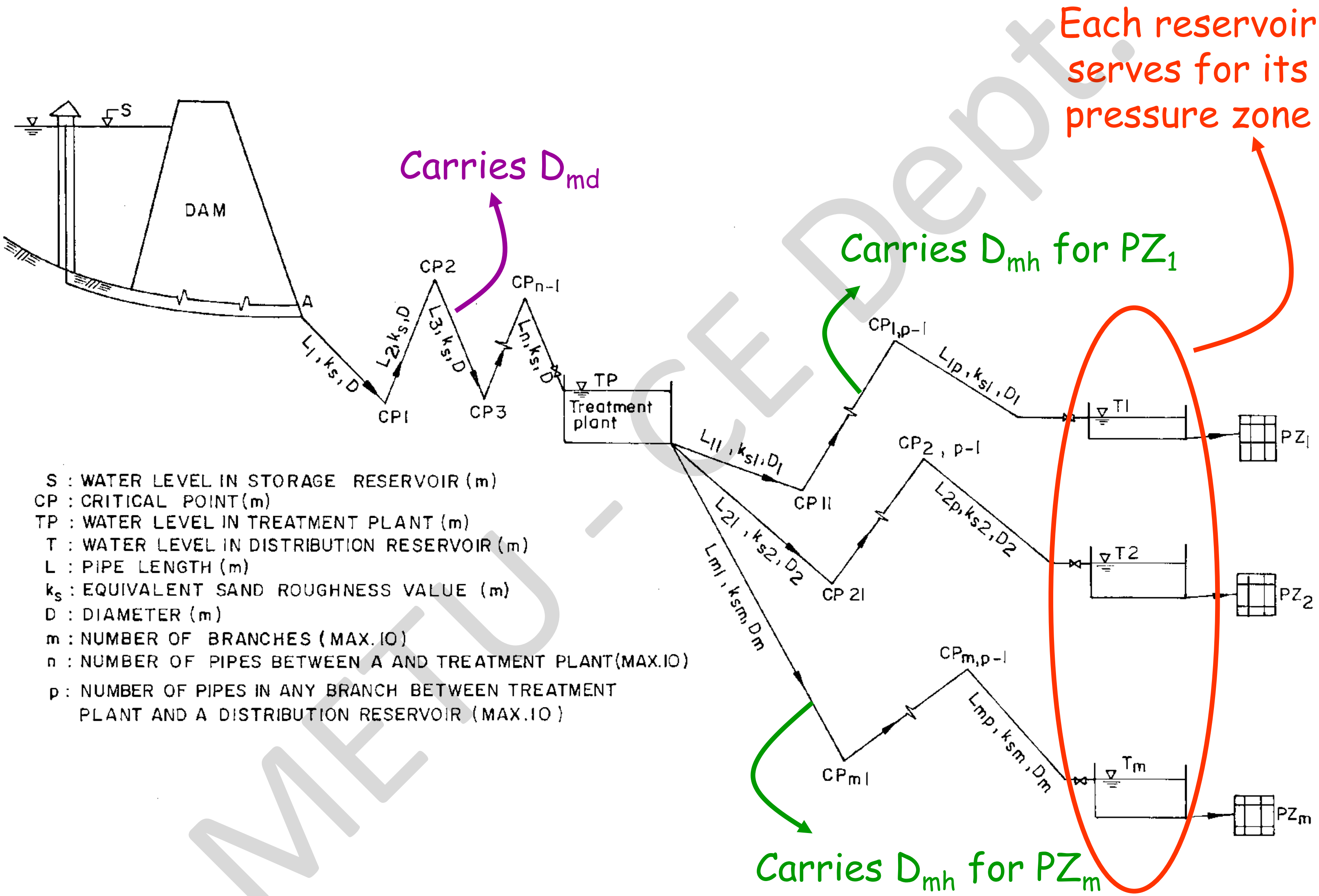
Main feeder is designed to carry

$$D_{mh} = D_{ad}*(P.F)_{day}*(P.F)_{hour}$$

Are designed to
- meet hourly fluctuations
- store water for fire fighting
- stabilize pressures in the distribution system

Codes of the Turkish Bank of Provinces

D_{md} for the transmission line
D_{md} + fire discharge for the main feeder


Each reservoir serves for its pressure zone
Carries D_{md}
Carries D_{mh} for PZ_1
Carries D_{mh} for PZ_m
DAM
S
A
CP1
CP2
CP3
CPn-1
TP
Treatment plant
CP11
CP1,p-1
CP21
CP2, p-1
CPm1
CPm,p-1
T1
T2
Tm
PZ1
PZ2
PZm
S : WATER LEVEL IN STORAGE RESERVOIR (m)
CP : CRITICAL POINT (m)
TP : WATER LEVEL IN TREATMENT PLANT (m)
T : WATER LEVEL IN DISTRIBUTION RESERVOIR (m)
L : PIPE LENGTH (m)
k_s : EQUIVALENT SAND ROUGHNESS VALUE (m)
D : DIAMETER (m)
m : NUMBER OF BRANCHES (MAX. 10)
n : NUMBER OF PIPES BETWEEN A AND TREATMENT PLANT (MAX. 10)
p : NUMBER OF PIPES IN ANY BRANCH BETWEEN TREATMENT PLANT AND A DISTRIBUTION RESERVOIR (MAX. 10)

- A water distribution network is composed of:
  - pipes
  - valves
  - hydrants
  - pumps
  - distribution (service) reservoirs

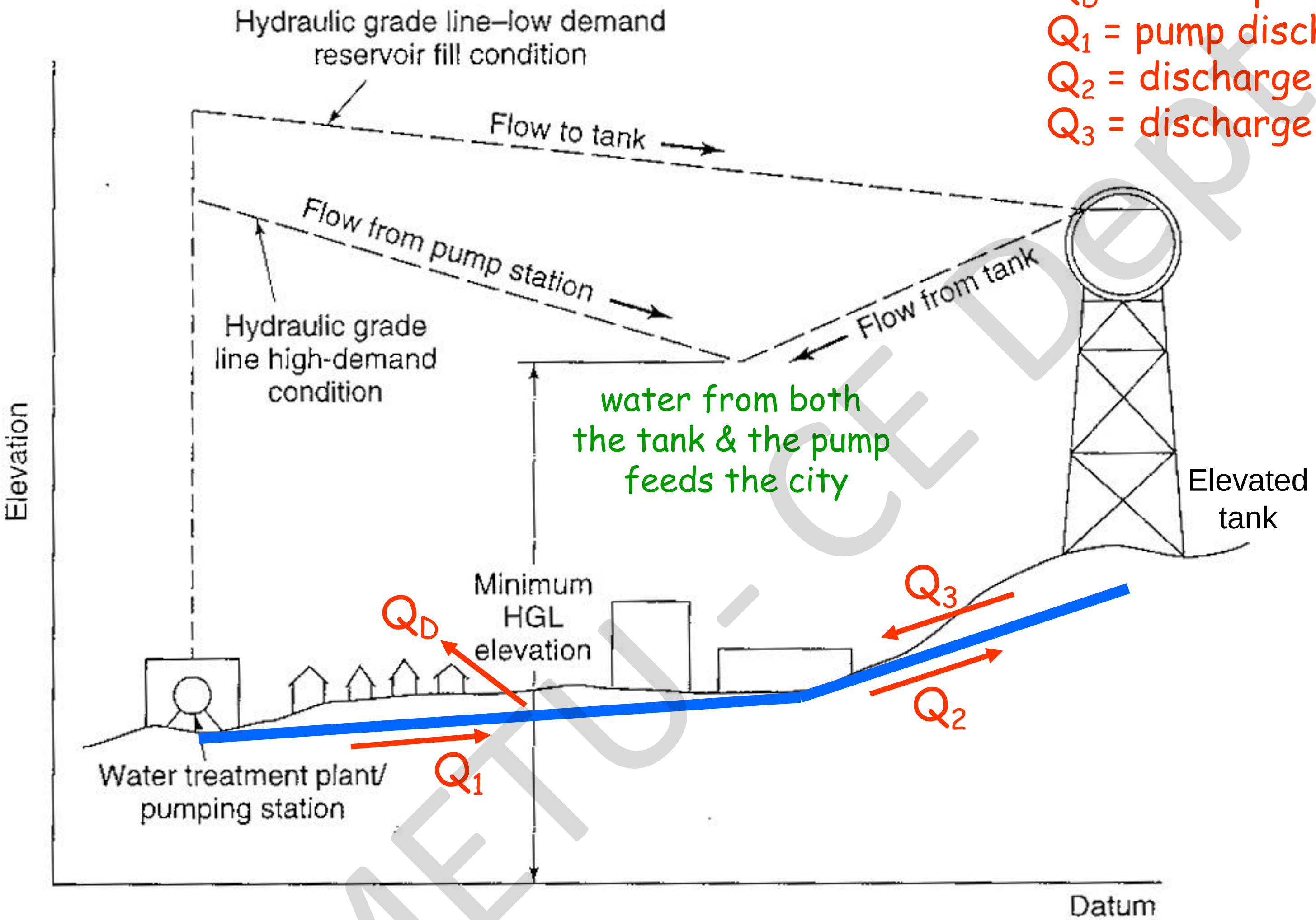
Receives water from the main feeder & delivers it to individual consumers

- Distribution by: *gravity and/or pumping*
- Pumping without storage is not desirable

emergency use like fires or repair works ?

