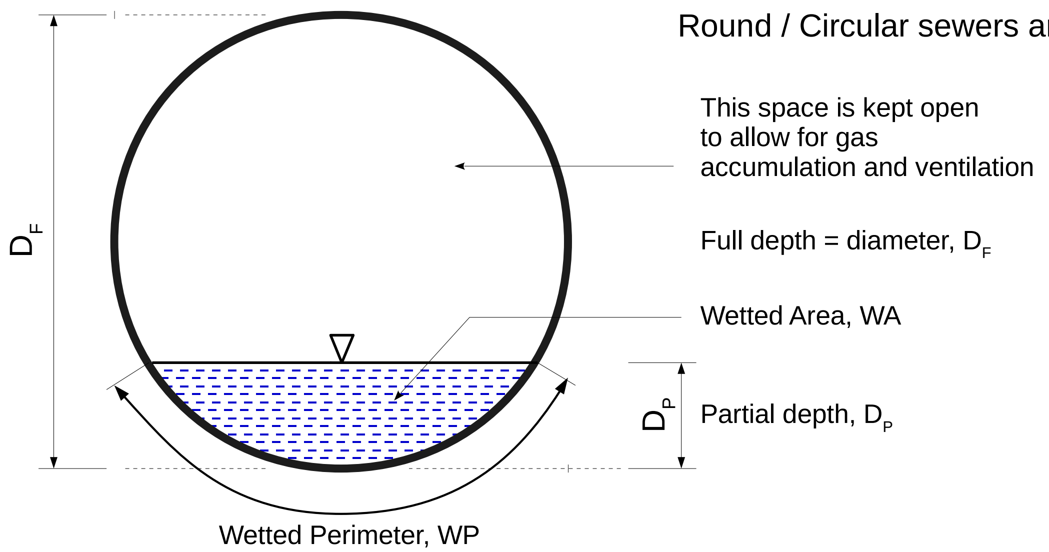
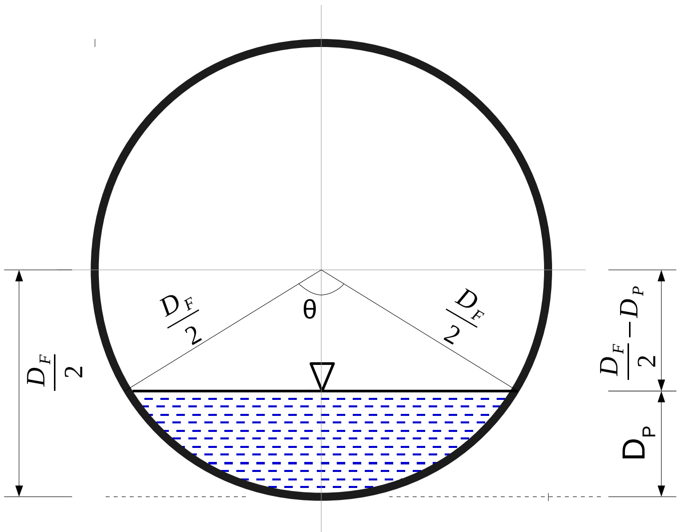
Sewer Design

Round / Circular sewers are most common





$$\theta = 2\cos^{-1}\left(1 - \frac{2\,D_P}{D_F}\right)$$

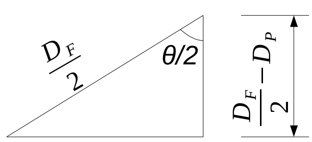
$$\mathrm{WP} = \frac{\pi\,\theta}{360^0}\,D_F$$

$$\mathrm{WA} = \frac{D_F^2}{4}\left(\frac{\pi\,\theta}{360^0} - \frac{1}{2}\sin\theta\right)$$

