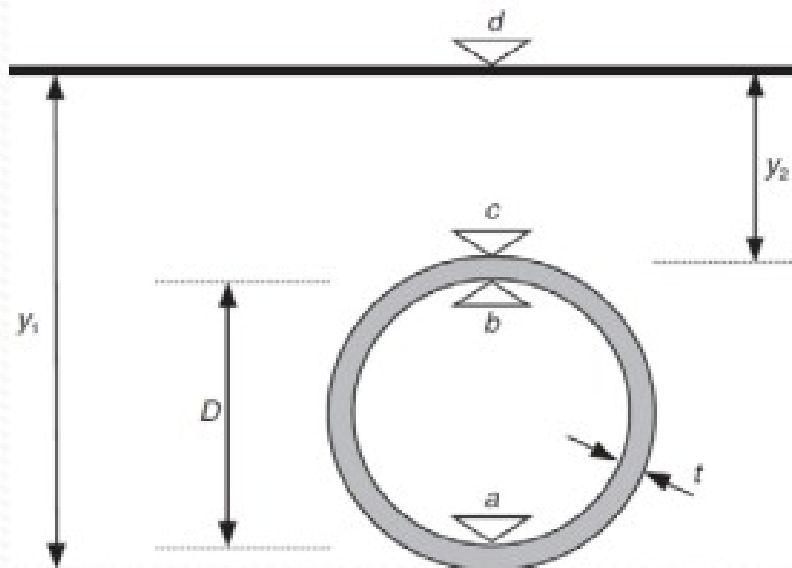


Design of sewer systems

Vertical alignment

- The invert of a pipe refers to the lowest point on the inside of the pipe.
- Soffit level is the highest point on the inside of the pipe.
- The crown is the highest point on the outside of the pipe.



a = invert level (IL)
b = Soffit level
c = Crown level
d = Ground level
D = internal diameter of pipe
t = pipe wall thickness
b = a + D
c = b + t

Example

A 375 mm diameter pipe with 15 mm walls has an invert level of 52.665 m. If the ground level is 54.930, calculate the pipe: (a) soffit level, (b) depth and (c) cover.

Solution

- (a) soffit level: $b = a + D = 52.665 + 0.375 = 53.040 \text{ m}$
- (b) depth (equation 7.1): $y_1 = d - a + t = 54.930 - 52.665 + 0.015$
 $= 2.280 \text{ m}$
- (c) cover (equation 7.2): $y_2 = y_1 - D - 2t = 2.280 - 0.375 - 0.030$
 $= 1.875 \text{ m}$

Design philosophy

- A sewer system is a network of pipes used to convey storm runoff and/or wastewater in an area.
- The design of sewer system involves the determination of
 - Diameters,
 - Slopes, and
 - Crown or invert elevations for each pipe in the system

Hydraulic Formulae

- The design of sewer is done on the basis of the following hydraulic formulae

(1) The Chézy equation,

$$V = C \sqrt{R.S}$$

..

V = velocity of flow (m/sec.)

S = hydraulic gradient or slope of the sewer

R = hydraulic mean radius (*m*) = A/P

A = area of cross-section (m^2)

P = wetted perimeter.

C = Chezy's constant

(2) The Gauckler-Manning equation, and

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

Hydraulic Formulae

(3) The Darcy-Weisbach equation.

$$h_f = \frac{\lambda L}{D} \cdot \frac{v^2}{2g}$$

The Colebrook-White equation:

$$\frac{1}{\sqrt{\lambda}} = -2 \log_{10} \left(\frac{k_s}{3.7D} + \frac{2.51}{R_e \sqrt{\lambda}} \right)$$

$$v = -2 \sqrt{2gS_f D} \log_{10} \left(\frac{k_s}{3.7D} + \frac{2.51v}{D \sqrt{2gS_f D}} \right)$$

k_s	pipe roughness (m)
S_f	hydraulic gradient or friction slope, h_f/L (-)
ν	kinematic viscosity (m^2/s).

Design Equations

- The Manning equation has found wide application in sewer design because it applies both to sewers flowing full and those flowing partially full—the latter being the condition most frequently encountered.

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

$$S = \frac{(v^2)(n^2)(6.3448)}{(D^{1.333})}$$

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

where v = velocity, m/s

n = coefficient of roughness, unitless

R = hydraulic radius, m

$= \frac{\text{cross-sectional area of flow, m}^2}{\text{wetted perimeter, m}}$

S = slope of energy grade line, m/m

D = diameter of pipe, m

Q = flow rate, m³/s

A = cross-sectional area of flow, m²

Design Equations

- The selection of an appropriate value for n is typically based on the pipe material and its condition.

Typical values of n that are used with the Manning equation

Pipe material	Condition		
	Good	Fair	Deteriorated
DIP (lined)	0.011	0.013 ^a	0.015
HDPE	0.010 ^a	0.011	0.013
PVC	0.010 ^a	0.011	0.013
RCP	0.013	0.015 ^a	0.018
VCP	0.013 ^a	0.015 ^a	0.017

^aValues commonly used in design.

Hydraulic characteristics of circular sewer

- For circular sewer running full, the hydraulic radius is defined as

$$R = \frac{(\pi/4)(D)^2}{\pi D} = \frac{D}{4}$$

- Similarly, for a pipe flowing half-full, $R = D / 4$.
- For pipes flowing full or half-full, other useful forms of Manning's equation are:

$$v = \frac{0.397}{n}(D)^{2/3} S^{1/2}$$

$$Q = \frac{0.312}{n}(D)^{8/3} S^{1/2}$$

$$S = \frac{10.3(n^2)(Q^2)}{(D^{16/3})}$$

Hydraulic characteristics of circular sewer

- For circular sewer running partially full,

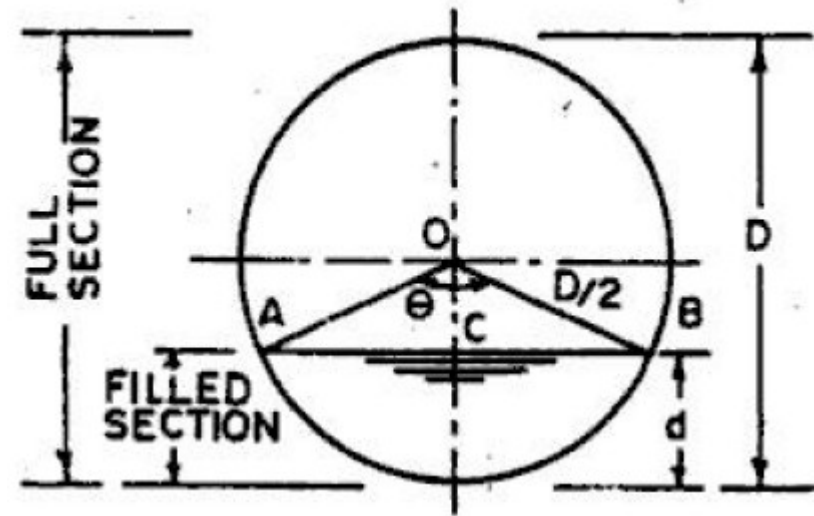
$$\cos \frac{1}{2} \theta = 1 - 2d/D$$

$$\text{Proportional depth} = \frac{d}{D} = \frac{1}{2} \left(1 - \cos \frac{\theta}{2} \right)$$

$$\text{Proportional area} = \frac{a}{A} \left[\frac{\theta}{360^\circ} - \frac{\sin \theta}{2\pi} \right]$$

$$\text{Proportional perimeter} = \frac{p}{P} = \frac{\theta}{360^\circ}$$

$$\text{Proportional H.M.D.} \quad \frac{r}{R} = \left[1 - \frac{360^\circ \sin \theta}{2\pi \theta} \right]$$



$$\text{Proportional velocity} = \frac{v}{V} = \frac{N}{n} \cdot \left(\frac{r}{R}\right)^{2/3}$$

$$\text{If } \frac{N}{n} = 1.0, \frac{v}{V} = \left(\frac{r}{R}\right)^{2/3} = \left[1 - \frac{360^\circ \sin \theta}{2\pi \theta}\right]^{2/3}$$

Taking $N/n = 1.0$, we have

$$\text{Proportionate discharge} = \frac{q}{Q} = \frac{a.v}{AV} = \frac{a}{A} \times \left(\frac{r}{R}\right)^{2/3}$$

$$\frac{q}{Q} = \left[\frac{\theta}{360^\circ} - \frac{\sin \theta}{2\pi}\right] \left[1 - \frac{360^\circ \sin \theta}{2\pi \theta}\right]^{2/3} = \frac{\theta}{360} \left[1 - \frac{360^\circ \sin \theta}{2\pi \theta}\right]^{5/3}$$

For variable values of $\frac{N}{n}$, we get

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

Another relationship

Angle of flow:

$$\theta = 2 \cos^{-1} [1 - 2 (d/D)]$$

Area of flow:

$$a = D^2 [(\theta - \sin \theta) / 8]$$

Wetted perimeter:

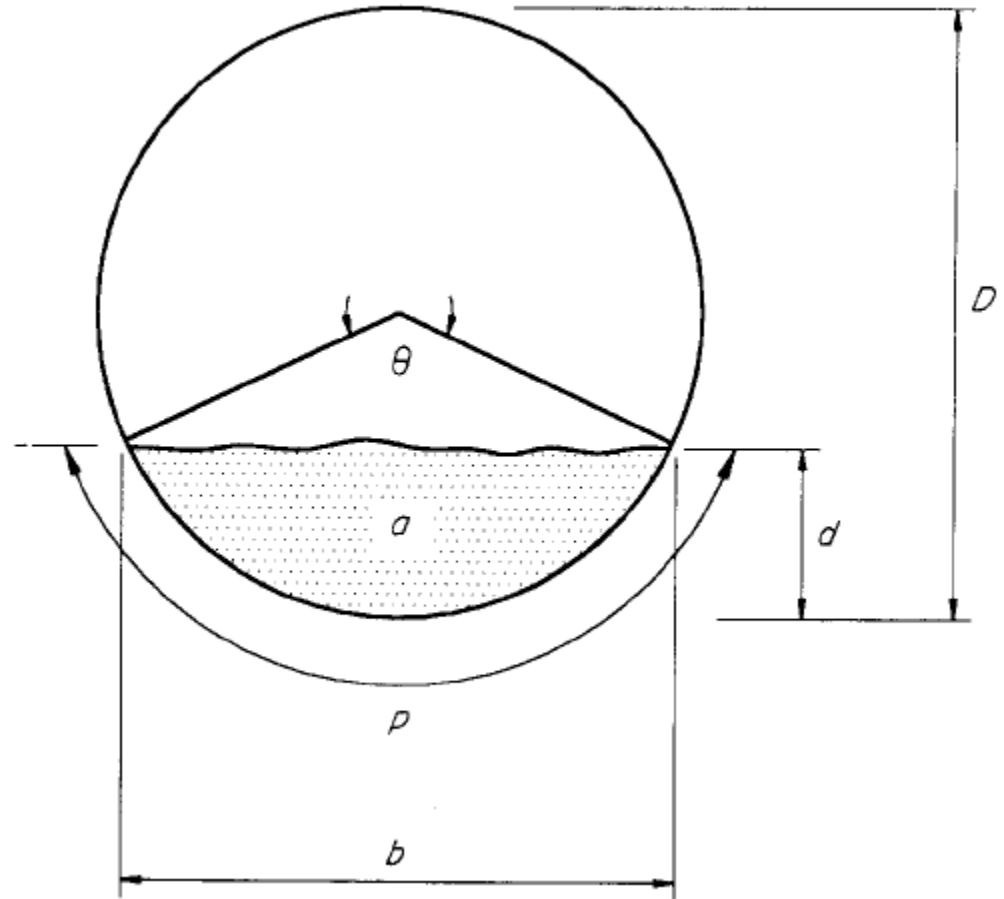
$$p = \theta D/2$$

Hydraulic radius (= a/p):