- Pumping with storage is desirable

Q_D = municipal demand
Q_1 = pump discharge
Q_2 = discharge to the reservoir
Q_3 = discharge from the reservoir



Low demand → $Q_1 - Q_D = Q_2$

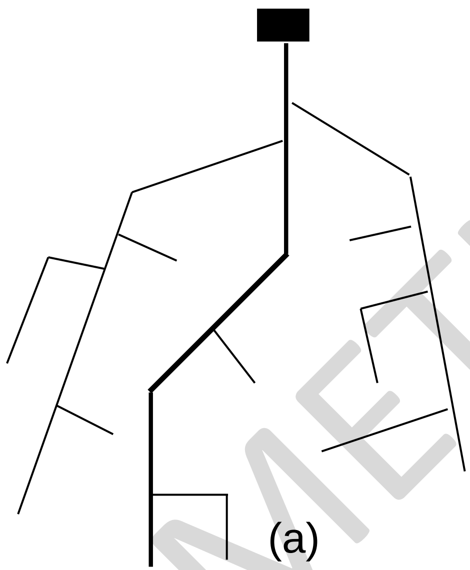
High demand → $Q_1 + Q_3 = Q_D$

No flow from storage → $Q_1 = Q_D$

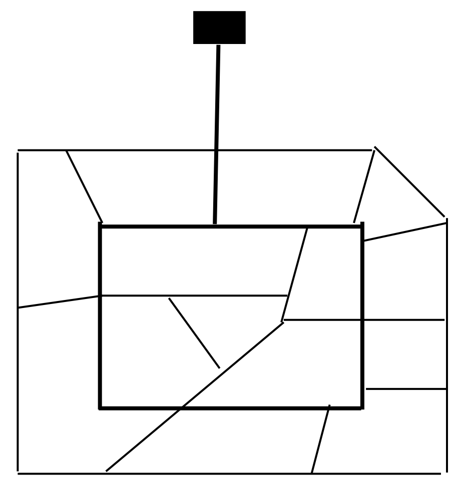
Types of distribution network:

a) a branching pattern with dead ends

b) a gridiron pattern with central feeder



(a)



(b)

Distribution Reservoirs

- In large cities (P > 100000)
- Pumping stations and distribution (service) reservoirs are operated in conjunction with each other

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- Pressure requirements dictate level of interference !

  Pumping schedule ⇒ capacity of distribution reservoir

  a) Pumping of D_{ad} 24 hours ⇒ Small capacity ⇒ Not feasible!

  b) Pumping during off-demand hours

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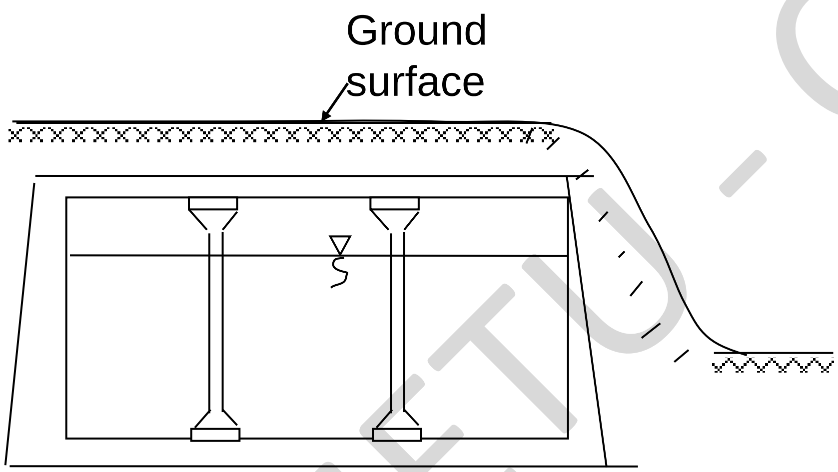
  Greater capacity ⇒ Feasible

- Location of the distribution reservoir → should be located close to the center of use.

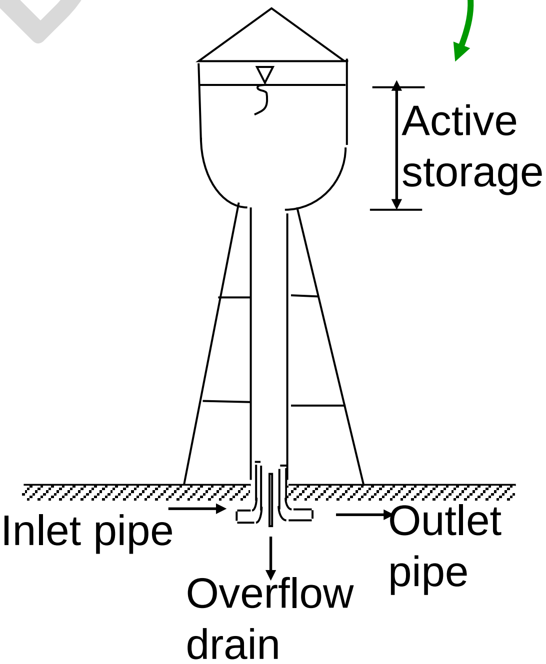
Types of distribution reservoir

- elevated tanks
- buried reservoirs
- stand pipe

Usually reinforced-concrete used
Circular x-section
Top is sloped for proper drainage



Buried reservoir



Elevated tank

- Maximum capacity: Cylindrical container

- Capacity determination:
  - a) Storage to meet hourly fluctuations:
    1. Obtain demand values of maximum demand day
    2. Apply mass curve technique
  - b) Required storage to put out a fire
  - c) Storage to meet emergencies

- No additional volume if a and b are considered jointly

$$
\left.\begin{array}{rl}
P \leq 10\,000, & C_{fire} = 36 \text{ m}^3 \\
10\,001 \leq P \leq 50\,000, & C_{fire} = 72 \text{ m}^3 \\
P \geq 50\,000, & C_{fire} = 360 \text{ m}^3
\end{array}\right\}
$$

Turkish Bank of Provinces values

- Pipe material should be strong enough to resist:
  - the forces produced by the static pressure of water
  - centrifugal forces at the bends
  - external loads like soil load and traffic load
  - changes in temperature
  - water hammer

- Pipe materials:
  - reinforced concrete
  - asbestos cement
  - ductile iron
  - steel
  - plastic

Each type of material pipe is available
at different sizes &
can take different pressures & stresses

Ductile iron pipes

have high durability and long life

subject to corrosion ! $\Rightarrow$interior coating with cement

Steel pipes

in cases with large D and (P/γ)

buckling under high negative pressures

coating $\Rightarrow$ resistance for corrosion and buckling

Reinforced concrete pipes

used in large projects

carry excessive stresses

no corrosion problem

Corrosion: a process in which a metal is converted into salts or oxides with a loss of mechanical strength

Asbestos cement pipes

- extremely smooth inner surfaces
- limited use cancerous effect of asbestos fibers

Plastic pipes

- highly smooth and light
- require a small diameter
- easily installed and removed
- limited use according to the project size

Valves

Flow regulation and isolation

* sluice or gate valves → Used to isolate flow esp. during repairs
* butterfly valves → Usually used at the exit of distribution reservoirs for regulation and isolation purposes
* check valves → To stop flow automatically in the reverse direction

