Water amd wastewater treatemt
Hydraulics

2111
2005

NORWEGIAN UNIVERSITY OF LIFE SCIENCES

Hydraulics

- Objective
  - Analysis of pipe flow system
  - Head losses in pipes
  - Flow measurements
  - Small diameter gravity and vaccum sewers
  - Introduction to tutorial questions

Pipe flow analysis

The Bernoulli's Equation

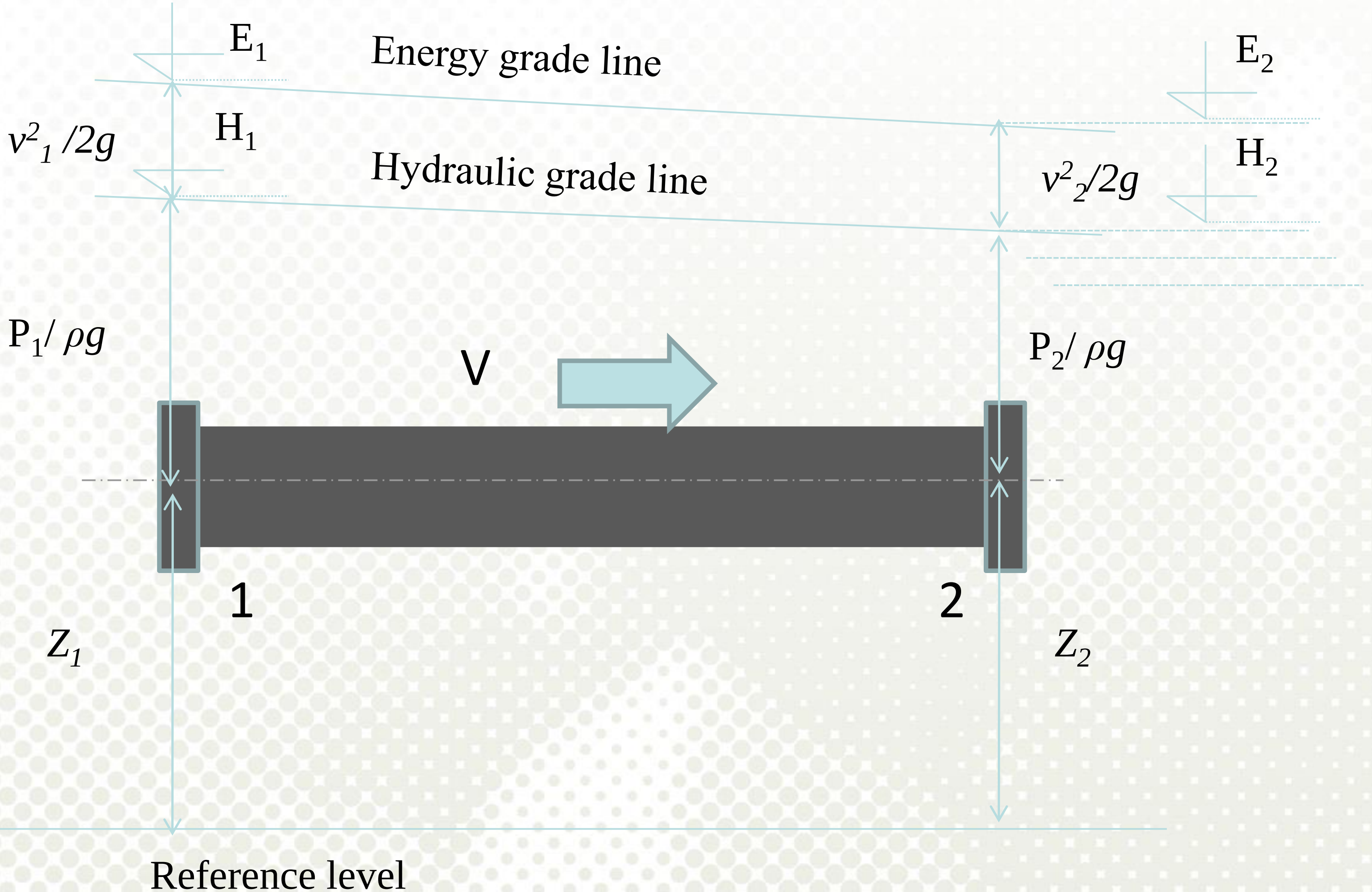
$$E_1 = E_2 \pm \Delta E$$

$$P_1/\rho g + v^2_1/2g + Z_1 = P_2/\rho g + v^2_2/2g + Z_2 \pm \Delta E$$