$$r = (D/4) [1 - ((\sin \theta) / \theta)]$$

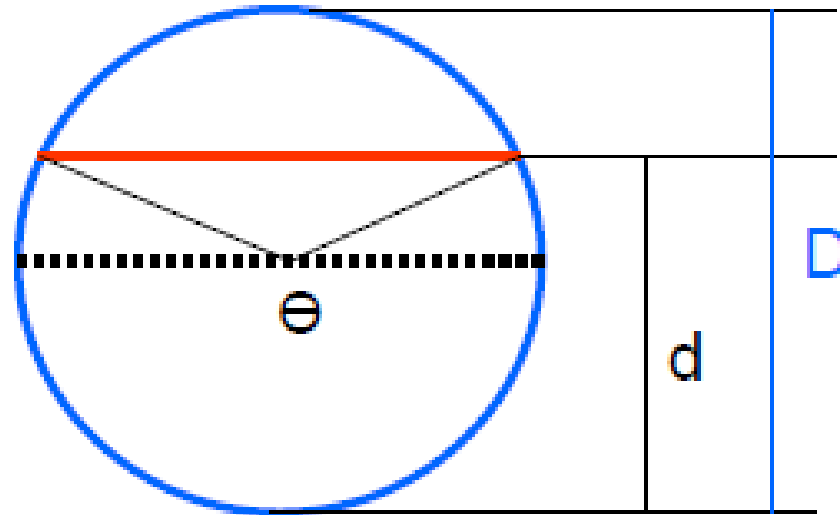
Breadth of flow:

$$b = D \sin (\theta/2)$$



Quiz

- Derive the equations for circular sewer running above half



Example

- Calculate the velocity of flow, and discharge in a sewer of circular section having diameter of 1m, laid at a gradient of 1 in 500. the sewer runs at 0.6 depth. use Manning's formula taking $N = 0.012$.

solution

$$\frac{d}{D} = 0.6$$

$$\cos \frac{\theta}{2} = 1 - 2 \frac{d}{D} = 1 - 2 \times 0.6 = -0.2$$

$$\theta = 203.07^\circ ; \sin \theta = -0.3919$$

$$\text{For sewer running full, } A = \frac{\pi}{4} (1)^2 = 0.7854 \text{ m}^2$$

$$P = \pi D = \pi \times 1 = 3.1416 \text{ m}$$

$$R = D/4 = 1/4 = 0.25 \text{ m.}$$

For partially full running,

$$\frac{a}{A} = \left[\frac{\theta}{360^\circ} - \frac{\sin \theta}{2\pi} \right] = \left[\frac{203.07}{360} + \frac{0.3919}{2\pi} \right] \\ = 0.6265$$

$$\therefore a = 0.6265 A = 0.6265 \times 0.7854 = 0.492 \text{ m}^2$$

$$\frac{r}{R} = \left[1 - \frac{360^\circ \sin \theta}{2\pi \theta} \right] = \left[1 + \frac{360 \times 0.3919}{2\pi (203.07)} \right] \\ = 1.1106$$

$$\therefore r = 1.1106 R = 1.1106 \times 0.25 = 0.2776$$

Now
$$v = \frac{1}{N} r^{2/3} S^{1/2} = \frac{1}{0.012} (0.2776)^{2/3} \left(\frac{1}{500} \right)^{1/2} \\ = 1.586 \text{ m/sec}$$

Also,
$$q = a \times v = 0.492 \times 1.586 \approx 0.78 \text{ cumes}$$

Note : If the sewer were to run full, the corresponding values would be :

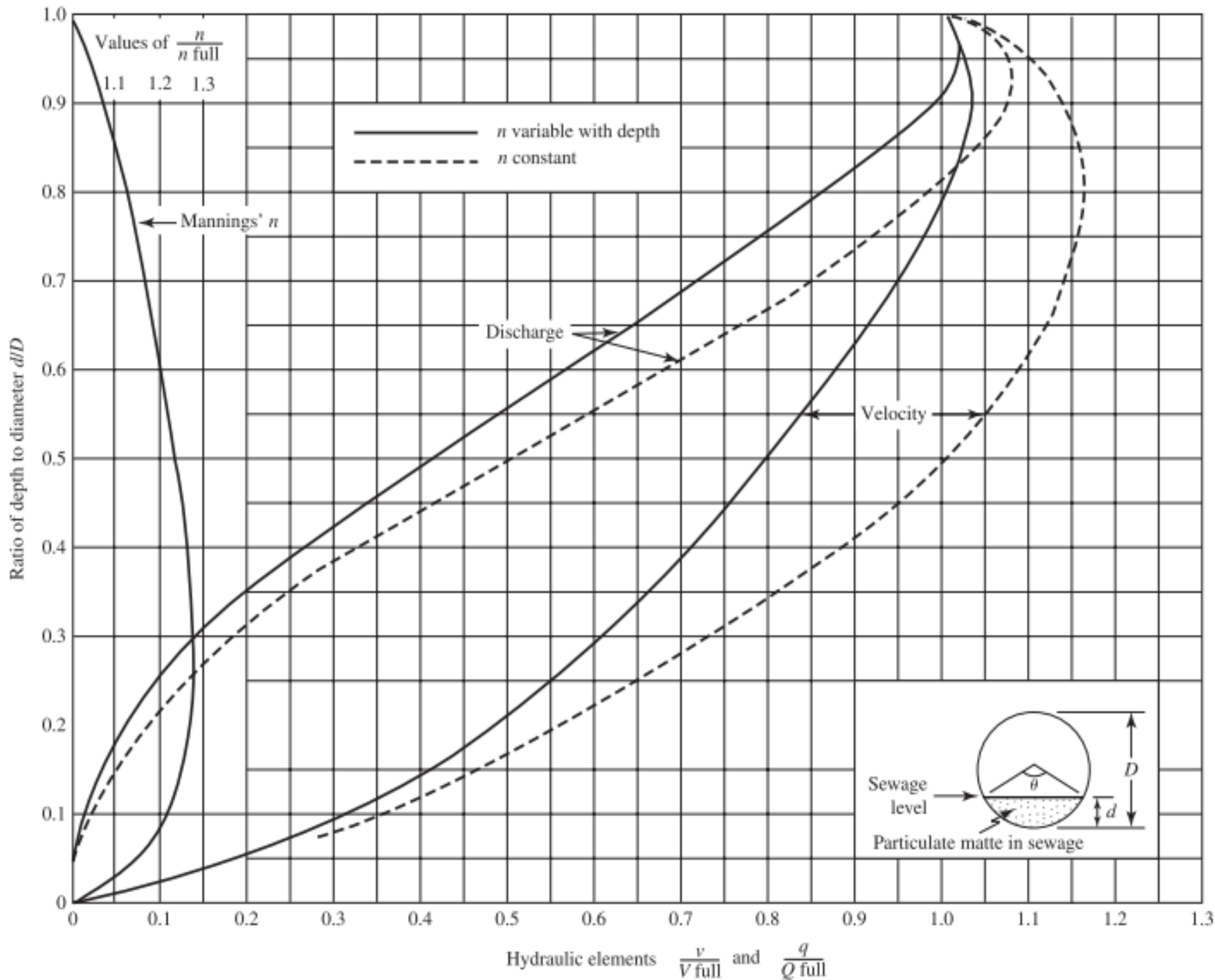
$$V = \frac{1}{0.012} (0.25)^{2/3} \left(\frac{1}{500} \right)^{1/2} = 1.479 \text{ m/sec}$$

and $Q = A \times V = 0.7854 \times 1.479 = 1.162 \text{ cumecs}$

Hence $\frac{v}{V} = \frac{1.586}{1.479} = 1.072$ and $\frac{q}{Q} = \frac{0.78}{1.162} = 0.671.$

**TABLE 4.8 HYDRAULIC ELEMENTS OF CIRCULAR SEWERS
RUNNING PARTIALLY FULL**

$\frac{d}{D}$	$\frac{a}{A}$	$\frac{p}{P}$	$\frac{r}{R}$	For $N/n = 1.0$		$\frac{N}{n}$	For variable N/n	
				v/V	q/Q		v/V	q/Q
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
1.00	1.000	1.000	1.000	1.000	1.000	1.00	1.000	1.000
0.90	0.949	0.795	1.192	1.124	1.066	0.94	1.057	1.002
0.80	0.858	0.705	1.217	1.140	0.988	0.88	1.003	0.869
0.70	0.748	0.631	1.185	1.120	0.838	0.85	0.952	0.712
0.60	0.626	0.564	1.110	1.072	0.671	0.83	0.890	0.557
0.50	0.500	0.500	1.000	1.000	0.500	0.81	0.810	0.405
0.40	0.373	0.436	0.857	0.902	0.337	0.79	0.713	0.266
0.30	0.252	0.369	0.684	0.776	0.196	0.78	0.605	0.153
0.20	0.143	0.295	0.482	0.615	0.088	0.79	0.486	0.070
0.10	0.052	0.205	0.254	0.401	0.021	0.82	0.329	0.017
0.00	0.000	—	—	—	0.000	—	—	—



Example

Example 19-1. Determine the velocity of $0.0081 \text{ m}^3/\text{s}$ flow in a 200 mm diameter sewer at a slope of 0.0040 m/m . The pipe is new VCP.