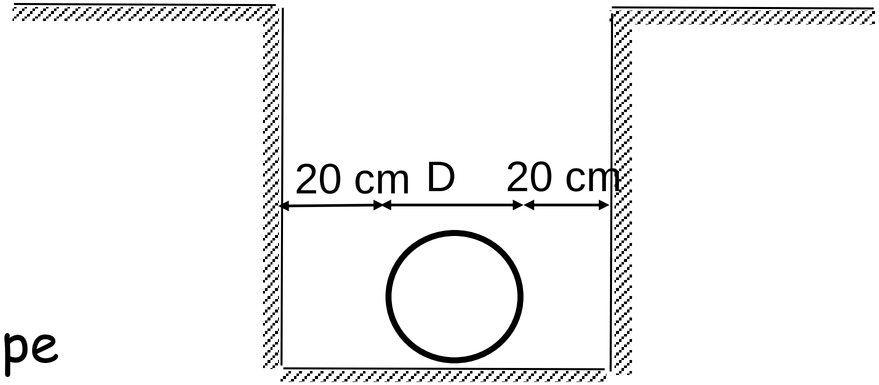
Hydrants

Withdrawal of pressurized flow for fires

Construction & maintenance of water supply systems

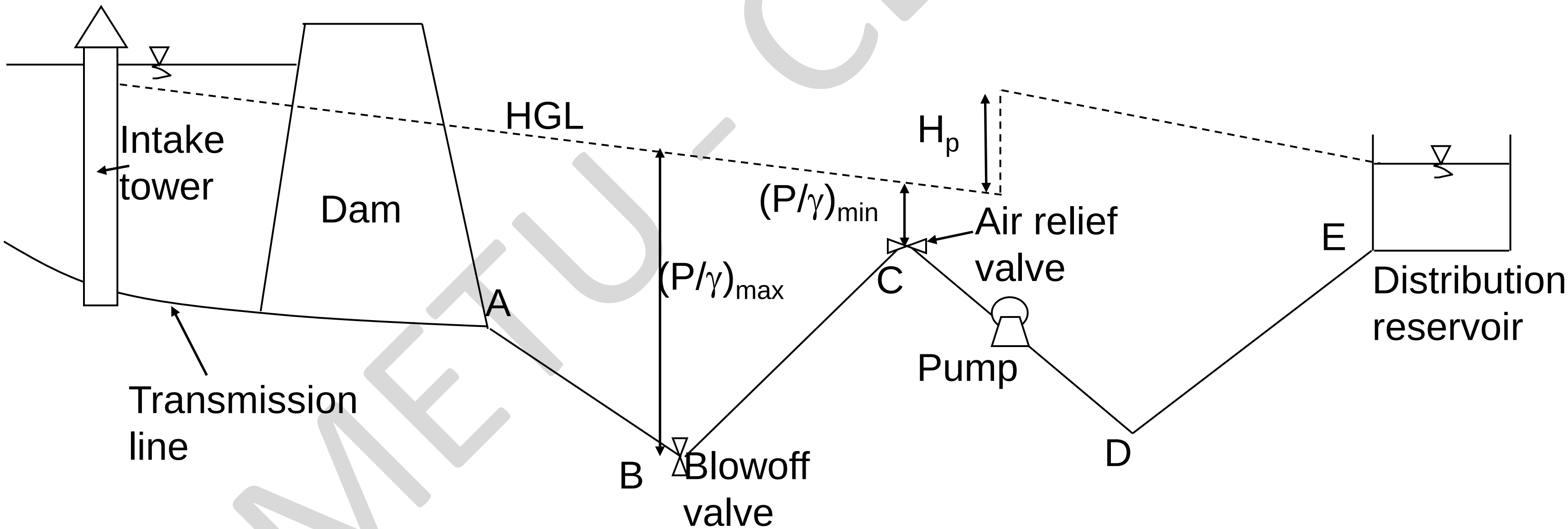
- Laying of pipes:
  - need for stiff foundation to limit settlement
  - excavation of trenches
  - transportation & handling of pipes & appurtenances
  - backfilling and repaving
  - avoid sharp curvatures
  - bends should be blocked

- The depth of burial of pipes
  - depth of frost line
  - external loads acting on the pipe

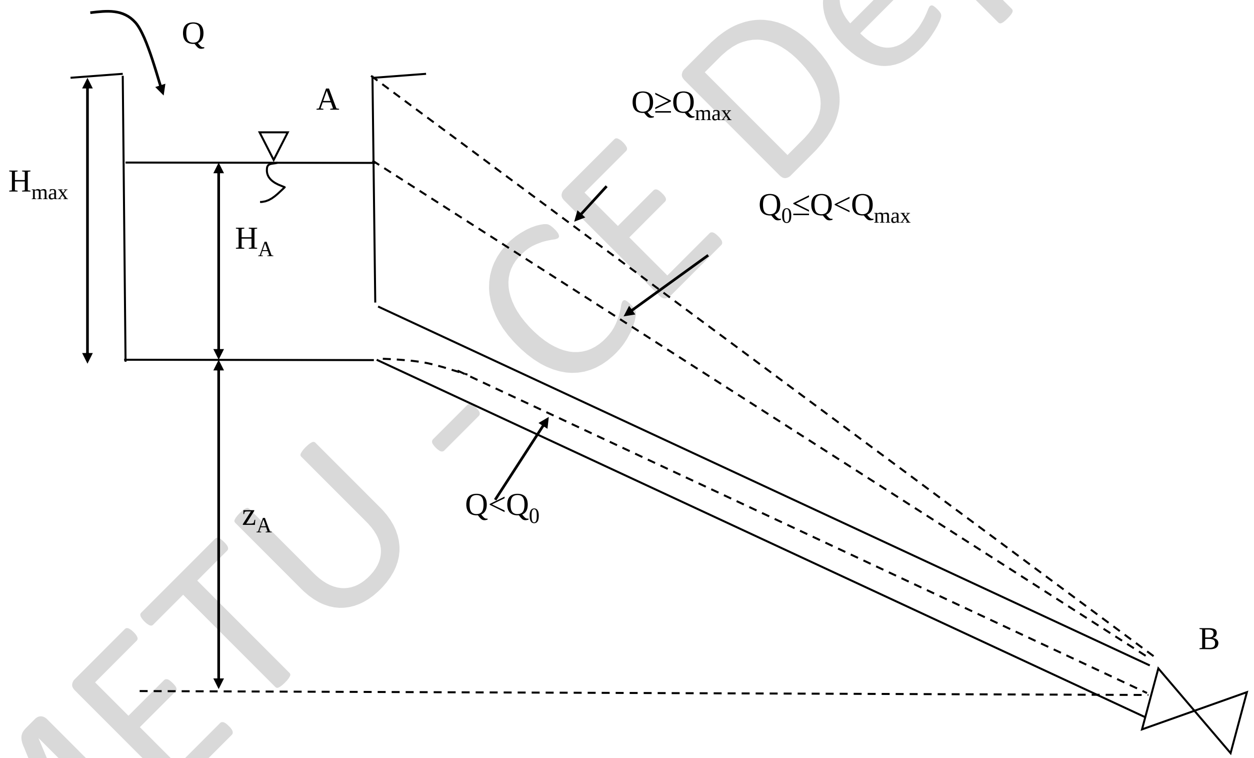


Hydraulic design criteria

- velocity: $0.5\ m/s \leq u \leq 2.0\ m/s$
- pressure: $3\text{-}5\ m \leq P/\gamma \leq 80\ m$ → transmission line
- $20 - 30\ m \leq P/\gamma \leq 80\ m$ → city network



Hydraulics and Operation of Gravity Pipelines



The energy equation between points A and B:

$$H_A + z_A + \frac{P_A}{\gamma} + \frac{u_A^2}{2g} = z_B + \frac{u_B^2}{2g} + \frac{P_B}{\gamma} + h_f$$

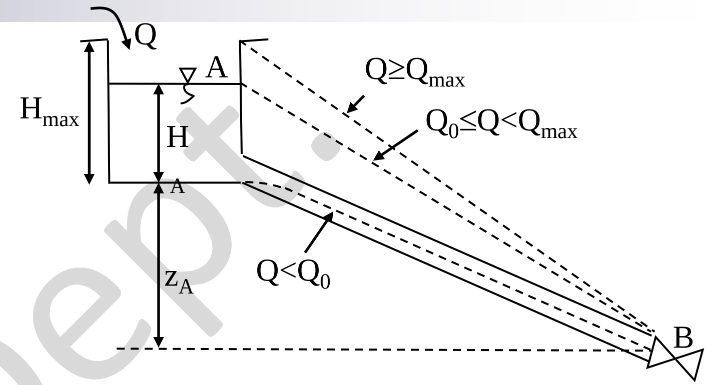
$P_A=P_B=0$, $z_B=0$, and $u^2/2g \approx 0$ for $u<\sim 2.0$ m/s:

$$H_A + z_A = h_f$$

Using Darcy-Weisbach equation:

$$H_A + z_A = \frac{8fL}{g\pi^2 D^5} Q^2$$

For given f, L, and D:



$$H_A + z_A = KQ^2$$

$$Q_{max} = \left(\frac{H_{max} + z_A}{K} \right)^{1/2} \qquad Q_0 = \left(\frac{z_A}{K} \right)^{1/2}$$

Q_0 is minimum pressurized flow rate.