$$R = \frac{WA}{\mathrm{WP}}$$; R is the hydraulic radius

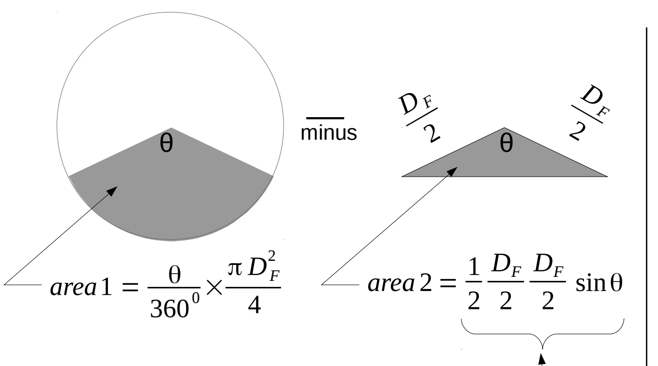
$$V = \frac{1}{n}\,R^{\frac{2}{3}}\,S^{\frac{1}{2}}$$; Manning's Equation (MKS units)

How this formulae is/are derived is very simple (you do not need to memorise them for exams)



$$\cos\frac{\theta}{2} = \frac{\frac{D_F}{2} - D_P}{\frac{D_F}{2}} = 1 - \frac{2\,D_P}{D_F}$$

$$\theta = 2\cos^{-1}\left(1 - \frac{2\,D_P}{D_F}\right)$$

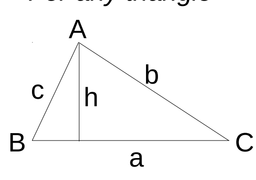


$$area\,1 = \frac{\theta}{360^0} \times \frac{\pi\,D_F^2}{4}$$

$$area\,2 = \frac{1}{2}\,\frac{D_F}{2}\,\frac{D_F}{2}\,\sin\theta$$

WA = area1 - area2

For any triangle



$$h = b\,\sin C = c\,\sin B$$

$$Area = \frac{1}{2}\,a\,h$$

$$= \frac{1}{2}\,ab\,\sin C$$

$$= \frac{1}{2}\,ac\,\sin B$$

$$similarly, = \frac{1}{2}\,bc\,\sin A$$

$$= \frac{1}{2} \times arm\,1 \times arm\,2$$

$$\times\,Sine\ of\ included\ angle$$

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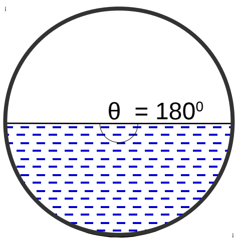
Example: Determine the hydraulic radius of a circular pipe flowing half filled.



For half-filled pipe, $\theta = 180^0$

Let the diameter of pipe = D

Wetted perimeter is the length of half cirlce, or by formula,

$$\text{WP} = \frac{\pi\theta}{360^0} D_F = \frac{\pi \times 180^0}{360^0} D = \frac{\pi D}{2}$$

Wetted area is the area of half cirlce, or by formula,

$$\text{WA} = \frac{D_F^2}{4}\left(\frac{\pi\theta}{360^0} - \frac{1}{2}\sin\theta\right) = \frac{D^2}{4}\left(\frac{\pi 180^0}{360^0} - \frac{1}{2}\sin 180^0\right)$$
$$= \frac{D^2}{4}\left(\frac{\pi}{2} - \frac{1}{2}\times 0\right) = \frac{\pi D^2}{8}$$

Hydraulic radius:

$$R = \frac{WA}{\text{WP}} = \frac{\pi D^2}{8} \times \frac{2}{\pi D} = \frac{D}{4}$$

For design purpose, it is safe to assume that the pipes will have half-filled flow. In such cases the following analysis can be done for a flow of Q

$$Q = AV = WA \times \frac{1}{n} R^{\frac{2}{3}} S^{\frac{1}{2}} = \frac{\pi D^2}{8} \times \frac{1}{n}\left(\frac{D}{4}\right)^{\frac{2}{3}} S^{\frac{1}{2}} = \frac{\pi\sqrt{S}}{2^{\frac{13}{3}} n} D^{\frac{8}{3}}$$