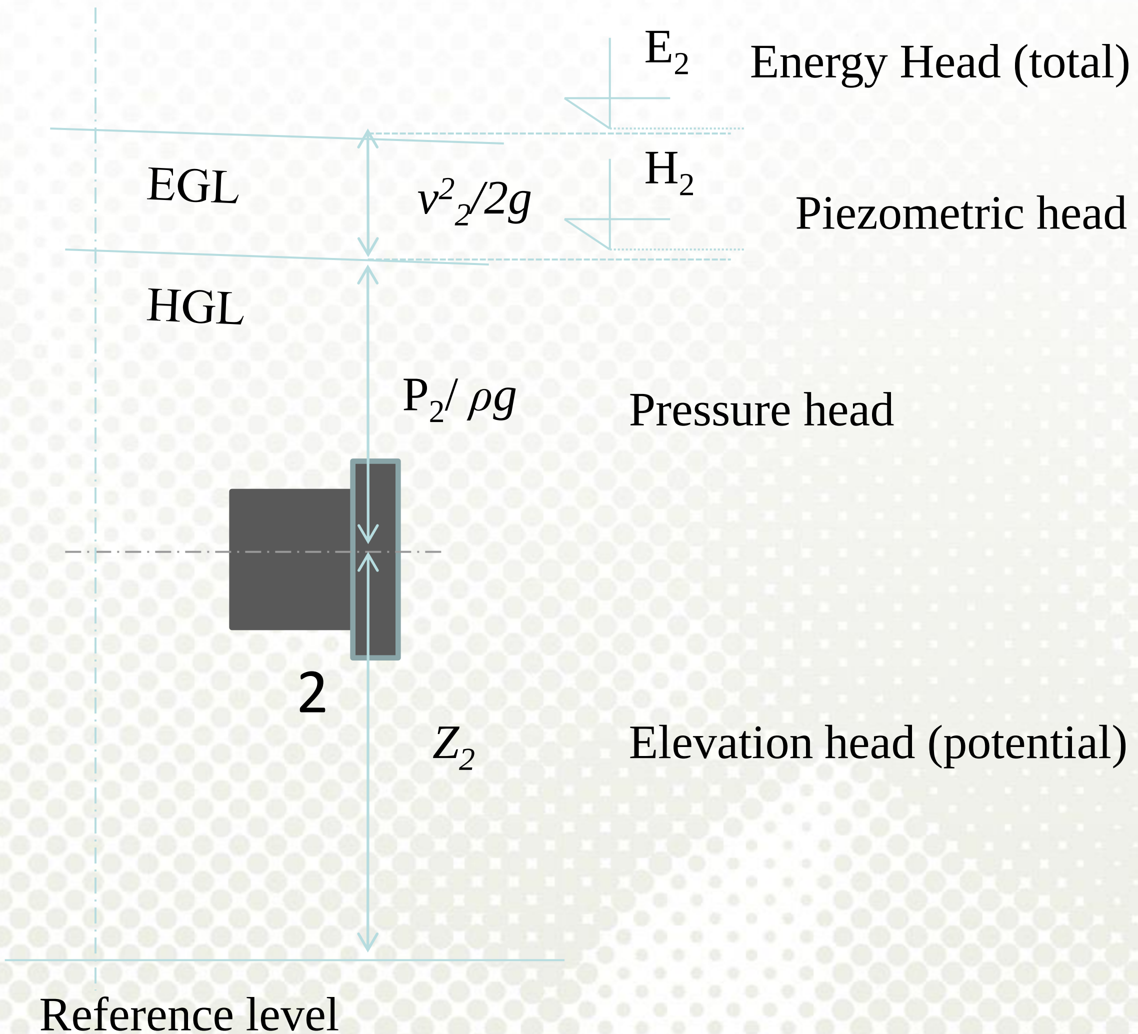
Bernoulli's equation

- BE is used in analysis of pipe flow
- It states that total energy remains constant along a stream line (That is total head is constant)
- It uses certain assumptions
  - Flow is steady
  - Fluid is incompressible
  - Valid at two points along a single streamline
- **The hydraulic grade and the energy line are graphical presentations of the Bernoulli' s equation (BE)**