Solution.

- a. Estimate the velocity and flow rate for the sewer flowing full. The hydraulic radius for flowing full is $D/4$ and $n = 0.013$ for new VCP (Table 19-5). Using Equation 19-6:

$$\begin{aligned} v_{\text{full}} &= \frac{0.397}{0.013} (0.200 \text{ m})^{2/3} (0.0040 \text{ m/m})^{1/2} \\ &= (30.53)(0.3420)(0.0632) = 0.66 \text{ m/s} \end{aligned}$$

Using Equation 19-7:

$$\begin{aligned} Q_{\text{full}} &= \frac{0.312}{0.013} (0.200 \text{ m})^{8/3} (0.0040 \text{ m/m})^{1/2} \\ &= (24.00)(0.0137)(0.0632) = 0.0208 \text{ m}^3/\text{s} \end{aligned}$$

- b. Calculate Q/Q_{full} .

$$\frac{Q}{Q_{\text{full}}} = \frac{0.0081 \text{ m}^3/\text{s}}{0.0208 \text{ m}^3/\text{s}} = 0.39$$

- c. Enter Figure 19-9 on the abscissa at $Q/Q_{\text{full}} = 0.39$ and draw a vertical line to the discharge curve labeled “ n variable with depth.” From the intersection point, draw a horizontal line to the velocity curve labeled “ n variable with depth.” From this intersection point, draw a vertical line down to the abscissa and read $v/v_{\text{full}} = 0.78$.
- d. The velocity flowing partially full is then

$$v = 0.78 v_{\text{full}} = (0.78)(0.66 \text{ m/s}) = 0.51 \text{ m/s}$$

Comments:

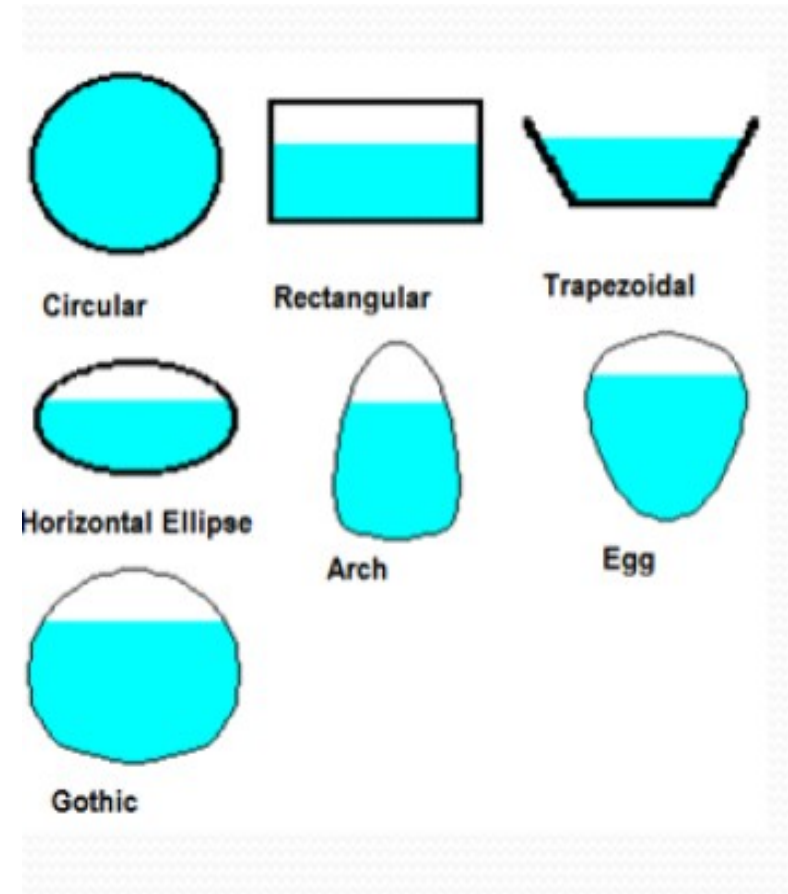
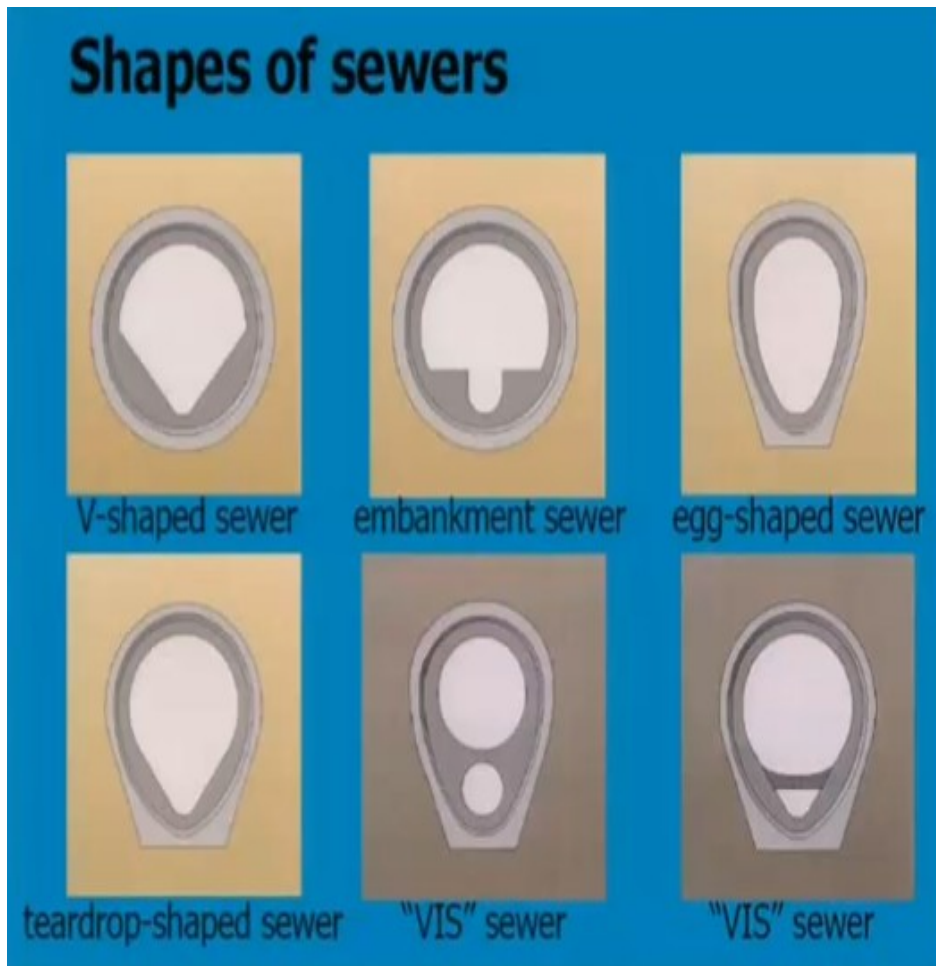
1. The specification of new VCP pipe was used to select $n = 0.013$ and to select the “ n variable with depth” curves. For plastic pipe, the value for n is 0.010, and the curves selected would be “ n constant.”
2. The use of the graphs for estimating v/v_{full} implies that calculated velocities should have no more than two significant figures. In all likelihood, given the inherent errors in estimating flow rates and Manning’s n , as well as the use of the nominal pipe diameter, one might argue that velocities should be limited to one significant figure.

Sewers

- Material-Must be durable and strong.
 - Cast and ductile iron,
 - PVC (polyvinyl chloride),
 - Concrete, asbestos cement,
 - HDPE (high density polyethylene),
 - Brick, and vitrified clay
- Most sewer pipes are made of concrete.

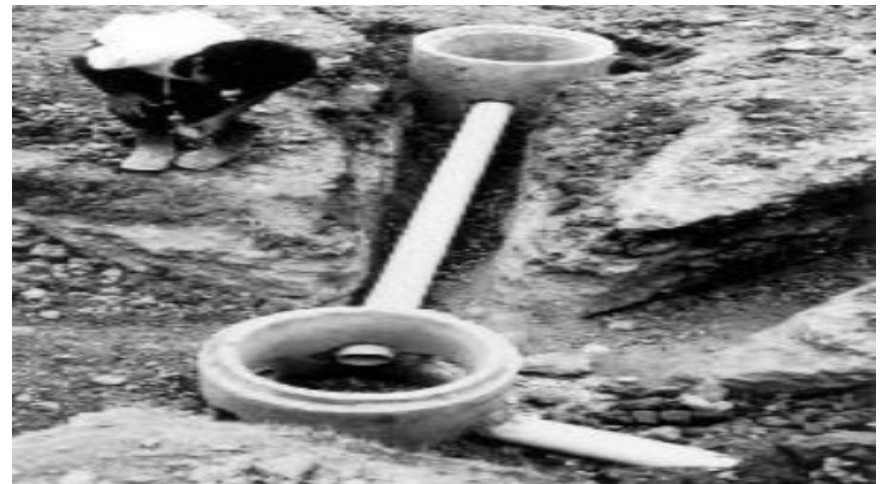
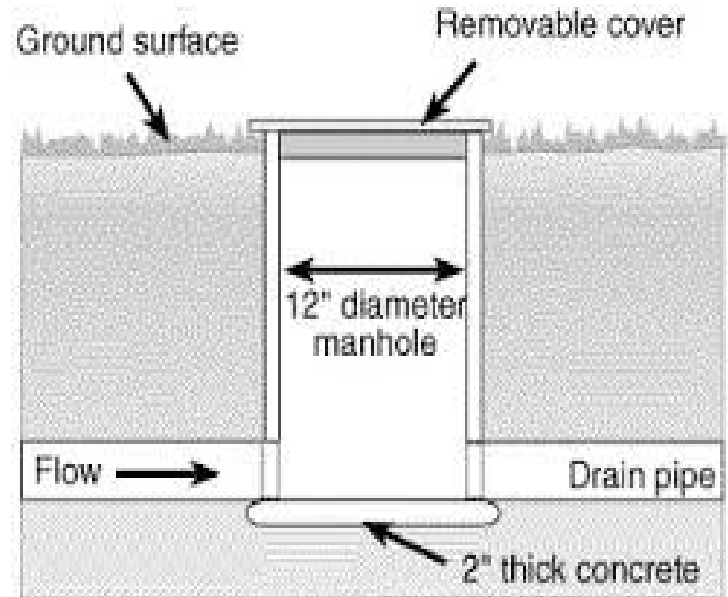
Sewer shapes

- Most new sewers are circular in cross-section.