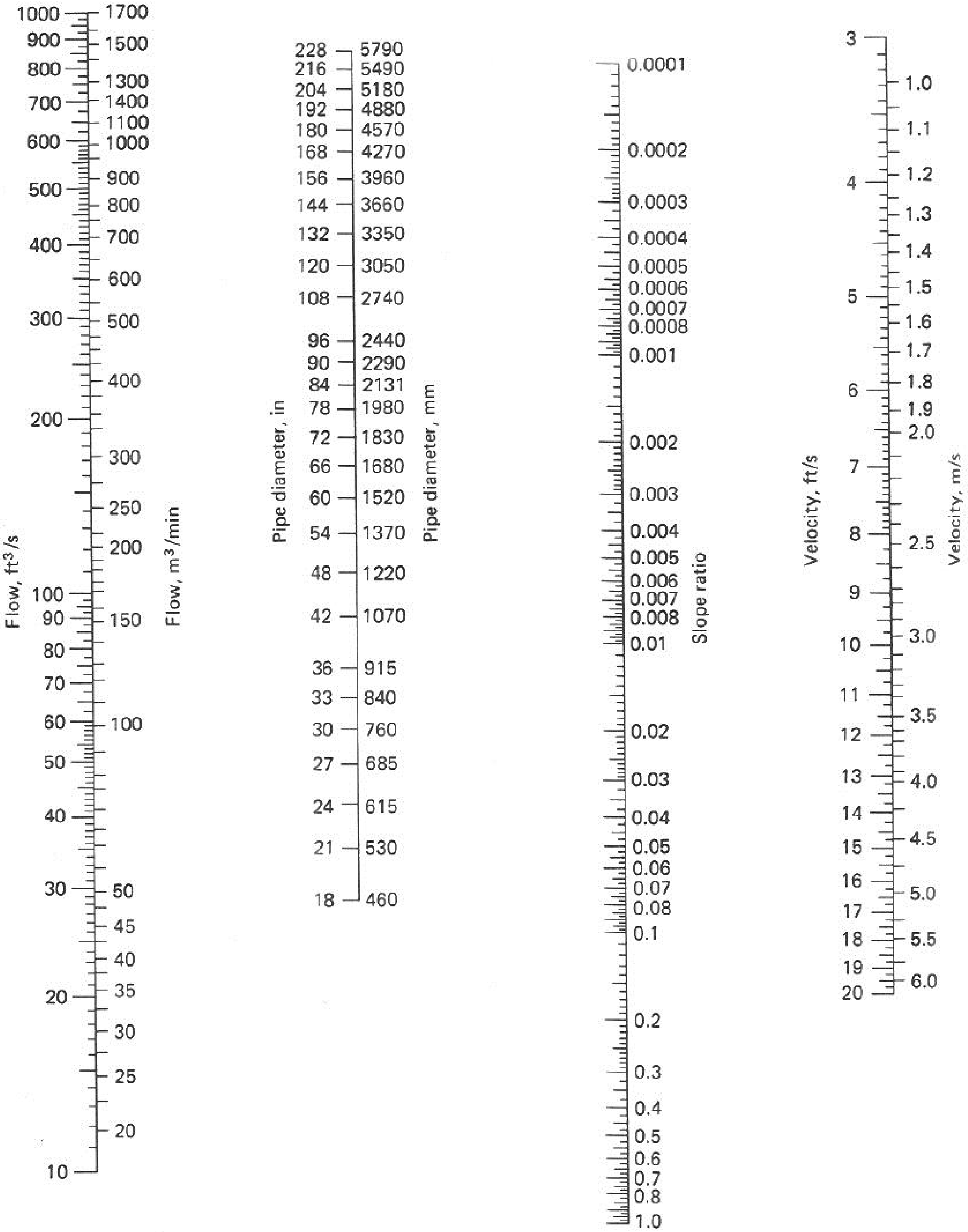
$$\Rightarrow D^{\frac{8}{3}} = \frac{2^{\frac{13}{3}} Q n}{\pi\sqrt{S}} \qquad \Rightarrow D = \frac{2^{\frac{13}{8}} Q^{\frac{3}{8}} n^{\frac{3}{8}}}{\pi^{\frac{3}{8}} S^{\frac{3}{16}}}$$