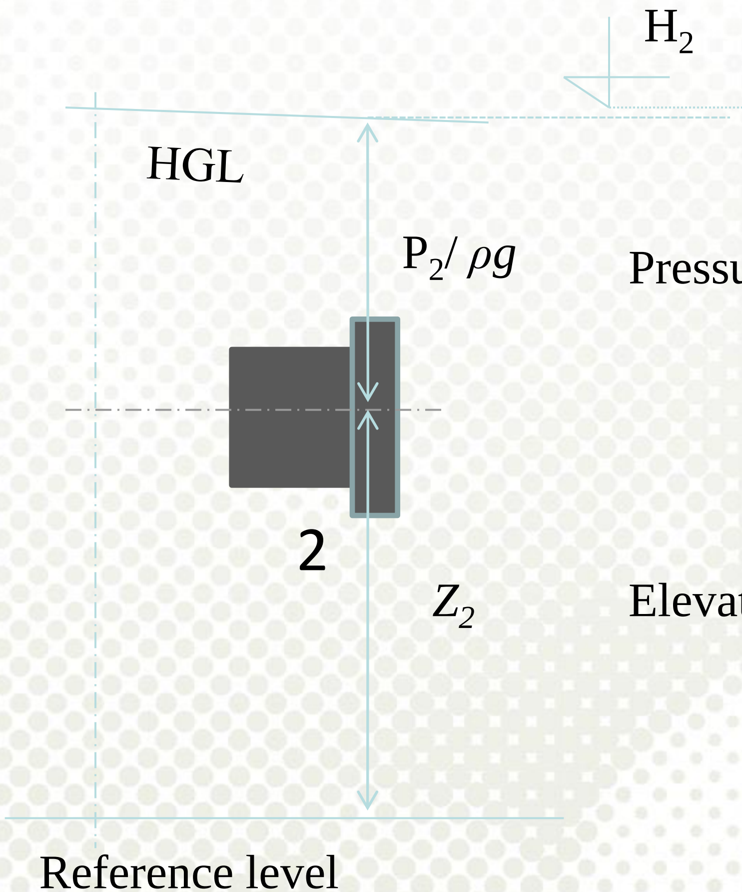
Energy and hydrulic grade line



Energies, Head



Energies, Heads



Piezometric head

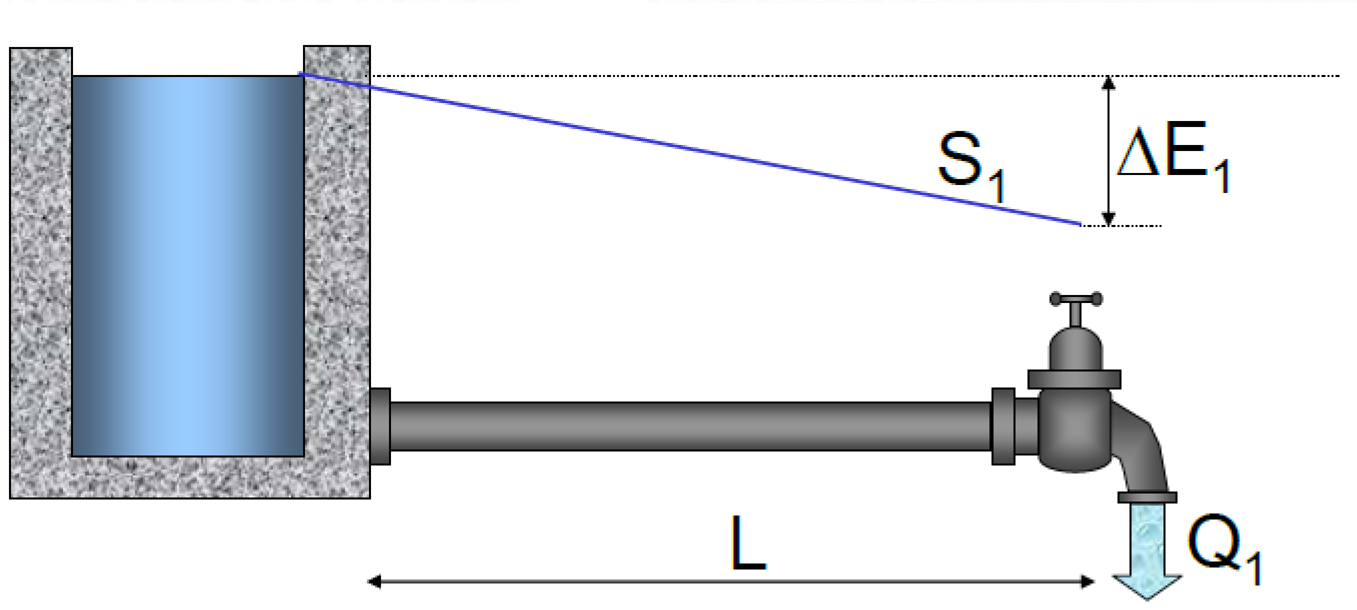
Pressure head

Velocity head neglected except well above 1 m/s (example: pumping stations)

Elevation head (potential)