Manholes

- Means of access for inspection, repair and cleaning
- placed at changes in
 - Direction,
 - Pipe size,
 - Grade and elevation, and
 - at junctions, and
 - at intervals of 90-120 m



Manholes



Ventilation

- To ensure that aerobic conditions are maintained within the pipe, and to avoid the possibility of build-up of toxic or explosive gases.
- Above-ground ventilation shafts
- Ventilated manhole covers



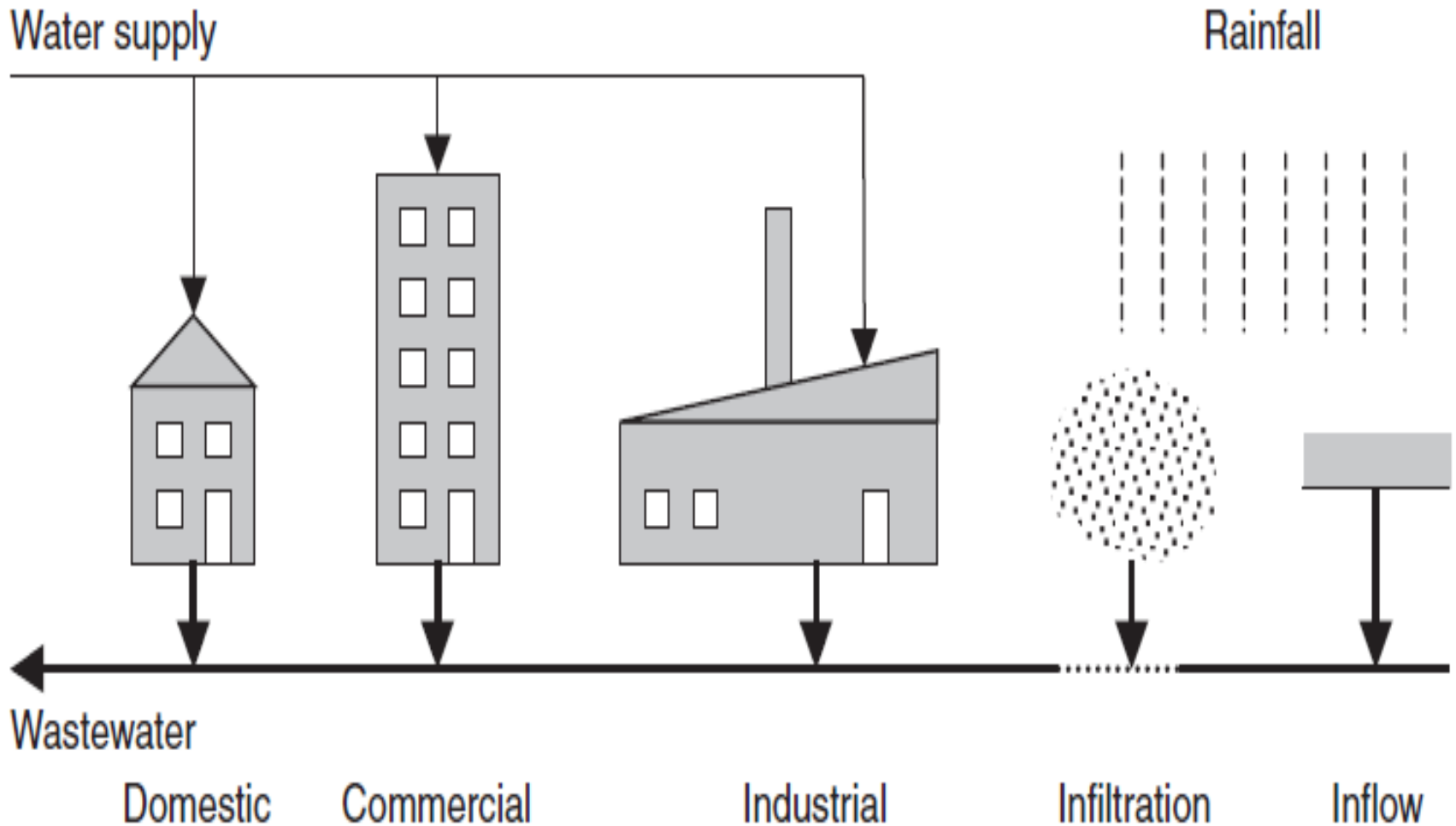
Design steps

- The issues that must be addressed in network design :
 - Estimation of wastewater flow rates.
 - Pipe material selection.
 - Design criteria.
 - Design equations.
 - Collection system layout.
 - Design of a lateral or branch.

Estimation of wastewater flow rates

- The components that make up the wastewater flow from a community depend on the type of collection system used and may include the following:
 - Domestic (also called sanitary) wastewater
 - Industrial wastewater
 - Infiltration/Inflow (I/I)
- The wastewater flow is also known as **dry weather flow**; wet weather flow refers to the flow under rainfall conditions.

Sources of wastewater

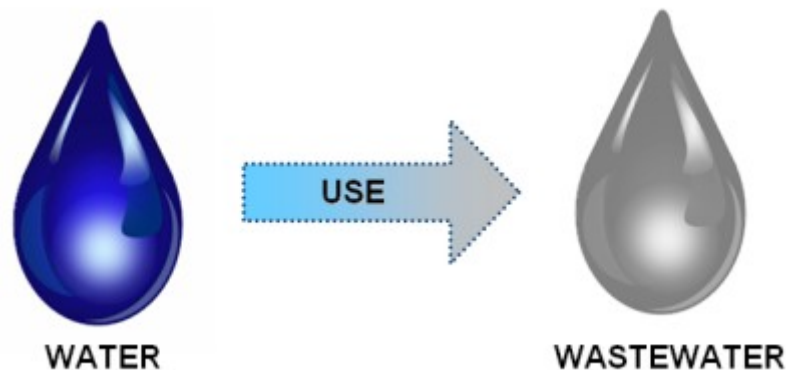


Cont..

- Accurate estimation of sewage discharge is necessary for hydraulic design of the sewers.
- Far lower estimation than reality will soon lead to **inadequate sewer size** after commissioning of the scheme or the sewers may not remain adequate for the entire design period.
- Similarly, very high discharge estimated will lead to
 - larger sewer size affecting **economy** of the sewerage scheme
 - lower discharge in the sewer may not meet the criteria **of self cleansing velocity** and leading to deposition in sewers.
- Actual measurement of the discharge is not possible if the sewers do not exist.
- Since sewers are designed to serve for some more future years, engineering skills have to be used to accurately estimate the sewage discharge.

Domestic wastewater

- In many networks, the domestic component of wastewater is the most important.
- Most domestic wastewater is the water left over from consumptive uses.
- The volume of domestic wastewater discharged in sanitary sewer represent, in general 60 to 80% of the total drinking water volume distributed.



Losses

- A part of the supplied drinking water is lost during the consumption process and does not reach the sewer system.
 - This refers for instance to water used for watering gardens, fire-fighting, street cleaning, filling up swimming pools etc
 - Leakage losses that occur in the distribution network also play a large part in explaining the difference between drinking water consumption and wastewater production.
 - These losses can make up 10 to 50% of drinking-water production.
- For example in Addis Ababa the losses drinking water due to leakage is greater than 40%.

Industrial wastewater

- The amount of industrial drinking-water consumed varies per type of company.
- The quantity and quality of wastewater evacuated through the sewer by the main industries must be carefully analyzed and measured.
- If flow rates are impossible to measure average values like the one shown in the table can be used.
- In general, water used as cooling agent is evacuated in the storm sewer system.
- Sometimes certain industries (soft drink and breweries) do not drain their wastewater into the sewerage system. This must be taken into account.

Industrial wastewater

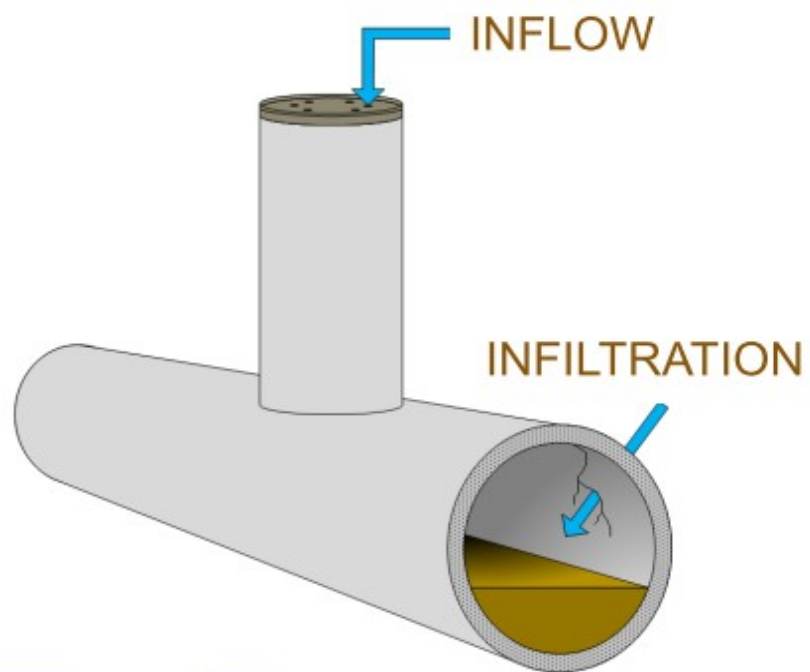
Type of industry	Average wastewater flowrate [m ³ /(ha·d)]
Industries for which the manufacturing process does not require water (clothing, transportation material, etc.)	10
Industries for which the manufacturing process requires small amounts of water (textile, wood, etc.)	25
Industries requiring large amounts of water (canning, pulp and paper, steel mill, etc.)	> 50
The surfaces of the infrastructures (road, parking lots, etc.) are included in the total surface area. Water used as a cooling agent is evacuated in the storm sewer system.	

Daily volume and pollutant load of wastewater produced from various commercial sources

Category	Volume (l/day)	BOD ₅ load (g/day)	Per
Hotels, boarding houses	150–300	50–80	Bed
Restaurants	30–40	20–30	Customer
Pubs, clubs	10–20	10–20	Customer
Cinema, theatre	10	10	Seat
Offices	750	250	100m ²
Shopping centre	400	150	100m ²
Commercial premises	300	100	100m ²

Infiltration/Inflow

- Water that enters the sewer system through indirect and direct means.
- **Infiltration** is extraneous (not directly connected) water that enters the sewer system through leaking joints, cracks and breaks, or porous walls.
- **Inflow** is storm water that enters the sewer system from storm drains connection, roof leaders, or through the manhole covers.