If we design sewer for a area, we can estimate the flow Q; the value of n can be selected for pipe material, and, the existing slope of the land or the design slope reuirement can be taken as the value of S. (MKS unit system)

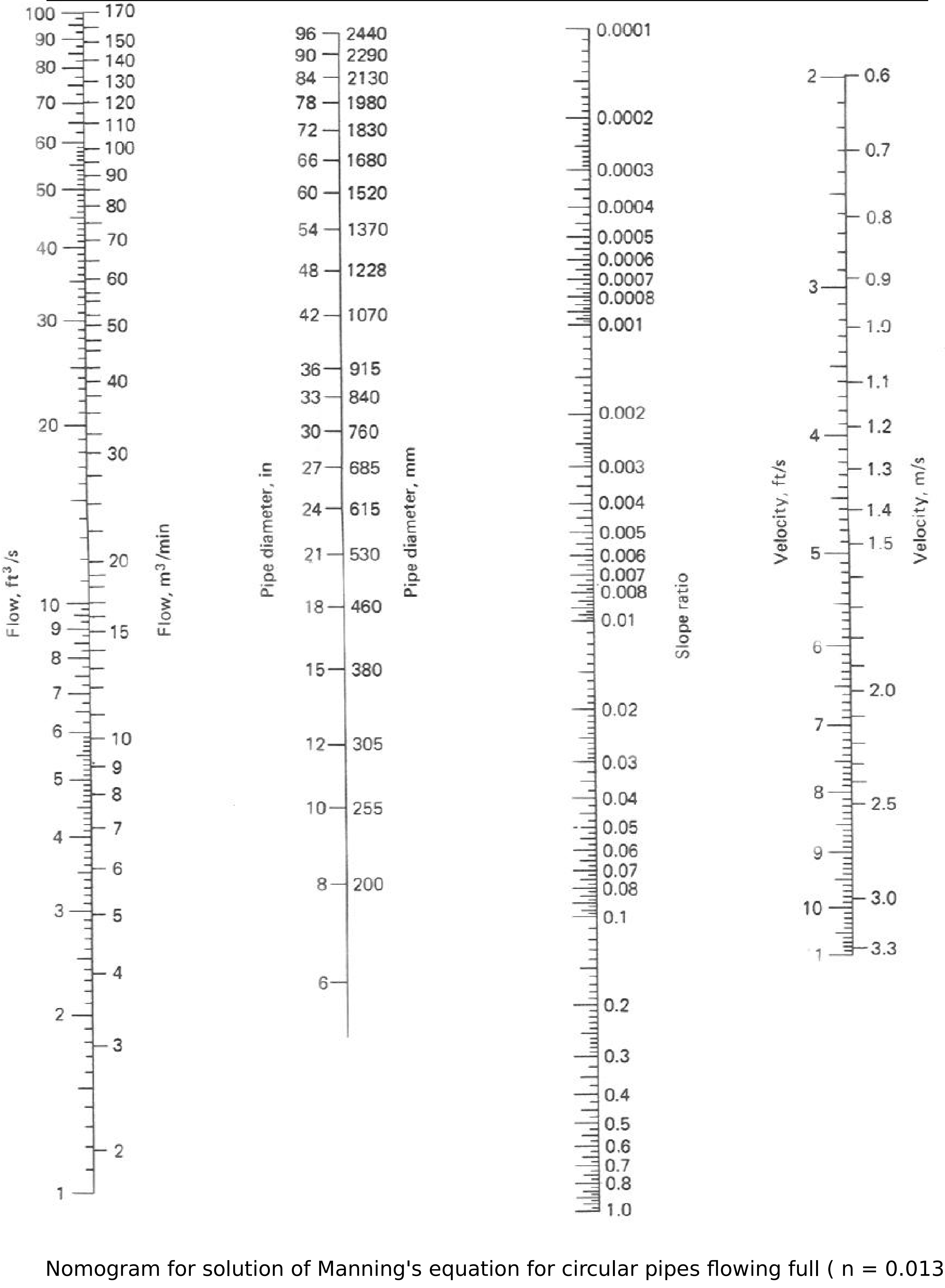
Do it yourself: Determine the hydraulic radius of a circular pipe flowing full.