When $Q>Q_{max}$, $Q-Q_{max}$ spills

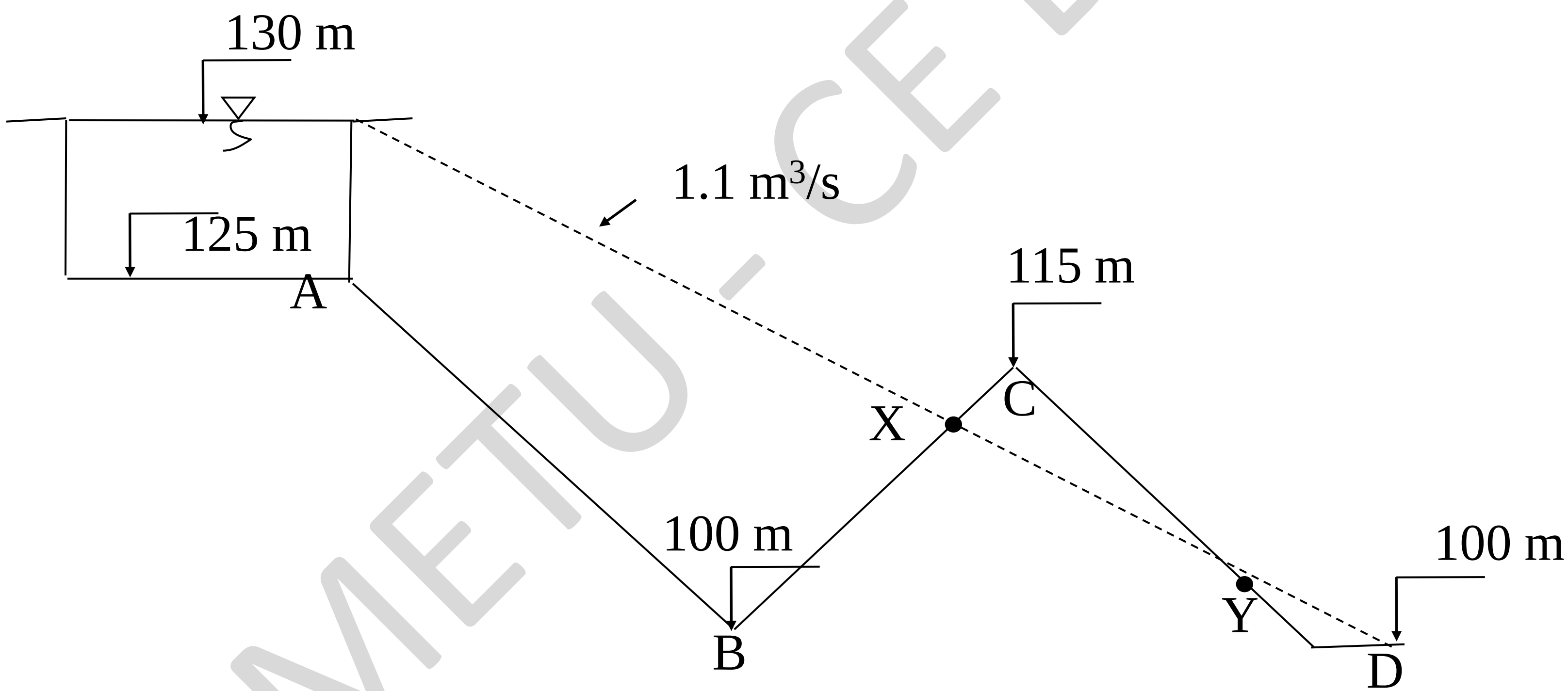
When $Q<Q_0$, open channel flow! (use exit valve)

$$H_A + z_A = KQ^2 + H_v$$

Air entrainment

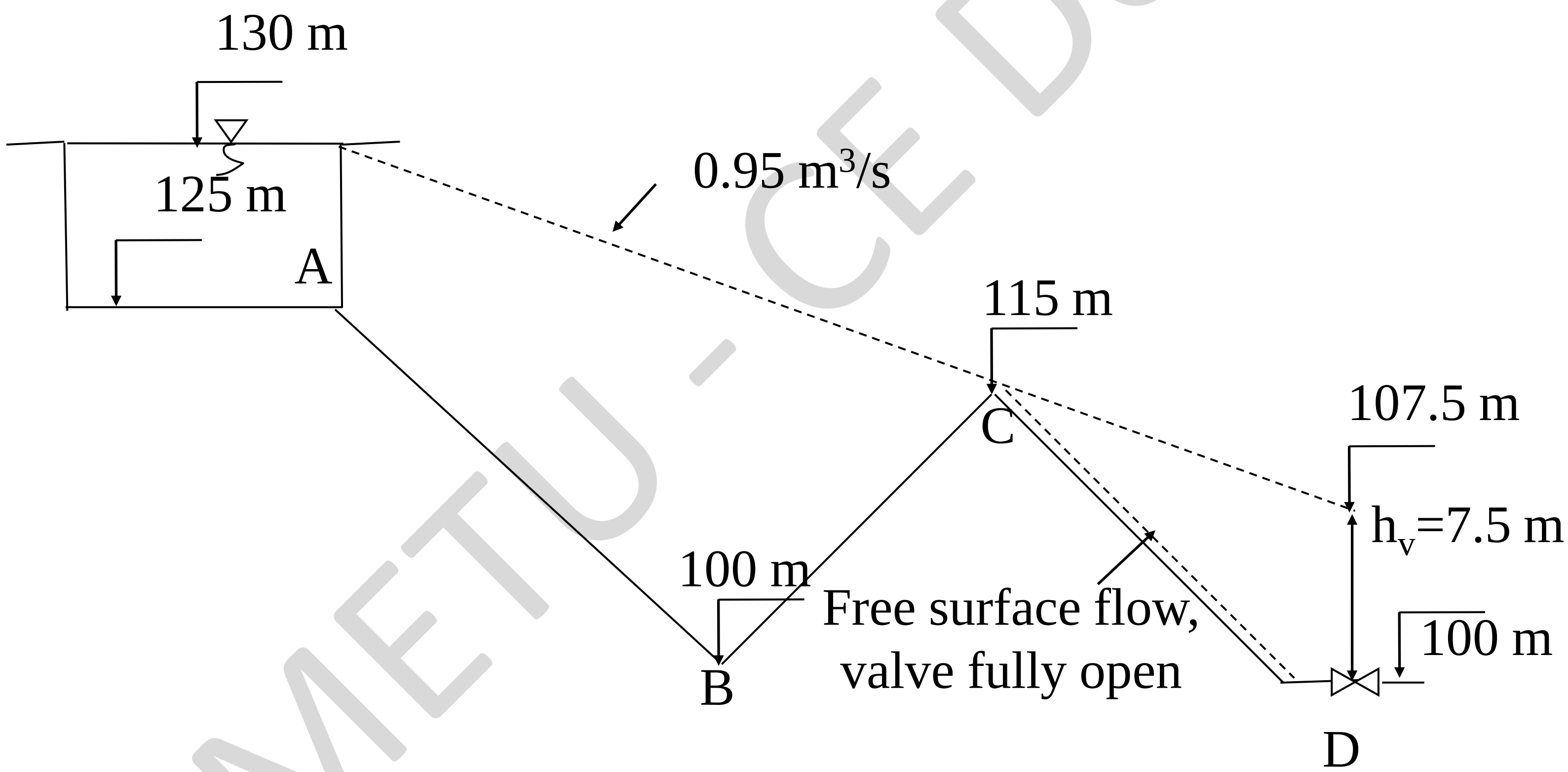
Consider a gravity pipeline with L=5000 m, f=0.02, and ϕ1000 for all pipes.

Energy equation between points A and D gives Q=1.1 m^3/s (!!!)