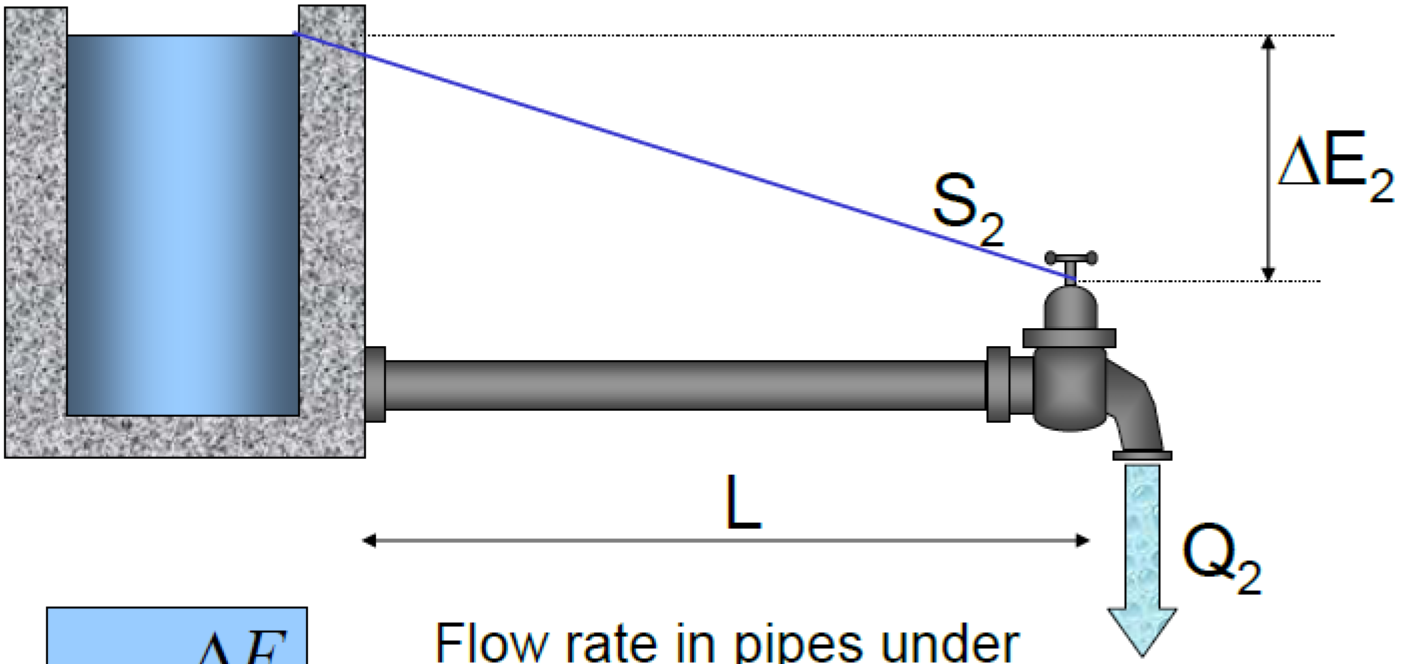
Hydraulic gradient

Slope of the hydraulic grade line



Hydraulic gradient

Slope of the hydraulic grade line

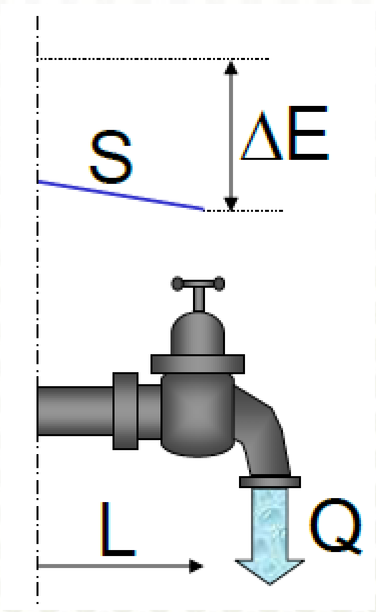


$$S = \frac{\Delta E}{L}$$

Flow rate in pipes under pressure is related to the hydraulic gradient!

Hydraulic losses

Friction, minor



ΔE results from a friction between the water and the pipe wall, and /or a turbulence developed by obstructions of the flow

$$\Delta E = h_f + h_m = R_f Q^{n\,(f)} + R_m Q^{n\,(m)}$$

$h_{f,m}$ = Friction, Minor loss (respectively)
R_f,m = Pipe resistance
Q = Flow
$n_{f,\,m}$ = exponents

NORWEGIAN UNIVERSITY OF LIFE SCIENCES

Friction Losses

- Darcy- Weisbach

$$h_f = R_f Q^{n_f} = \frac{8\lambda L}{\Pi^2 g D^5} Q^2 = \frac{\lambda L}{12.1 D^5} Q^2$$

  - λ = Friction factor (-)
  - L = Pipe length (m)
  - D = Pipe diameter (m)
  - Q = Pipe flow (m^3 /s)
  - Or propotional to the kinetic energy

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

Friction factor

Friction factor, λ is the most important parameter in the Darcy-weisbach equation

– Is the complex function of the Reynolds number and relative roughness

Reynolds Number

$$R_e = \frac{VD}{\nu}$$

V = Flow velocity (m/s)
D = Pipe diameter (m)
ν = Kinematic viscosity (m^2/s)

$$\nu = \frac{497 \times 10^{-6}}{(T + 42.5)^{1.5}}$$

Temperature, T(^{0} C)