Sewer analysis

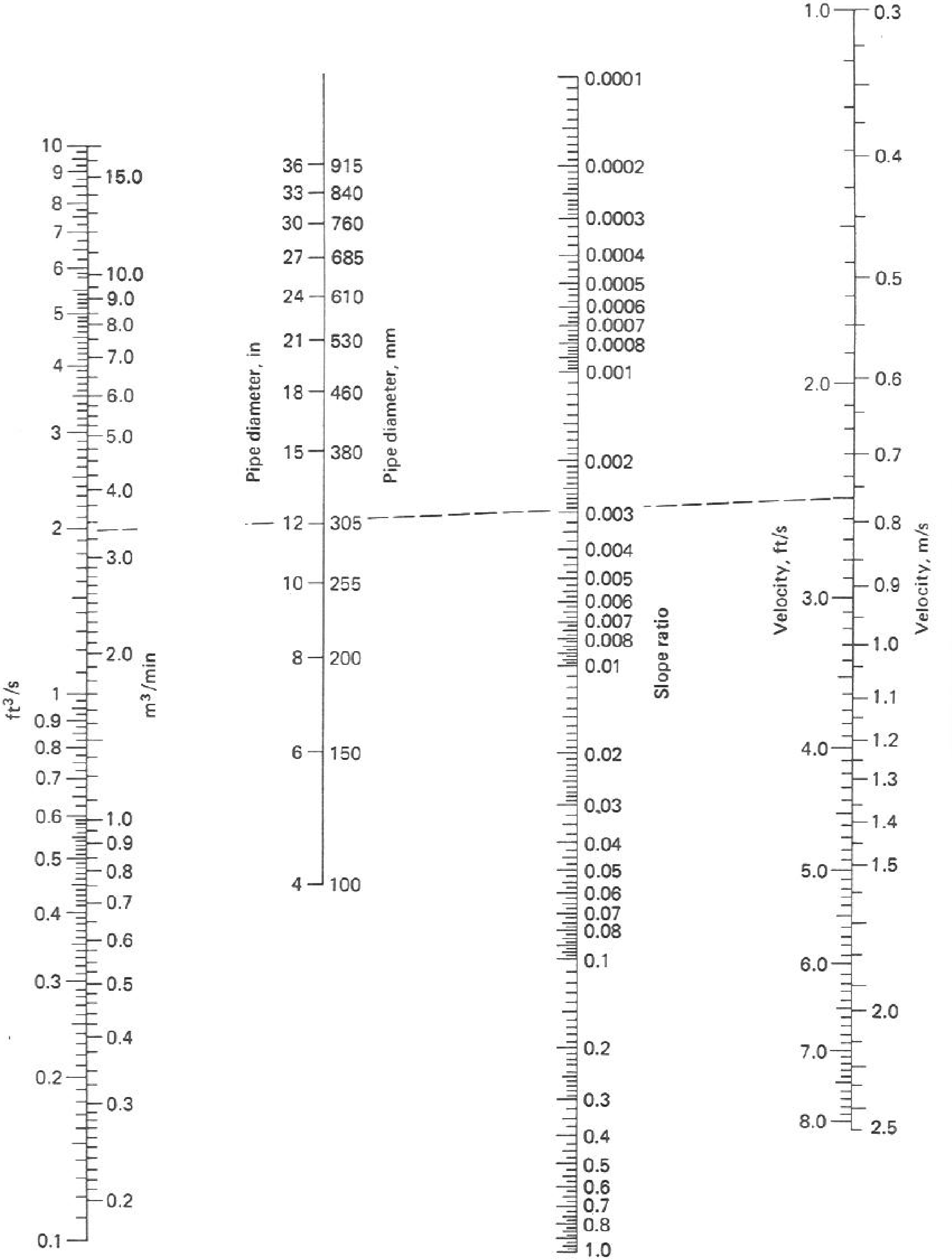
Question: A 24" sewer with a Manning's roughness coefficient of 0.015 is constructed on a grade of 0.013. Please determine the flow rate when the depth of flow is 15".