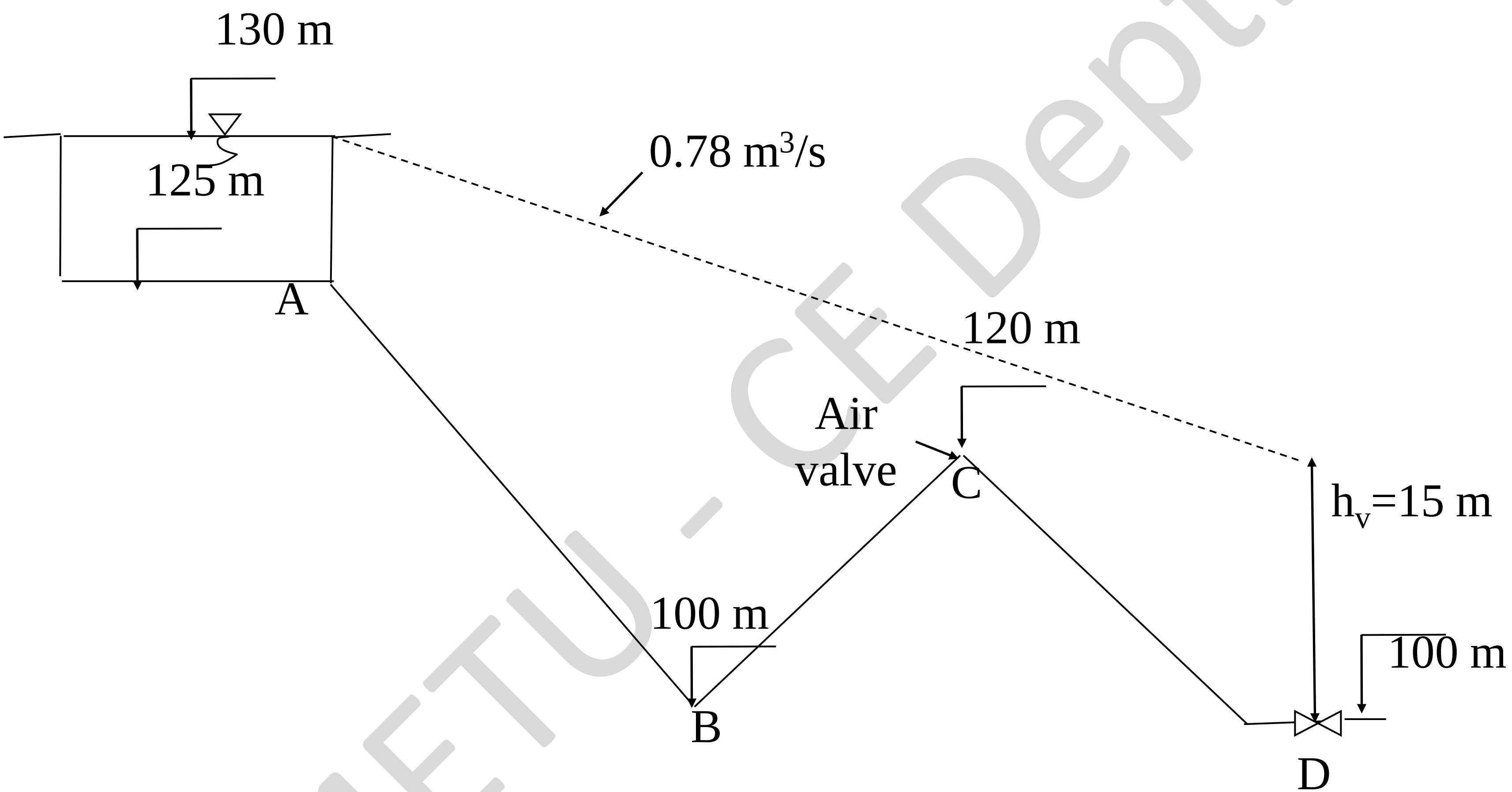


a) Air suction due to negative pressure

Air or surrounding groundwater is sucked into the pipeline through the joints and H_C will rise to atmospheric value (H_C=115 m and Q=0.95 m^3/s)