Flow regime

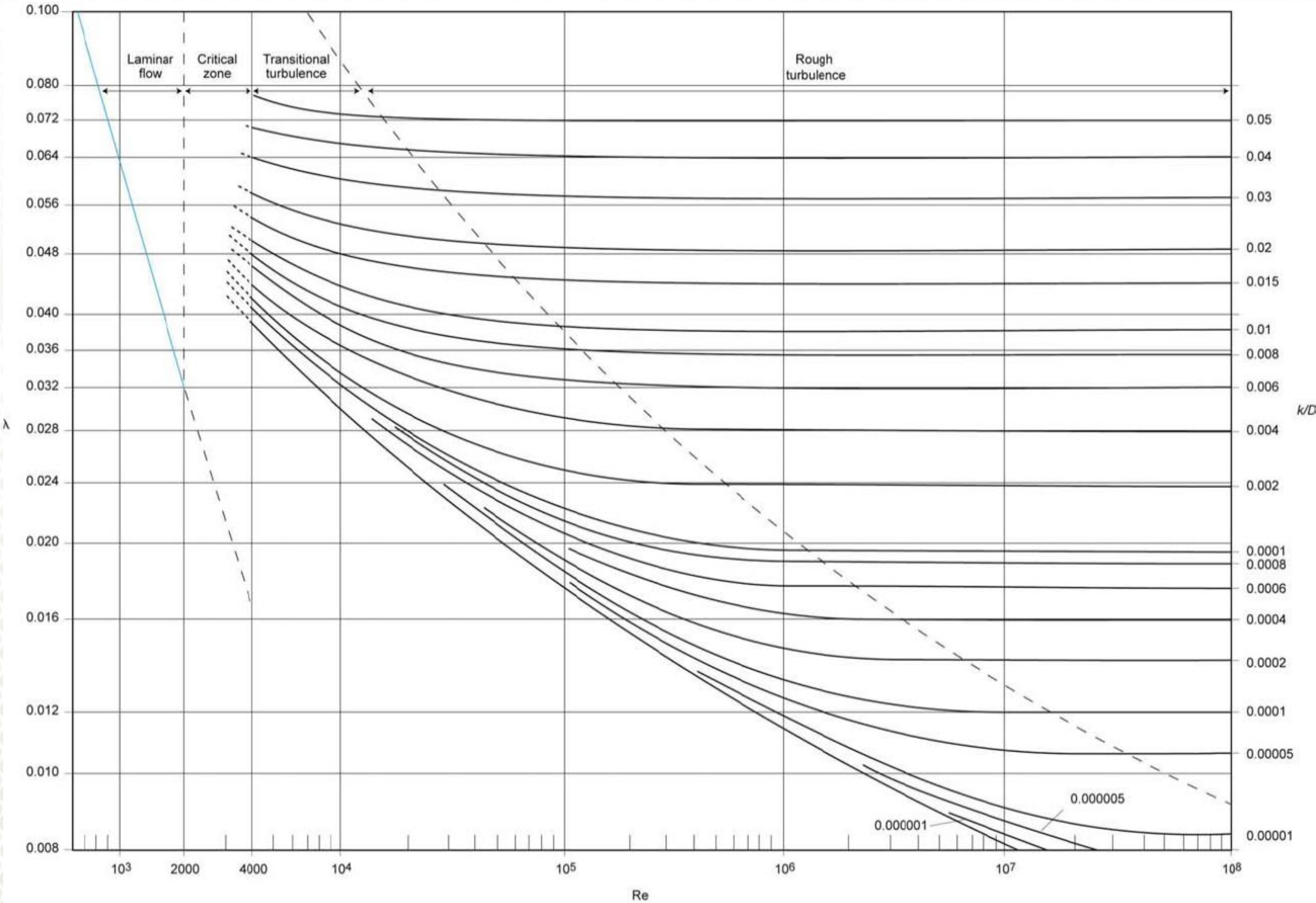
- Laminar flow – R_e falls under 2000
- Transitional zone - R_e falls between 2000 and 4000
- Turbulent flow - R_e above 4000
- For Laminar flow
- $\lambda = 64/ R_e$

Choice for rough pipes

- There are empirical formula and diagrams to determine friction factor (f) depending on the pipe roughness and Reynolds Number
  - Moody diagram
  - Colebrook-white equations etc.