Net quantity of sewage

- The net quantity of sewage production can be estimated by considering the addition and subtraction

Net quantity of sewage	=	Accounted quantity of water supplied from the water works	+	Addition due to unaccounted private water supplies	+	Addition due to infiltration	-	Subtraction due to water losses	-	Subtraction due to water not entering the sewerage system
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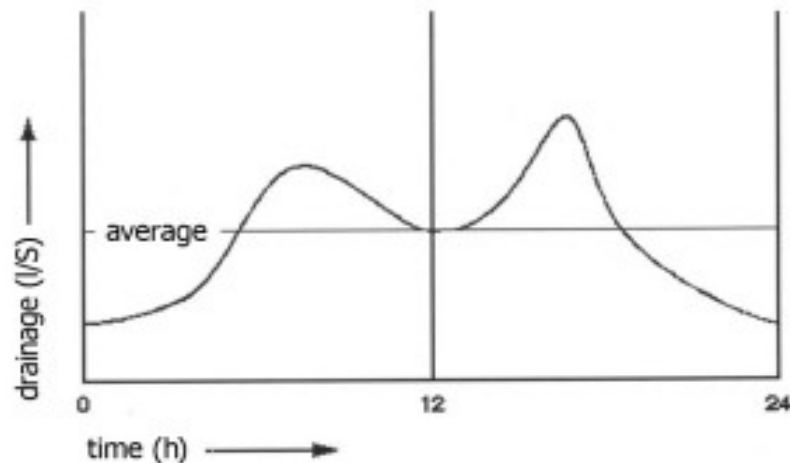
- *unaccounted private water supplies** - People using water supply from private wells, tube wells, etc certain industries utilize their own source of water.
- Generally, 60 to 80% of accounted water supplied is considered as quantity of sewage produced.

Variation in Domestic wastewater flow rate

- Wastewater is not produced evenly throughout the day; at night there is barely any wastewater flow.
- The largest amount of wastewater is produced during about 10 hours of the day.
- Wastewater production in most systems shows a peak in the morning and evening.
- The sewer should be so designed that it can take the maximum load.

Peak Factors

- Usually to determine minimum and maximum flowrates, peak factors are used.
- Peak factors vary according to regions and characteristics of the users.
- When a sewer system is already in place, these peak factors are determined by measuring the flowrate.
- When there is no existing sewer system we rely on peak factors suggested by government agencies or specialists in the field.



Peaking factors

- Most sewer laterals and mains are designed to convey peak hourly flow rates

$$Q_{peak} = Q_{avg} \times PF$$

- Some of the most common variable peaking factor (PF) calculation methods are as follows:

Ten-State Standards (1978):
(most widely used)

$$PF = \frac{18 + \sqrt{P / 1000}}{4 + \sqrt{P / 1000}} \quad P = \text{population}$$

Harmon (1918):

$$PF = 1 + \frac{14}{4 + \sqrt{P / 1000}}$$

Babbitt (1958):

$$PF = \frac{5}{(P / 1000)^{0.2}}$$

Federov (1975):

$$PF = \frac{2.69}{Q^{0.121}} \quad (Q = \text{ADF in L/s})$$

Peaking factors

- For estimating design discharge the following relation can also be considered:

<i>Sewer</i>	<i>Factor to multiply average rate of annular flow</i>
1. Domestic sewer	6
2. Lateral sewer	4-6
3. Branch sewer	3
4. Main sewer	2.5
5. Trunk or outfall sewer	2

Example

- A 40 hec drainage basin containing 24 hec net residential area with average 5 dwelling units per hec with 4 residents, and 16 hec zone commercial area. Determine the design flow for a sewer servicing this area. Assume a Peaking factor of 5.45

Take wastewater generation for

- Residential = 300 l/capita/day
- Commercial = 1800 l/hectare/day
- Peak I & I allowance = 9000 l/hectare/day = 9m³/hec/day

Solution

ADF for residential area= $(24 \text{ hec} \times 5 \text{ DU/hec} \times 4 \text{ Res./DU} \times 300 \text{ l/Res}) = 144 \text{ m}^3/\text{day}$

ADF for commercial area = $(16 \text{ hec} \times 1800 \text{ l/Hec}) = 288 \text{ m}^3/\text{day}$

ADF from Res. And Comm area= $144 \text{ m}^3/\text{day} + 288 \text{ m}^3/\text{day} = 432 \text{ m}^3/\text{day}$

Calculate PDF

PDF = $5.45 \times 432 + I \& I = 2354.4 + 9 \times 40 = 2714.4 \text{ m}^3/\text{day} = 0.0314 \text{ m}^3/\text{sec} = 1.885 \text{ m}^3/\text{min}$

Design Period

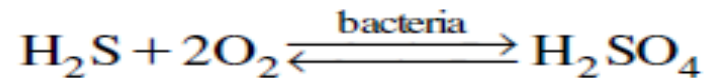
- Urban drainage systems have an extended life-span and are typically designed for conditions **25–50 years** into the future.
- **The design period depends upon the following:**
 - Ease and difficulty in expansion,
 - Amount and availability of investment,
 - Anticipated rate of population growth, including shifts in communities, industries and commercial investments,
 - Hydraulic constraints of the systems designed, and
 - Life of the material and equipment.

Crown Corrosion

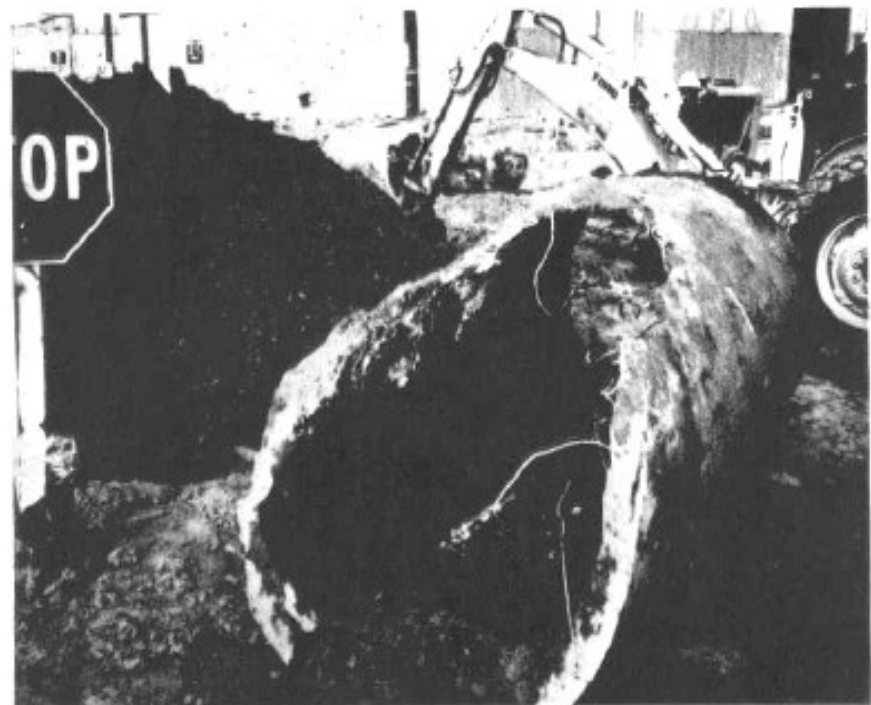
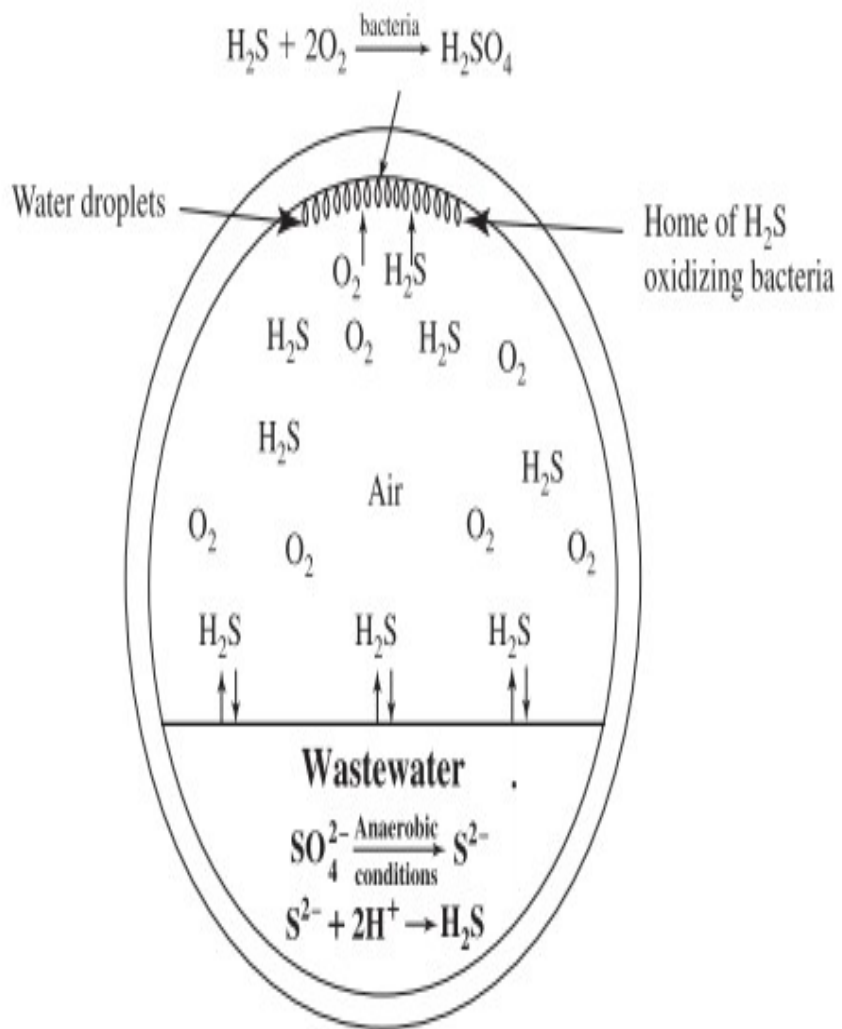
- The corrosion of the crown of a sewer is the result of biochemical reactions in the sewage and in the condensed moisture at the crown of the sewer.
- when sewage sits for long periods or when there is little oxygen transfer from the air in the sewer, the sewage becomes anoxic or anaerobic.
- Under these conditions, the sulfate in the sewage is reduced to sulfide.
- At the usual pH level of domestic sewage, the sulfide is converted to hydrogen sulfide.
- In poorly ventilated sewers, moisture collects on the walls and the crown. Hydrogen sulfide dissolves in this moisture. As such it does no harm.