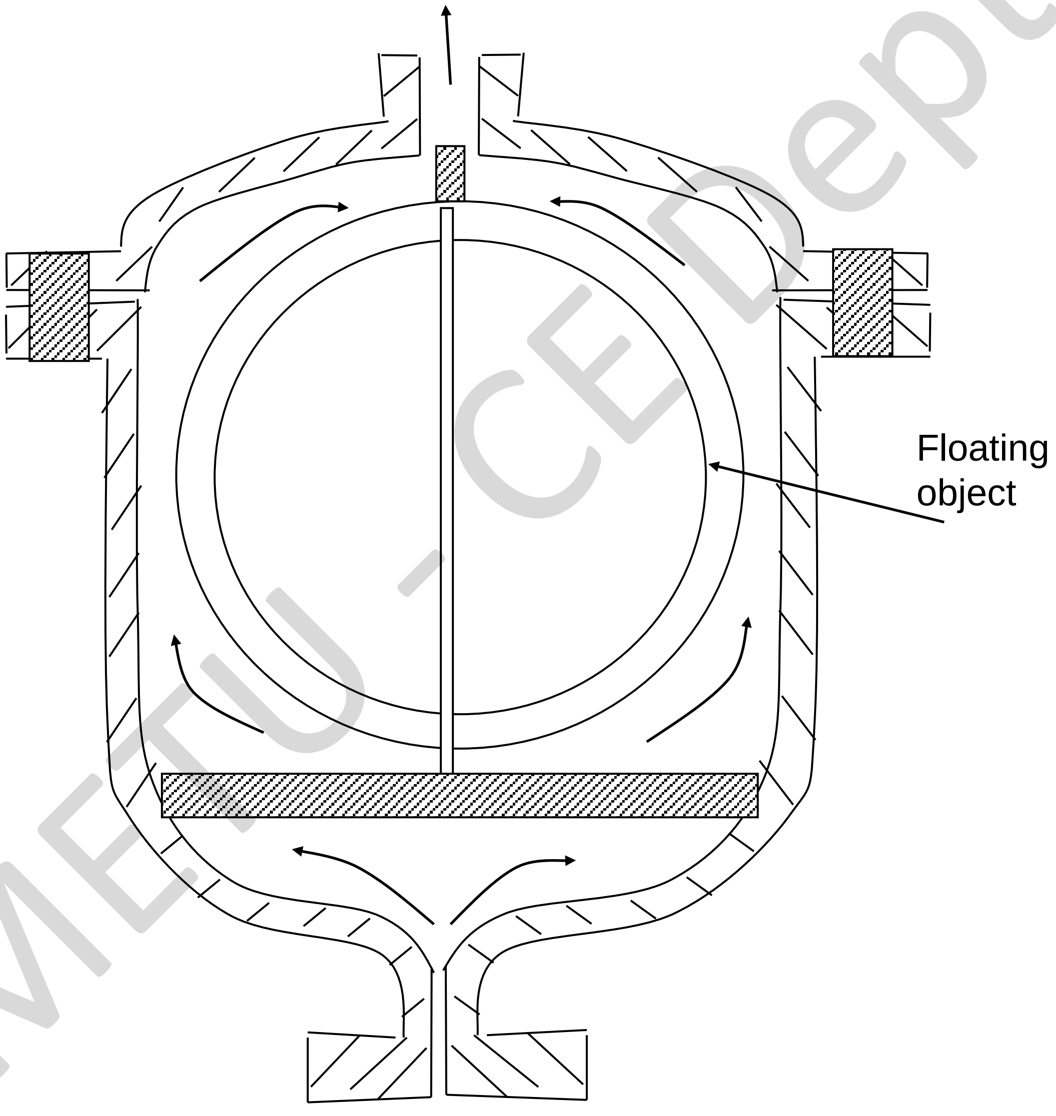


b) Air blockage from dissolved air



c) Air free operation

Air-relief valve



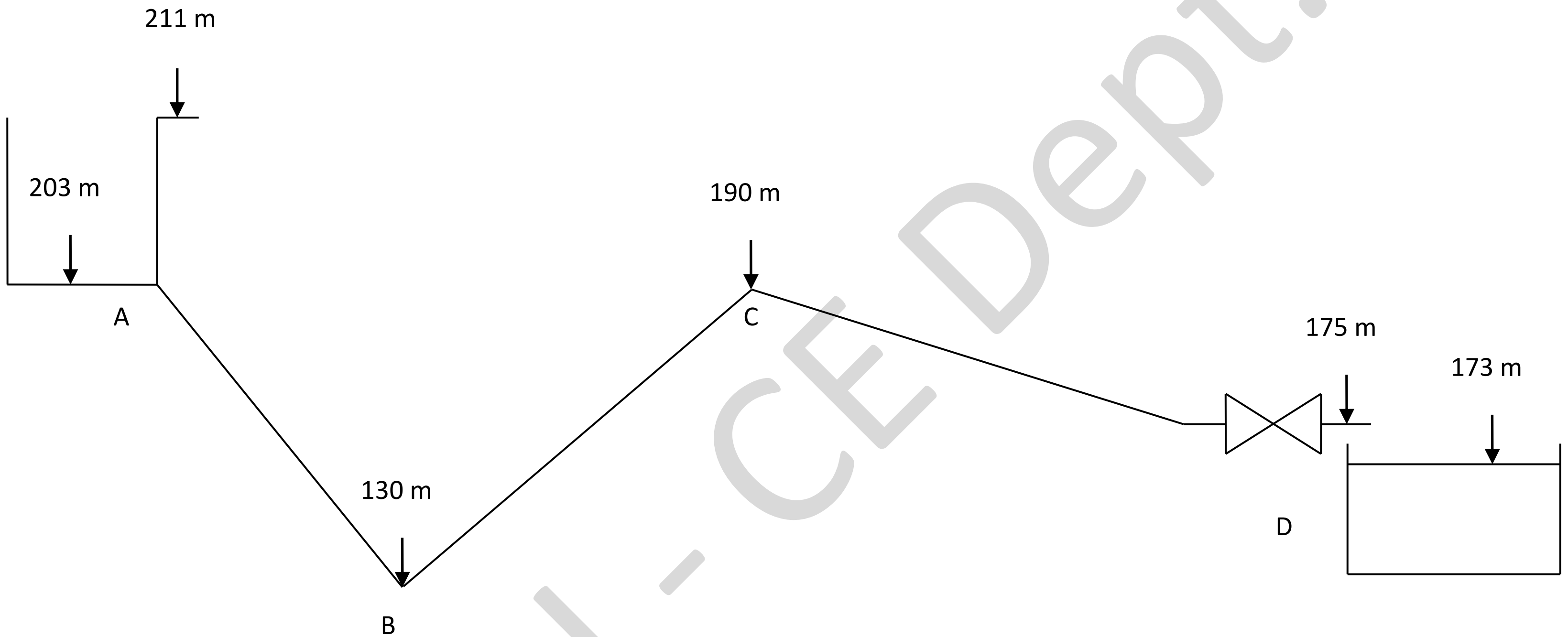
Example 23

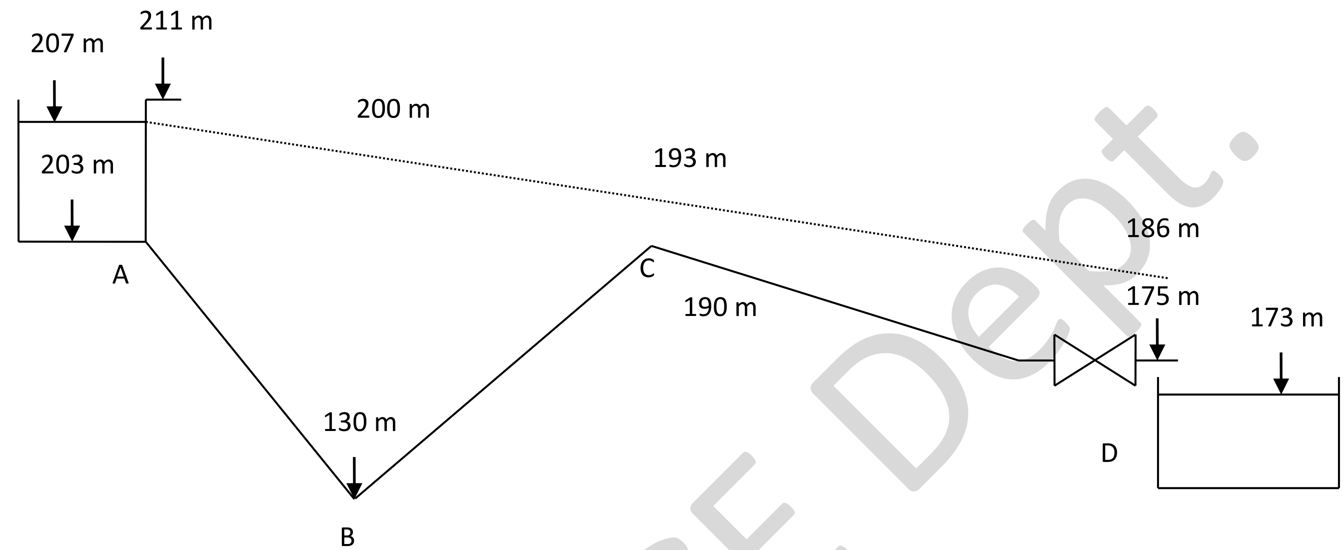
The following transmission line is analyzed. In the problem, consider the following criterion: 0.5 m/s $\leq u \leq$ 2.0 m/s and 3 m $\leq P/\gamma \leq$ 80 m. Take f = 0.02, D = 0.15 m, and L = 2000 m for all pipes.

1. It is desired to keep the water surface elevation at 207 m in the upper reservoir. Determine the discharge that can pass through this system. Determine also the maximum pressure head in the pipeline system.

2. Determine the minimum possible pressurized flow rate that can pass through this system. Determine also the headloss at the exit valve.

3. Determine the maximum possible discharge to be transmitted through this system. Find the population of the settlement, which is served by this discharge of this system. The daily and hourly peak factors are 1.5 and 2.5, respectively.


211 m
203 m
A
190 m
C
175 m
173 m
130 m
B
D



a)

$h_{L\,AB} = h_{L\,BC} = h_{L\,CD} = h_L$ $\qquad$ $h_L = 7$ m

$h_L = [\ (8*f*L) / (\pi^2*g*D^5)\ ] * Q^2$

$A = \pi*D^2 / 4$ $\qquad$ $A = 0.018\ m^2$

$7 = [\ (8.0.02*2000) / (\pi^2*9.81*0.15^5)\ ] * Q^2$

$Q = 0.013\ m^3/s = 13$ lt/s $\qquad$ Max pressure is at B = 70 m

$V = Q / A = 0.722$ m/s OK!

b)

Minimum velocity = 0.5 m/s

Q_{min} = 0.5 * 0.018 = 0.009 m^3/s = 9 lt/s

193 + $h_{L\ BC}$ + $h_{L\ AB}$ = H_{res}

H_{res} = 193 + 2 * h_L = 200 m NOT OK!

H_{res} = 203 (min. value)   203 – 193 = 2 * h_L

h_L = 5 m → Q_{min} = 0.011 m^3/s = 11 lt/s

H_{CD} = 193 – $h_{L\ CD}$ = 193 – 5 = 188 m c)

Maximum velocity = 2 m/s

Q_{max} = 2 * 0.018 = 0.036 m^3/s = 36 lt/s

$H_{res} = 193 + h_{L\ AB} + h_{L\ BC}$

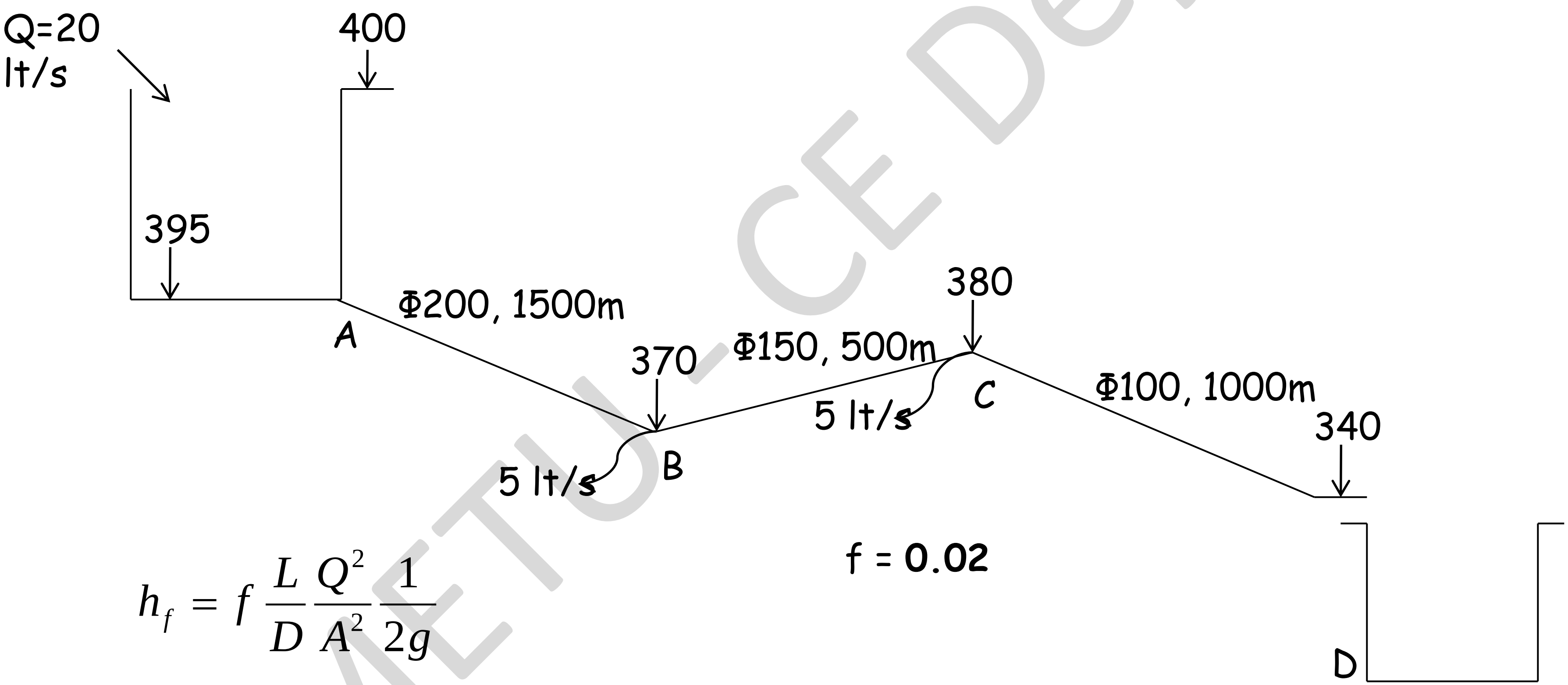
$h_L = [\ (8*0.02*2000) / (\pi^2*9.81*0.15^5)\ ] * 0.036^2 = 56$ m

NOT POSSIBLE !!! H_{res} cannot be greater than 211 m

$211 - 193 = h_{L\ AB} + h_{L\ BC}$

$h_L = 9 \rightarrow Q_{max} = 0.0143\ m^3/s = 14.3$ lt/s

Example 24 A water transmission system is shown below. 20 lt/s enters to reservoir A and 5 lt/s is withdrawn along the line at points B and C.



$$h_f = f\frac{L}{D}\frac{Q^2}{A^2}\frac{1}{2g}$$

a) Find and draw the piezometric line along the system when the valve at point D is fully open. Compute piezometric elevations at A, B, C and D.

b) Find the necessary amount of head loss in the valve at point D to avoid air entrainment problem, $(P_{min}/\gamma) = 3$ m.

c) Assuming no flow is withdrawn at B and C, find the maximum discharge that can be conveyed from reservoir A to reservoir D.