Nomogram for solution of Manning's equation for circular pipes flowing full (n = 0.013)



Nomogram for solution of Manning's equation for circular pipes flowing full (n = 0.013)



Nomogram for solution of Manning's equation for circular pipes flowing full (n = 0.013)

Example :

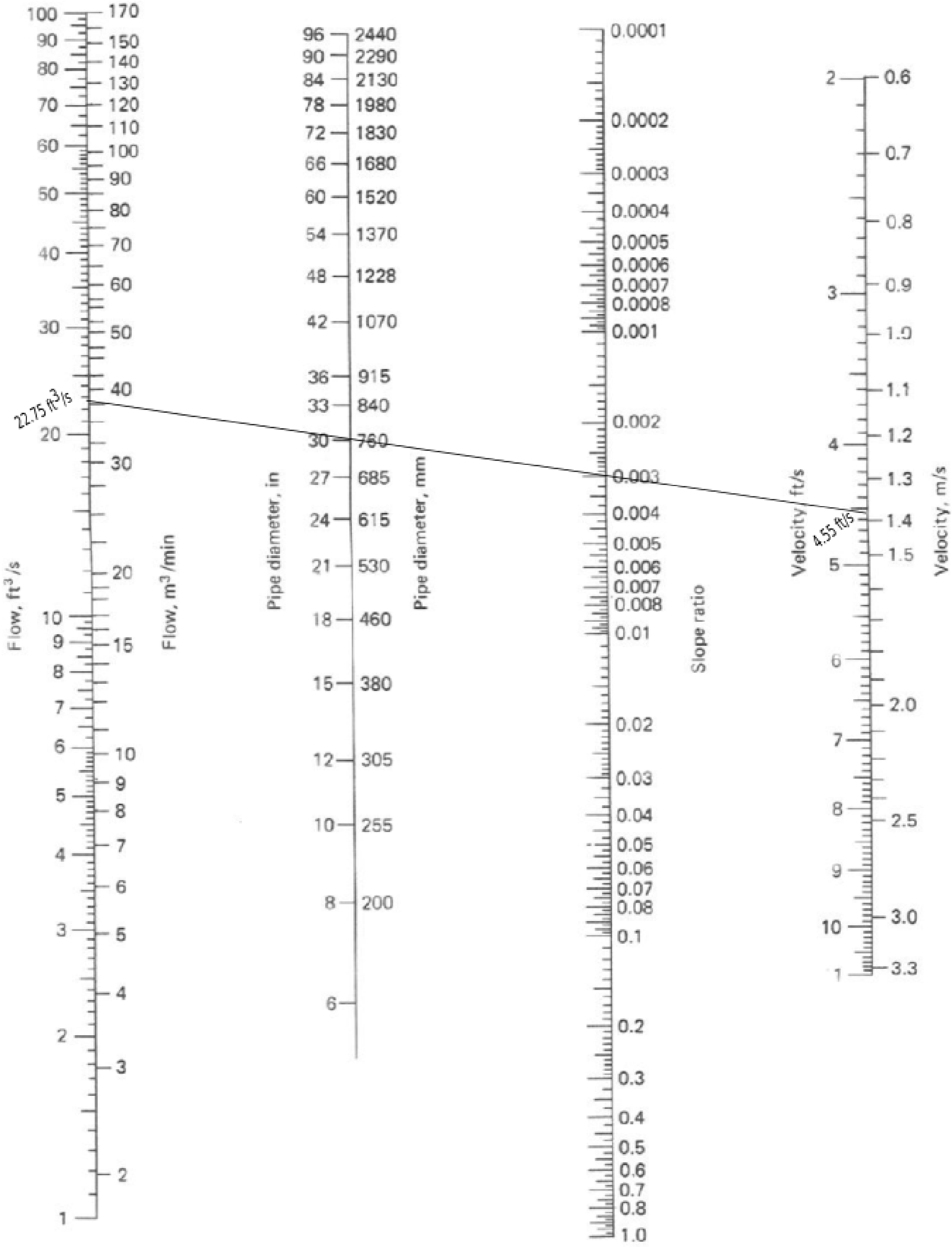
A 30" sewer is laid in a slope 0.003; what will be the depth of flow and velocity when the flow is 6.2 ft^3/sec. (Use the attached graphs and put them in your answer script)