Crown Corrosion

- Bacteria capable of oxidizing hydrogen sulfide, in particular those of the genus *Thiobacillus*, are always present in sewage.
- At high flows, these bacteria are brought to the walls and crown where they adhere after the high flows recede.
- They oxidize the hydrogen sulfide to sulfuric acid by the following reaction (Sawyer et al., 2003):



- This strong acid-attacks acid soluble materials such as concrete, iron, or steel. The corroded crown fails under the load of soil above it.
- VCP and PVC pipe are not susceptible to crown corrosion



Crown Corrosion

- The likelihood of H₂S generation is given by Pomeroy's (1990) Z factor:

$$Z = 3 (\text{BOD}_5) (1.07)^{T-20} i^{-1/2} q^{-1/3} (p/b)$$

where BOD₅ = 5-day, 20°C biochemical oxygen demand of the wastewater, mg/l

T = temperature, °C

i = sewer gradient, m/m

q = wastewater flow, l/s

p = wetted perimeter, m

b = breadth of flow

$Z < 5000$: H₂S generation unlikely

$5000 < Z < 10\,000$: H₂S generation possible

$Z > 10\,000$: H₂S generation very likely

Example

- Check the potential for sulfide generation for a flow of 1.5 l/s of wastewater with a BOD5 of 250 mg/l at 25°C in a sewer laid at 1 in 214 and flowing at a proportional depth of flow of 0.2.

Solution

$$\begin{aligned}\theta/2 &= \cos^{-1} [1 - 2 (d/D)] & \cos \frac{\theta}{2} &= 1 - 2d/D = 1 - (2 \times 0.2) \\ &= 0.927 \text{ radian} & \theta &= 106.26\end{aligned}$$

$$\begin{aligned}p/b &= (\theta/2)/\sin (\theta/2) & \frac{P}{b} &= \frac{\pi \theta}{360 \sin \frac{\theta}{2}} = \frac{\pi * 106.26}{360 \sin \frac{106.26}{2}} = 1.159 \\ &= 1.159\end{aligned}$$

$$\begin{aligned}Z &= 3 \times 250 (1.07)^5 (1/214)^{-1/2} (1.5)^{-1/3} (1.159) \\ &= 16\,000\end{aligned}$$

Thus H₂S generation is very likely,

Exercise

- Check the potential for sulfide generation in the trunk sewer made of concrete ($n=0.015$) having 1500 mm diameter laid on a slope of 1%. The peak discharge through the pipe is estimated to be 4000L/s. If 5-day BOD of the sewage is measured as 1600 mg/L and the ambient temperature in the sewer is 30°C.

Example

- A town has a population of 100,000 persons with a per capita water supply of 200 liters/day. Design a sewer running 0.7 times full at maximum discharge. Take a constant value of $N = 0.013$ at all depths of flow. The sewer is to be laid at a slope of 1 in 500. take a peaking factor of 3. Assume that 80 % of water supplied appears as sewage .

Solution

$$\begin{aligned}\text{Water supplied} &= 100,000 \times 200 = 20 \times 10^6 \text{ litres/day} \\ &= \frac{20 \times 10^6}{10^3 \times 24 \times 3600} = 0.2315 \text{ cumecs.}\end{aligned}$$

Assuming that 80% of the water supplied to the town appears as sewage, we have average discharge in the sewer
 $= 0.8 \times 0.2315 = 0.1852 \text{ cumecs.}$

At a peacking factor of 3,

$$\text{Max. discharge} = 3 \times 0.1852 = 0.5556 \text{ cumecs}$$

Since the sewer is to be designed as running 0.7 times the full depth, $d/D = 0.7$ and $q = 0.5556 \text{ cumecs.}$

For a sewer running partially full

$$\cos \frac{\theta}{2} = 1 - 2 \frac{d}{D} = 1 - 2 \times 0.7 = -0.4$$

$$\frac{\theta}{2} = 113.58^\circ; \theta = 227.16^\circ; \sin \theta = -0.7332$$

$$a = \frac{\pi}{4} D^2 \left[\frac{\theta}{360} - \frac{\sin \theta}{2\pi} \right] = \frac{\pi}{4} D^2 \left[\frac{227.16}{360} + \frac{0.7332}{2\pi} \right]$$

$$= 0.5872 D^2 \quad \dots$$

$$p = \pi D \frac{\theta}{360} = \pi D \frac{227.16}{360} = 1.9823 D$$

$$r = \frac{a}{p} = \frac{0.5872 D^2}{1.9823} = 0.2962 D$$

Now, $q = \frac{1}{N} a r^{2/3} S^{1/2}$

$$\therefore 0.5556 = \frac{1}{0.013} \times 0.5872 D^2 (0.2962 D)^{2/3} \left(\frac{1}{500} \right)^{1/2}$$

$$D^{8/3} = 0.6190$$

From which $D = 0.835 \text{ m}$

Other method

- Maximum sewage discharge = 0.5556 cumecs
- Now for $d/D = 0.7$, $q/Q = 0.838$, $v/V = 1.12$
- Therefore, $Q = 0.5556/0.838 = 0.663 \text{ m}^3/\text{sec}$

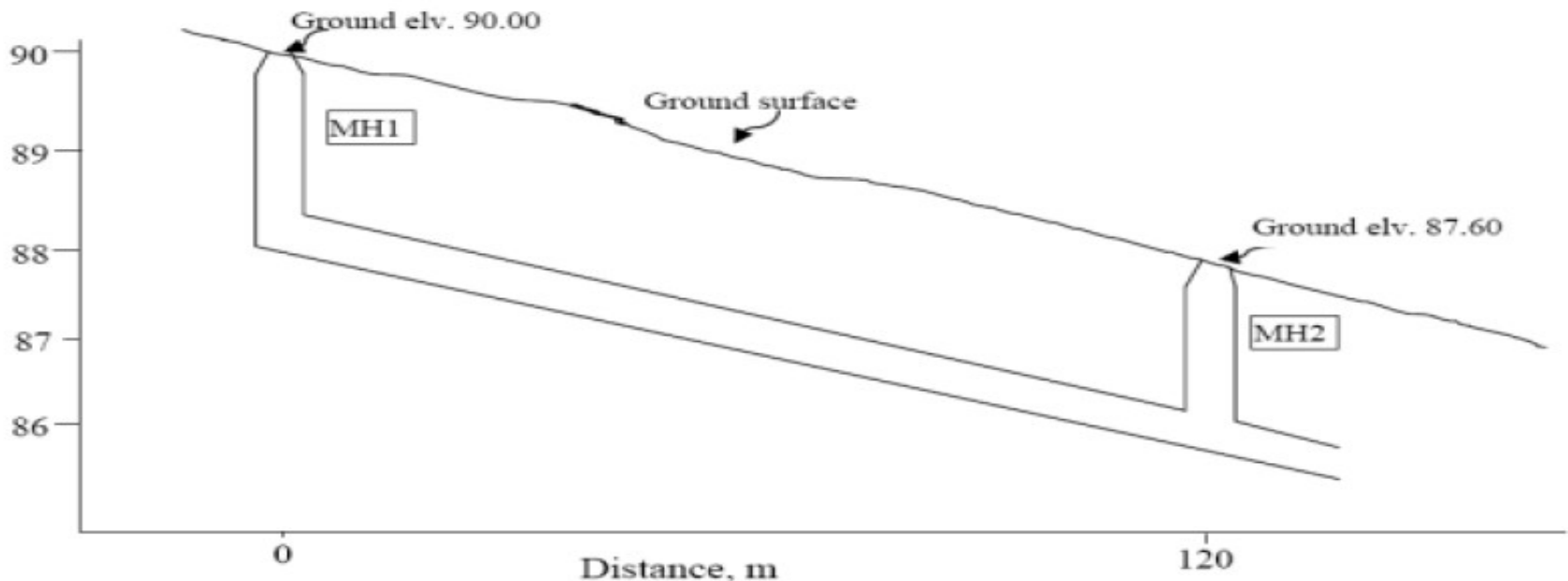
$$\text{Now } Q = \frac{1}{n} \frac{\pi D^2}{4} \left(\frac{D}{4}\right)^{2/3} S^{1/2}$$

$$0.663 = \frac{1}{0.013} \frac{\pi D^2}{4} \left(\frac{D}{4}\right)^{2/3} \left(\frac{1}{500}\right)^{1/2}$$

- Therefore **$D = 0.835 \text{ m}$**

Example

- A 120 m reach of sewer is to be designed with a flow capacity of 40 L/s. The street elevation at the upper manhole is 90.00 m and the lower manhole is 87.60 m, as shown below. Determine an appropriate pipe diameter and slope for this reach, and establish the pipe invert elevations at the upper and lower manholes. Assume a minimum earth cover of 2 m above the crown of the pipe. $N = 0.013$



Solution

- select a 300 mm diameter pipe to carry the flow.
- Ground slope = $(90 - 87.6)/120 = 0.02$
- Because the slope is steep use this for slope of the sewer

$$v_{full} = \frac{0.397}{0.013} (0.3)^{\frac{2}{3}} (0.02)^{\frac{1}{2}} = 1.93 \text{ m/s}$$