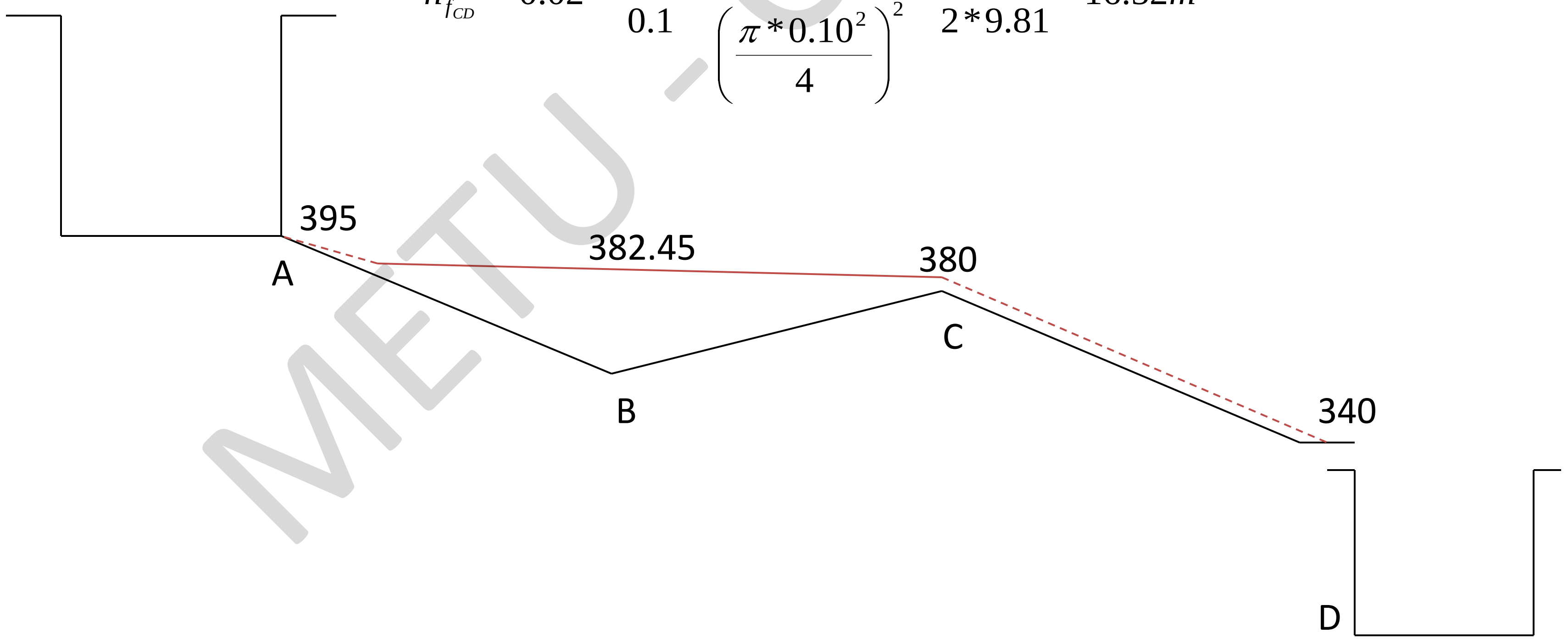
Solution:

a)

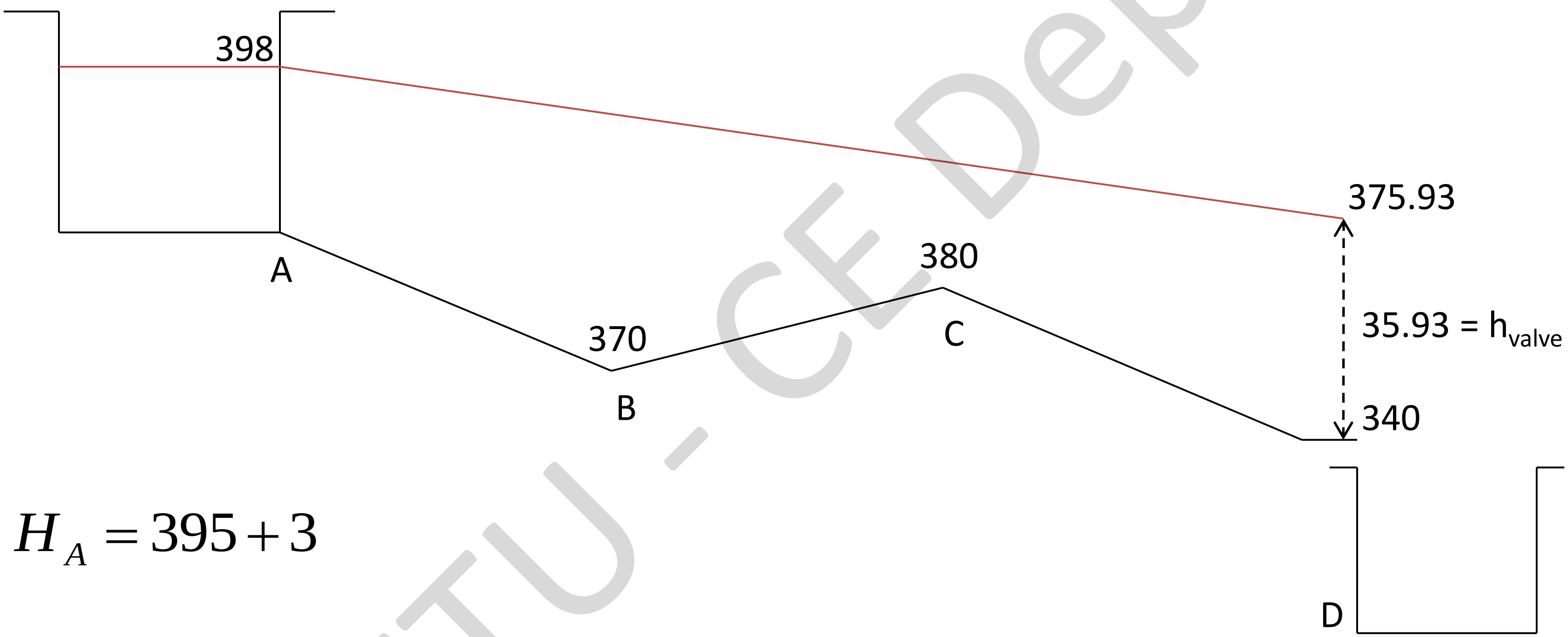
$$h_{f_{AB}} = 0.02 * \frac{1500}{0.2} * \frac{0.020^2}{\left(\frac{\pi * 0.2^2}{4}\right)^2} * \frac{1}{2 * 9.81} = 3.10m$$

$$h_{f_{BC}} = 0.02 * \frac{500}{0.15} * \frac{0.015^2}{\left(\frac{\pi * 0.15^2}{4}\right)^2} * \frac{1}{2 * 9.81} = 2.45m$$

$$h_{f_{CD}} = 0.02 * \frac{1000}{0.1} * \frac{0.010^2}{\left(\frac{\pi * 0.10^2}{4}\right)^2} * \frac{1}{2 * 9.81} = 16.52m$$



b)