Solution:

Step-1, use nomogram with data to solve Q_F and V_F for given D_F = 30″ and S = 0.003.

Q_F = 22.75 ft^3/s

V_F = 4.55 ft/s



Step 2: Calculate the flow ratio,

$$\frac{Q_P}{Q_F}=\frac{6.2(\text{from question})}{22.75(\text{from nomogram})}=0.27$$

Step 3: Use the hydraulic element diagram to determine the depth ratio.

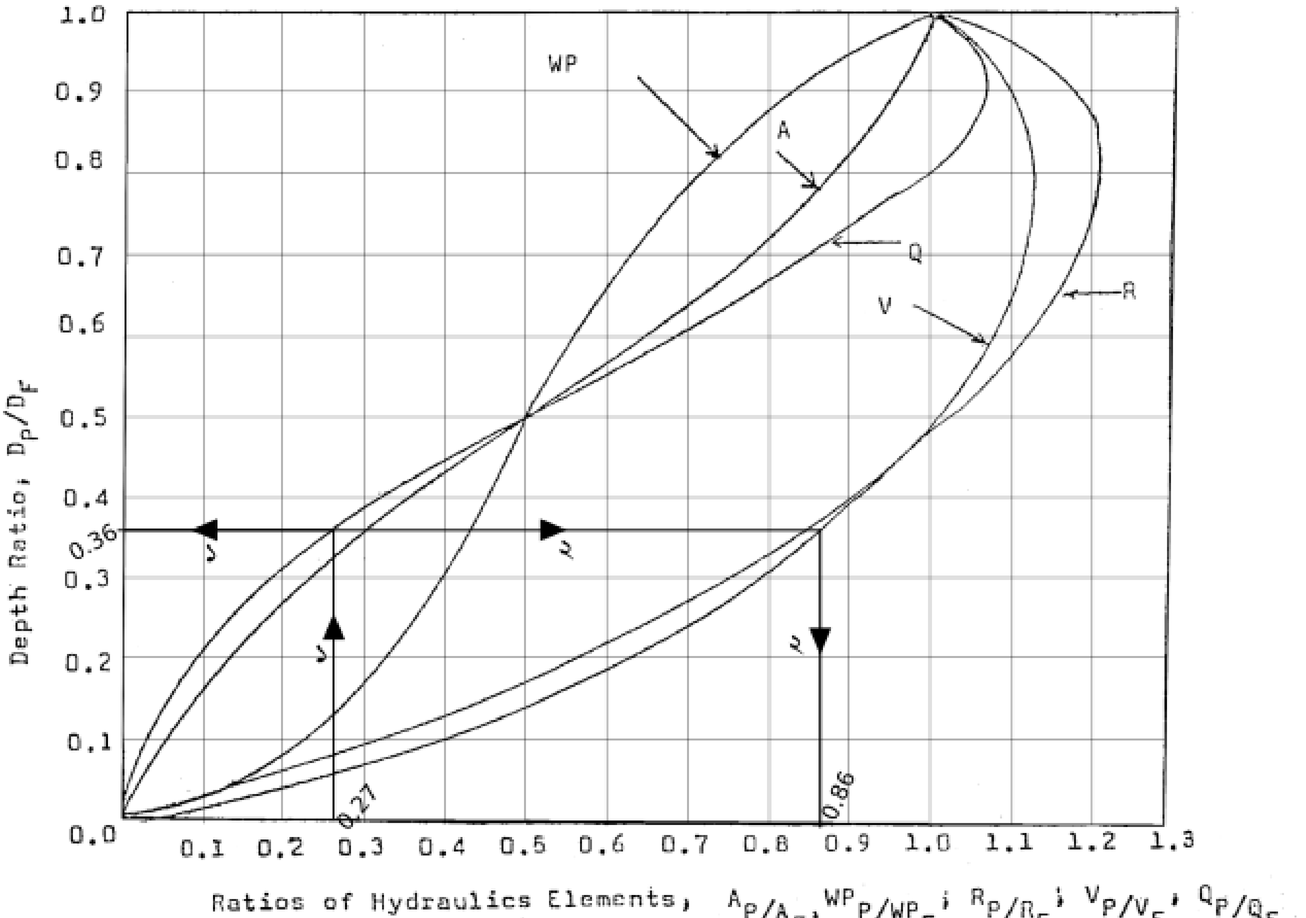


Fig. 5.3 Hydraulic Elements Diagrams

(At first put the value of Q_P/Q_F on x-axis and draw a vertical to the curve for Q. Than find the value of D_P/D_F on the y-axis.)

Here $D_P/D_F = 0.36$

$\therefore D_P = 0.36 \times D_F = 0.36 \times 30$ inch $= 10.8$ inch. **(Ans.)**

(Again, from $D_P/D_F = 0.36$ draw a horizontal line to reach the curve for V (velocity) to get V_P/V_F)

$V_P/V_F = 0.86$

$\therefore V_P = 0.86 \times V_F = 0.86 \times 4.55$ ft/s $= 3.91$ ft/s **(Ans.)**

Example :
A 18" sewer with a Manning's roughness coefficient of 0.015 is constructed on a grade of 0.013. Please determine the flow rate when the depth of flow is 12".