$$Q_{full} = 1.93 * \frac{\pi * 0.3^2}{4} = 0.136 \text{ m}^3/\text{s}$$

$$\frac{Q}{Q_{full}} = \frac{0.04}{0.136} = 0.29$$

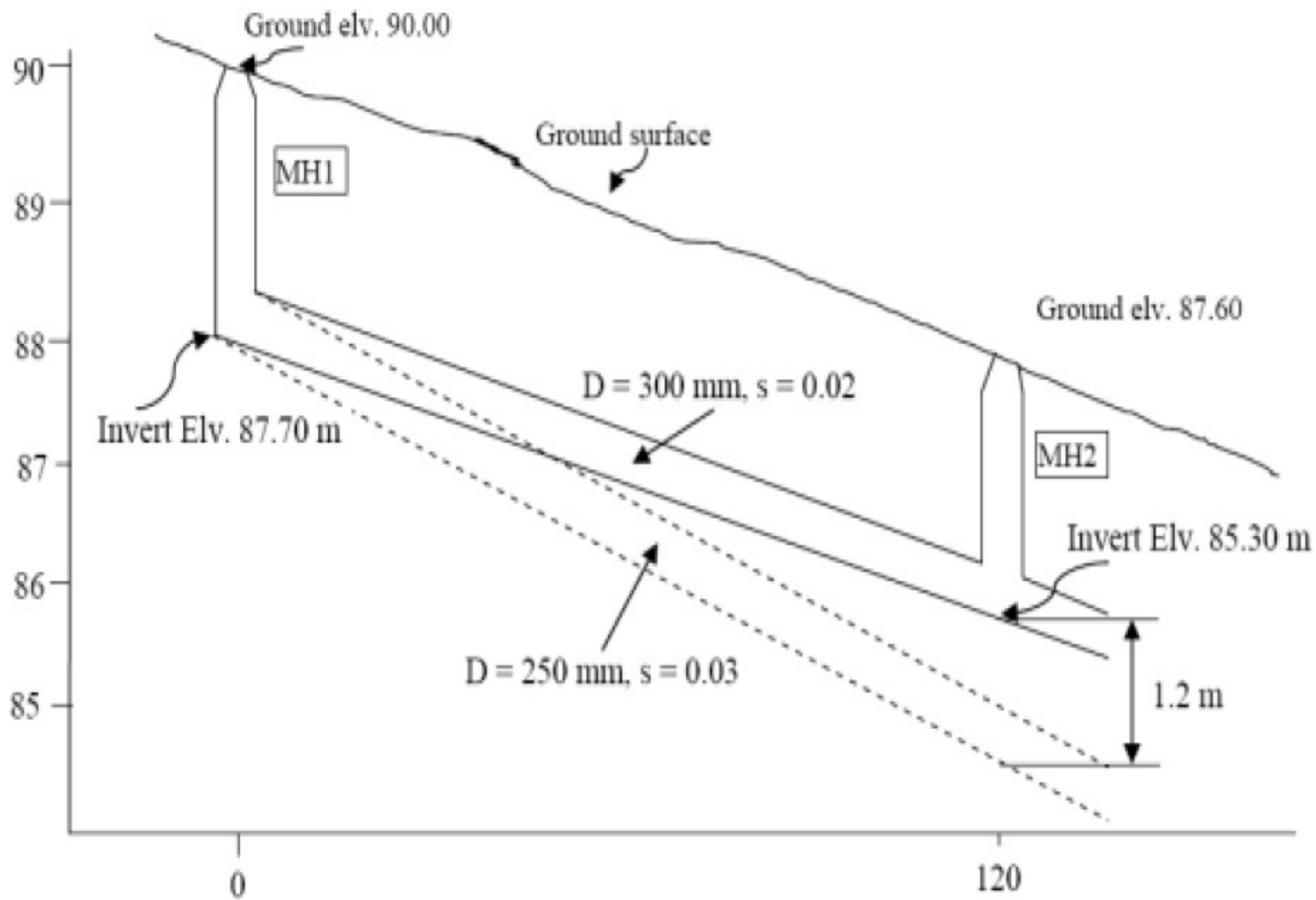
$$\frac{V}{V_{full}} = 0.75$$

$$V = 0.75 * 1.93 = 1.44 \text{ m/s}$$

- **Select 300 mm dia. at 0.02 slope**

Solution

- Fall of sewer = $0.02 \times 120 = 2.40 \text{ m}$
- Upper invert elevation = ground elv. - cover - pipe diameter - wall thickness
- Neglect wall thickness
$$= 90.00 - 2.00 - 0.3 = 87.70 \text{ m}$$
- lower invert elevation = Upper invert elevation - fall of sewer
$$= 87.70 - 2.4 = 85.30 \text{ m}$$



Design Example

Example 19-2. Design a sewer to connect two businesses (Koffee Au Noir and Elsie's Dairy Creamer) to an existing sewer main. The plan view of the proposed sewer line is shown in Figure 19-12. The distance between manholes is marked on the plan. It was selected based on an expectation that the sewer pipe diameter would be less than 375 mm. Surface elevations are given at each manhole. The proposed sewer must connect to the existing sewer at MH No. 48 at an invert elevation of 177.98 m. Assume that Koffee Au Noir and Elsie's Dairy Creamer both have basements. The peak flow rates for Koffee Au Noir and Elsie's Dairy Creamer are 20.2 L/s and 14.5 L/s, respectively. Infiltration and inflow are assumed to be negligible for this sewer main. A maximum velocity criterion of 2.5 m/s has been established by the local authority. No other establishments will connect to this line above MH 482. VCP has been selected as the pipe material. Ignore the customary 0.03 m drop through the manholes.

Koffee Au Noir



MH 485

201.10

76.2 m



Elsie's
Dairy Creamer

MH 484
201.80

61 m

199.64

MH 483

91 m

184.15

MH 482

91 m

183.24

MH 481

91 m

182.33

MH 48

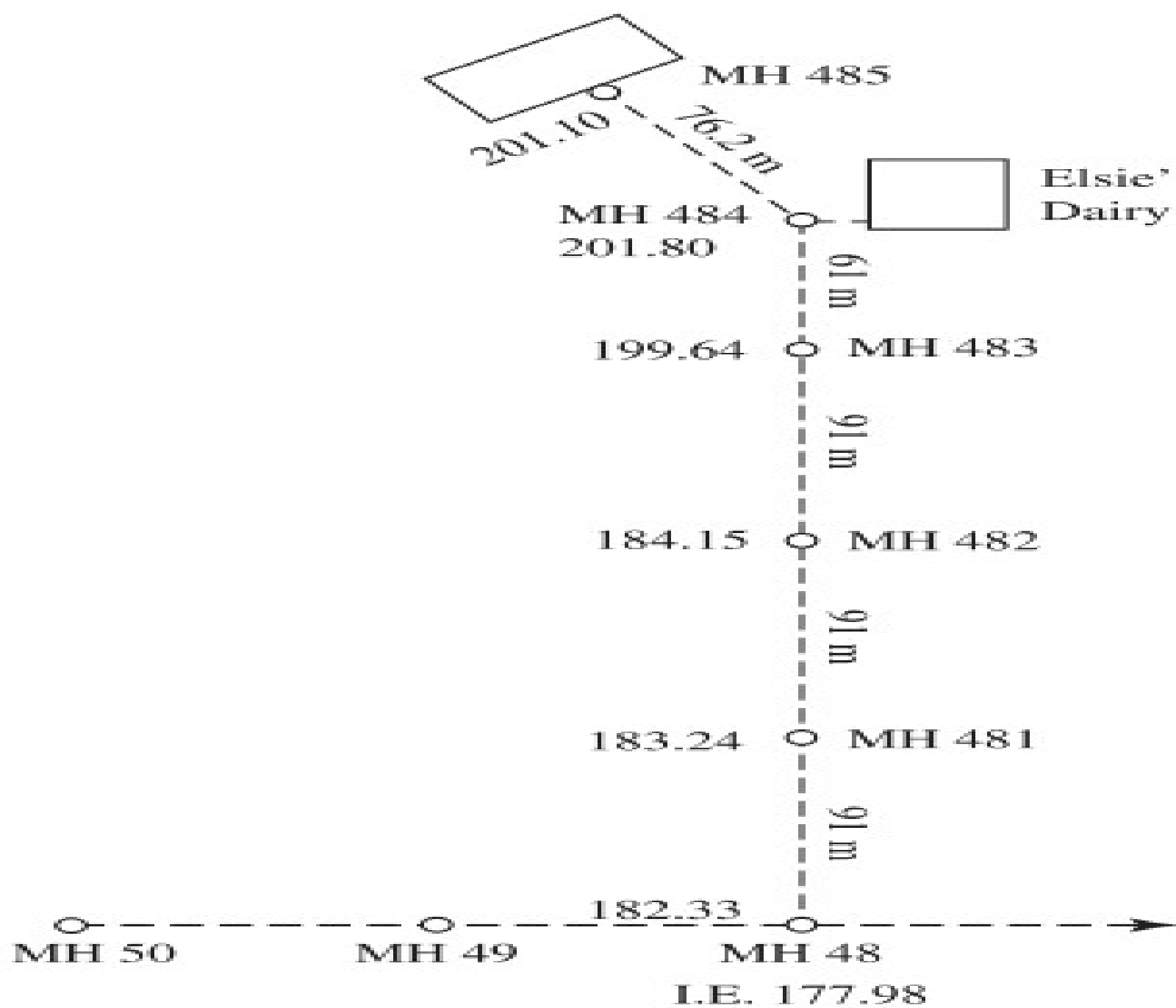
I.E. 177.98



MH 50



MH 49



Solution:

- a. Using the surface elevations from Figure 19-12, plot the ground surface profile on a scale drawing as shown in Figure 19-13.
- b. The calculations were performed on the spreadsheet shown below. Row and column calculations are explained below the table.
- c. The first four columns are self-explanatory.
- d. The flow rate in column 5, line 1 is the flow rate from Koffee Au Noir converted to compatible units for later calculations:

$$\frac{20.2 \text{ L/s}}{1,000 \text{ L/m}^3} = 0.0202 \text{ m}^3/\text{s}$$

- e. Column 6, line 1: Using Table 19-2, select a 250 mm diameter pipe because it will carry $0.029 \text{ m}^3/\text{s}$ flowing full at a minimum slope of 0.0025 m/m .
- f. Columns 7 and 8, line 1: These are the surface elevations given on the plan map (Figure 19-12).
- g. Column 9, line 1: The ground slope is calculated using the two manhole elevations and the distance between them:

$$\frac{201.10 \text{ m} - 201.80 \text{ m}}{76.2 \text{ m}} = -0.0092$$

The negative sign means that the slope is uphill.