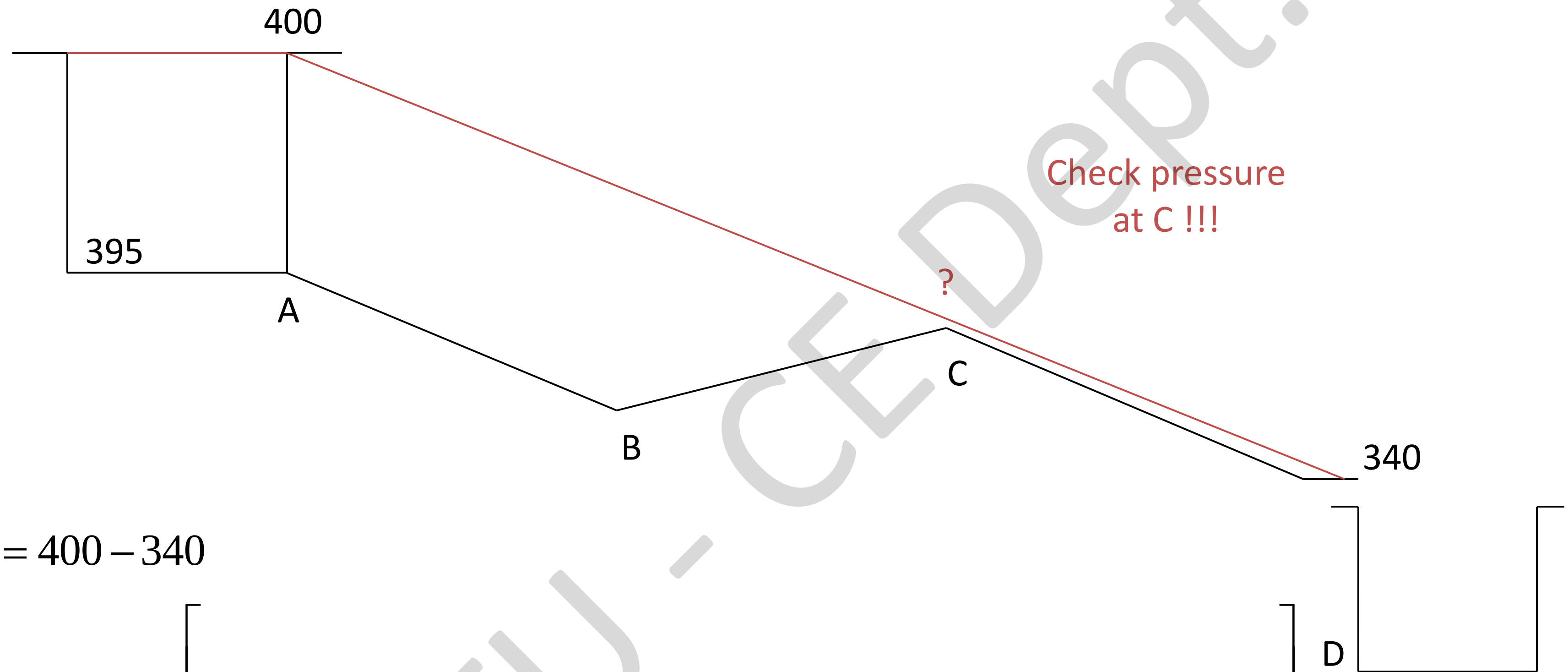


$$H_A = 395 + 3$$

$$H_A = h_{valve} + 3.10 + 2.45 + 16.52 + 340$$

$$h_{valve} = 35.93m$$

c)



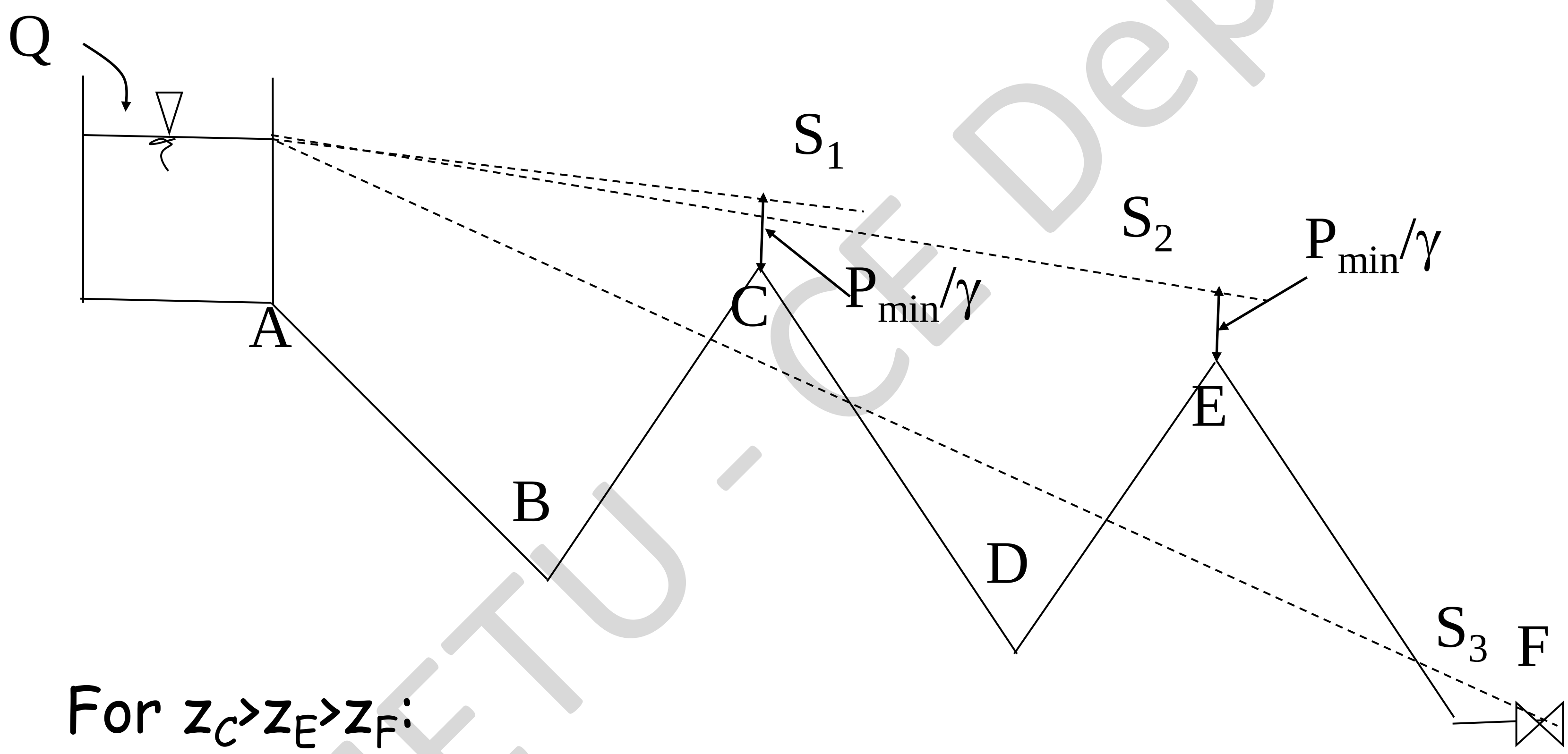
$$h_f = 400 - 340$$

$$h_f = Q^2 f \frac{1}{2g}\left[\frac{1500}{0.2} * \frac{1}{\left(\frac{\pi * 0.2^2}{4}\right)^2} + \frac{500}{0.15} * \frac{1}{\left(\frac{\pi * 0.15^2}{4}\right)^2} + \frac{1000}{0.2} * \frac{1}{\left(\frac{\pi * 0.1^2}{4}\right)^2}\right]$$

$$h_f = Q^2 \frac{f}{2g}[7{,}599{,}089 + 10{,}674{,}166 + 162{,}113{,}894]$$

$$Q = 18 \ \text{lt/s}$$

Design of Gravity Transmission lines



For $z_C > z_E > z_F$:

$$S_{min} = \frac{H_A - (z_c + P_{min}/\gamma)}{L_{AC}}$$

$$D_{com} = \left(\frac{8fQ^2}{g\pi^2 S_{min}} \right)^{1/5}$$

Choose one next size available at market

$$u = \frac{Q}{A} = \frac{4Q}{\pi D^2}$$

If $u_{min} < u < u_{max}$ then O.K.

If $u<u_{min}$, place a booster pump

$$H_A + H_P = z_C + \frac{P_{min}}{\gamma} + f\,\frac{L}{D}\,\frac{u_{min}^2}{2g}$$

If $u>u_{max}$

Compute new D from

$$\frac{\pi D^2}{4} \times u_{max} = Q$$

Install a pressure reduction valve if necessary

Repeat the same procedure for C-D-E and E-F separately

- Maintenance & operation → Governmental organization
- City maps: location of pipes, hydrants, valves, etc.

- Periodic records
  - for monitoring situation of pipes
  - detecting the excessive leakage

- The pipeline system should be
  - as watertight as possible
  - tested against leakage under pressure
  - disinfected periodically