Solution:

Partial depth of flow (12") As given in the question

$$\theta = 2\cos^{-1}\left(1-\frac{2D_P}{D_F}\right) = 2\cos^{-1}\left(1-\frac{2\times 12}{18}\right) = 218.94^o$$

Converting inch (in) to feet (ft): divide the value by 12

$$\text{Wetted Perimeter}, P_w = \frac{\pi\theta D_F}{360} = \frac{\pi\times 218.94\times\frac{18}{12}}{360} = 2.866\ ft$$

$$\text{Wetted Area},\ A_w = \frac{D_F^2}{4}\left(\frac{\pi\theta}{360}-\frac{1}{2}\sin\theta\right) = \frac{\left(\frac{18}{12}\right)^2}{4}\left(\frac{\pi\times 218.94}{360}-\frac{1}{2}\sin 218.94\right) = 1.252\ ft^2$$

$$\text{Hydraulic radius},\ R = \frac{A_w}{P_w} = \frac{1.252}{2.866} = 0.437\ ft$$

$$\text{Velocity of flow},\ V = \frac{1.486}{n}\ R^{\frac{2}{3}}\ S^{\frac{1}{2}} = \frac{1.486}{0.015}\times(0.437)^{\frac{2}{3}}\times(0.013)^{\frac{1}{2}} = 6.501\ ft/sec$$

$$\text{Flow rate},\ Q = AV = 1.252\times 6.501 = 8.137\ ft^3/sec$$ **(Ans.)**