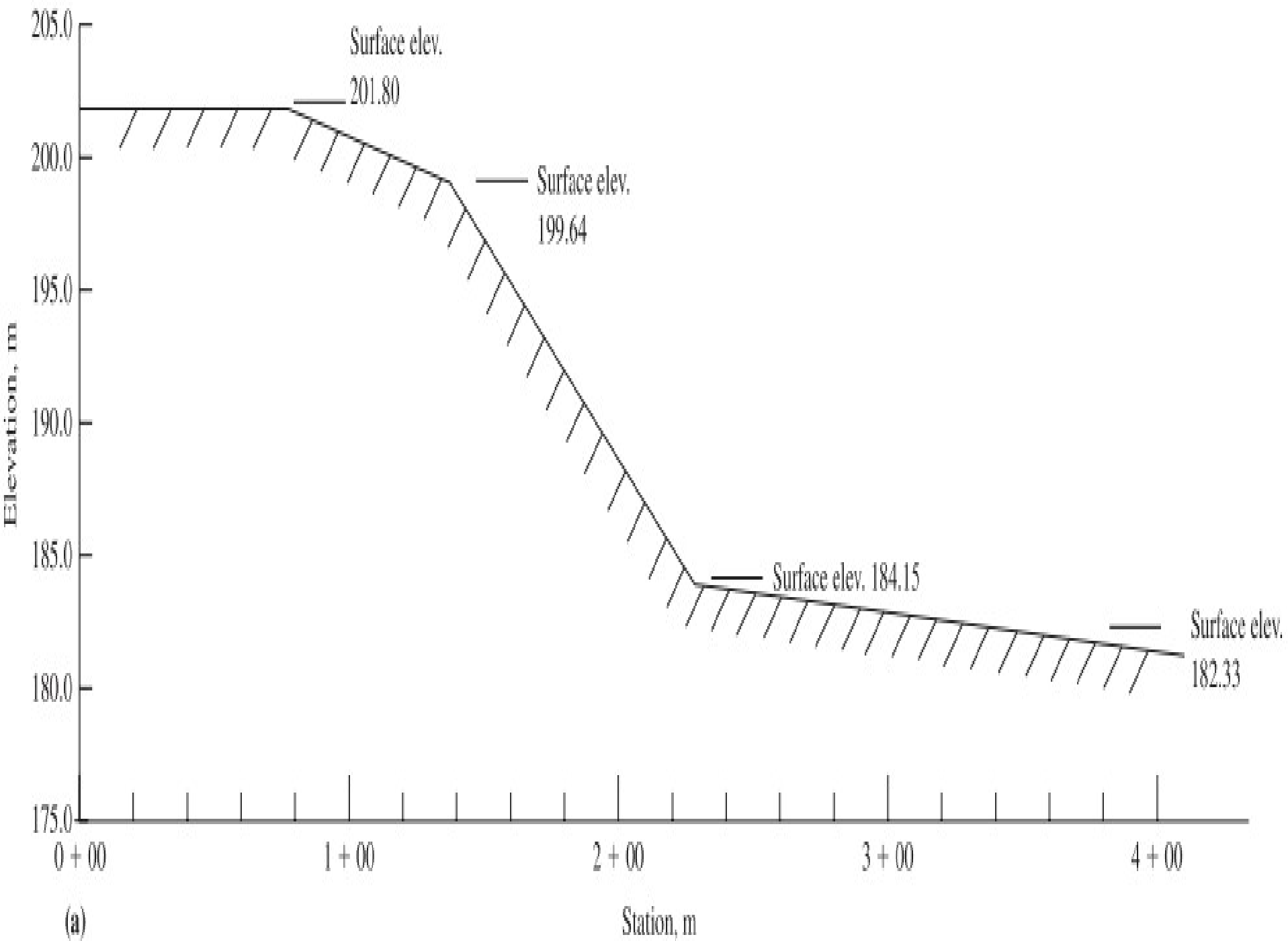
- h. Because the uphill slope is slight, the minimum slope from Table 19-2 for a 250 mm diameter VCP pipe was selected and entered in column 10, line 1: 0.0025 m/m.

This slope resulted in a velocity of 0.56 m/s when flowing partially full. The slope was adjusted to 0.0029 m/m to achieve a velocity of 0.60 m/s when flowing partially full.

- i. Column 11, line 1: Using Equation 19-6 because the pipe is flowing full, the velocity at a slope of 0.0029 m/m and a Manning's $n = 0.013$ is:

$$\begin{aligned} v &= \frac{0.397}{n} (D)^{2/3} S^{1/2} \\ &= \frac{0.397}{0.013} (0.250 \text{ m})^{2/3} (0.0029)^{1/2} \\ &= 0.65 \text{ m/s} \end{aligned}$$

Note: Manning's $n = 0.013$ because the pipe is new VCP.



						Ground elevations		Grade of surface, m/m	Grade of sewer, m/m	Velocity flowing full, m/s
Line	From MH	To MH	Length of line, m	Flow, m ³ /s	Pipe diameter, m	Upper MH, m	Lower MH, m			
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
1	485	484	76.2	0.0202	0.250	201.10	201.80	−0.0092	0.0029	0.65
2	484	483	61.0	0.0347	0.300	201.80	199.64	0.0354	0.0203	1.95
3	483	482	91.0	0.0347	0.300	199.64	184.15	0.1702	0.1702	5.65
3 revised	483	482	91.0	0.0347	0.300	199.64	184.15	0.1702	0.0933	4.18
4	482	481	91.0	0.0347	0.300	184.15	183.24	0.0100	0.0155	1.70
5	481	48	91.0	0.0347	0.300	183.24	182.33	0.0100	0.0155	1.70

- j. Column 12, line 1: Using Equation 19-7 because the pipe is flowing full, the flow rate at a slope of 0.0029 m/m and a Manning's $n = 0.013$ is:

$$\begin{aligned} Q &= \frac{0.312}{n} (D)^{8/3} S^{1/2} \\ &= \frac{0.312}{0.013} (0.25)^{8/3} (0.0029)^{1/2} \\ &= 0.0321 \text{ m}^3/\text{s} \end{aligned}$$

- k. Column 13, line 1: computation of Q/Q_{full} using Q from column 5 and Q_{full} from column 12:

$$\frac{0.0202}{0.0321} = 0.63$$

- l. Column 14, line 1: Using Figure 19-9 and the procedure outlined in step c in Example 19-1, find v/v_{full} :

$$\frac{v}{v_{\text{full}}} = 0.92$$

- m. Column 15, line 1: Calculate the velocity for the pipe flowing 92 percent full:

$$v_{\text{full}} = (0.92)(0.65 \text{ m/s}) = 0.60 \text{ m/s}$$

Note: The ratio (0.92) was computed in column 14, and the velocity was computed in column 11.

- n. Column 16, line 1: Calculate the change in elevation from the upper MH to the lower MH (called the *fall*) using the distance between manholes from column 4 and the slope from column 10:

$$(76.2 \text{ m})(0.0029 \text{ m/m}) = 0.22 \text{ m}$$

Invert elevations							
Q_{full} , m ³ /s	Q/Q_{full}	v/v_{full}	Velocity, m/s	Fall of sewer, m	Upper MH, m	Lower MH, m	Depth of lower MH, m
(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)
0.0321	0.63	0.92	0.60	0.22	197.75	197.53	4.27
0.1379	0.25	0.71	1.38	1.24	197.53	196.29	3.35
0.3993	0.09	0.52	2.94	15.49	196.29	180.80	3.35
0.2957	0.12	0.58	2.42	8.49	189.29	180.80	3.35
0.1205	0.29	0.72	1.23	1.41	180.80	179.39	3.85
0.1205	0.29	0.72	1.23	1.41	179.39	177.98	4.35

Picked depth of 3.35 m and
calculated slope of 0.0203

Drop MH = 7.0 m

- o. Column 17, line 1: The elevation of the upper MH is the difference between the surface elevation and the invert of the sewer, which is 3.35 m below the ground surface because Koffee Au Noir and Elsie's Dairy Kreamer have basements (see Table 19-4):

$$201.10 \text{ m} - 3.35 \text{ m} = 197.75 \text{ m}$$

- p. Column 18, line 1: The elevation of the lower MH invert is the difference between the upper MH invert (column 17) and the fall (column 16):

$$197.75 \text{ m} - 0.22 \text{ m} = 197.53 \text{ m}$$

Note: This elevation is copied to column 17, line 2.

- q. Column 19, line 1: This column is a check to make sure that the depth at the lower MH is equal to or greater than the required depth for basements. It is calculated as the surface elevation (column 8) minus the invert of the lower MH (column 18):

$$201.80 \text{ m} - 197.53 \text{ m} = 4.27 \text{ m}$$

Now working on Line 2

Now working on Line 2

- r. Column 5, line 2: The flow rate is the sum of that from Koffee Au Noir and Elsie's Dairy Kreamer:

$$0.0202 \text{ m}^3/\text{s} + \frac{14.5 \text{ L/s}}{1,000 \text{ L/m}^3} = 0.0347 \text{ m}^3/\text{s}$$

Note: Because there are no additional flows for the remainder of the lateral, this flow rate is repeated in the remaining lines of this column.

- s. Column 6, line 2: Because $0.0347 \text{ m}^3/\text{s}$ is greater than the flowing full capacity of the 250 mm diameter pipe at the minimum slope, use Table 19-2 and select a 300 mm diameter pipe to carry the flow.
- t. Column 10, line 2: Because the slope is steep, a trial calculation places the invert elevation of the lower MH at the minimum depth of 3.35 m. The logic in making this choice was to minimize excavation. Thus, the invert elevation at MH 483 is:

$$199.64 \text{ m} - 3.35 \text{ m} = 196.29 \text{ m}$$

The lower MH elevation is then entered in column 18.

The slope is then computed from the invert elevations in columns 17 and 18 and the distance between the MHs (column 4):

$$\frac{197.53 \text{ m} - 196.29 \text{ m}}{61.0 \text{ m}} = 0.0203$$

- u. Columns 11 through 19, line 2: follow the same logic as in line 1.

Now working on Line 3

- v. Columns 1 through 9: follow the logic in lines 1 and 2. Note that the distance in column 4, MH 483 to MH 482, is the horizontal distance. This is the distance to calculate the slope. The actual required pipe length is obviously longer.

w. Column 10, line 3: The slope of the ground surface was selected for this trial.

x. Columns 11 through 19, Line 3: follow the same logic as in Line 1.

Note: The velocity in column 15 exceeds the allowable velocity of 2.5 m/s.

Now working on Line 3 revised

y. Because of the excessive velocity, a drop manhole at MH 483 was selected to reduce the slope of the sewer. After several trials, using the velocity criterion of 2.5 m/s to determine acceptability, a drop of 7.0 m was selected. The upper MH elevation is:

$$196.29 \text{ m} - 7.0 \text{ m} = 189.29 \text{ m}$$

z. Column 10, line 3 revised: Keeping the lower MH elevation at the same value as in the first trial for line 3, the slope is then:

$$\frac{189.29 \text{ m} - 180.80 \text{ m}}{91.0 \text{ m}} = 0.0933$$

aa. Columns 11 through 19 for line 3 revised are calculated as in Line 1.

bb. Lines 4 and 5: Because the grade is uniform from MH 482 to MH 48, the slope was computed from the invert at MH 482 to the invert specified for connection at MH 48, that is, 177.98 m. It is

$$\frac{180.80 \text{ m} - 177.98 \text{ m}}{2(91.0 \text{ m})} = 0.0155$$

Note: The factor of 2 in the denominator is to account for the two manhole distances between MH 482 and MH 48.

cc. Assuming that the slope remains constant, it is entered in column 10 for lines 4 and 5. The computations in columns 11 through 19 for lines 4 and 5 are calculated as in line 1. The depth of the lower MH is checked to make sure that it is equal to or greater than 3.35 m. This satisfies the requirements for the sewer and completes the computations for this lateral.