Department of Plant and Environmental Sciences
NORWEGIAN UNIVERSITY OF LIFE SCIENCES

The Moody diagram



NORWEGIAN UNIVERSITY OF LIFE SCIENCES

Absolute rougness

Pipe material	k (mm)
Asbestos cement	0.015 - 0.03
Galvanised/Coated cast iron	0.03 - 0.15
Uncoated cast iron	0.15 - 0.6
Ductile iron	0.03 - 0.06
Uncoated steel	0.015 - 0.06
Coated steel	0.03 - 0.15
Concrete	0.06 - 1.5
Plastic, PVC, PE	0.02 - 0.05
Glass fibre	0.06
Brass, cooper, lead	0.003

Source: Wessex Water, 1993

Friction losses

- Hazen –Williams

$$h_f = R_f Q^{n_f} = \frac{10.68L}{C^{1.852} D^{4.87}} Q^{1.852}$$

Or

$$V = 0.85 \times C \times R^{0.63} \times S^{0.54}$$

L = Pipe length (m)
C = Hazen-Williams factor
D = Pipe diameter (m)
Q = Pipe flow (m^3 /s)
R = Hydrualic Radius (flow area/wetted perimeter)
S = Slope of energy grade line = h_f /L

Hazen-Williams Factors

Pipe material / D (mm)	75	150	300	600	1200
Uncoated cast iron	121	125	130	132	134
Coated cast iron	129	133	138	140	141
Uncoated steel	142	145	147	150	150
Coated steel	137	142	145	148	148
Galvanised iron	129	133	-	-	-
Uncoated asbestos cement	142	145	147	150	-
Coated asbestos cement	147	149	150	152	-
Concrete, min. values	69	79	84	90	95
Concrete, max. values	129	133	138	140	141
Prestressed concrete	-	-	147	150	150
PVC, brass, cooper, lead	147	149	150	152	153
Wavy PVC	142	145	147	150	150
Bitumen/cement lined	147	149	150	152	153

Source: Bhave, 1991

Friction losses

- Manning

$$h_f = R_f Q^{n_f} = \frac{10.29 n^2 L}{D^{16/3}} Q^2$$

or

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

L = Pipe length (m)
n = mannings factor ($m^{-1/3}$ s)
D = Pipe diameter (m)
Q = Pipe flow (m^3 /s)
R = Hydrualic Radius (flow area/wetted perimeter)
S = Slope of energy grade line = h_f /L

Manning factor

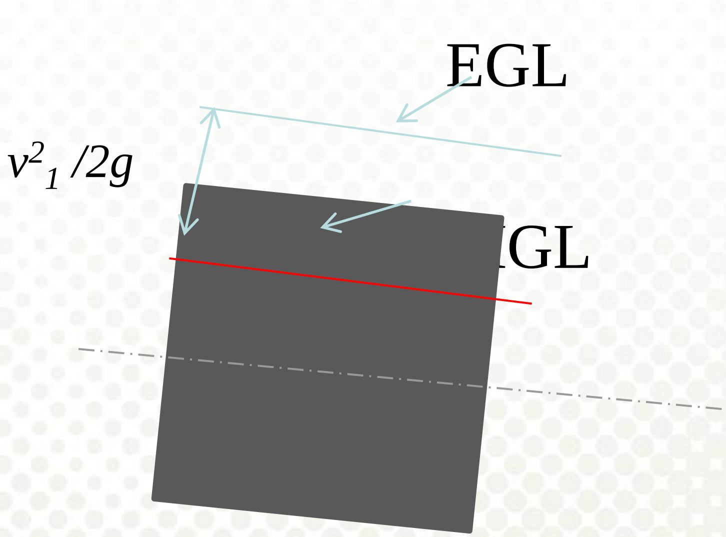
Pipe material	N ($m^{-1/3}s$)
PVC, brass, lead, copper, glass fibre	0.008 - 0.011
Prestressed concrete	0.009 - 0.012
Concrete	0.010 - 0.017
Welded steel	0.012 - 0.013
Coated cast iron	0.012 - 0.014
Uncoated cast iron	0.013 - 0.015
Galvanised iron	0.015 - 0.017

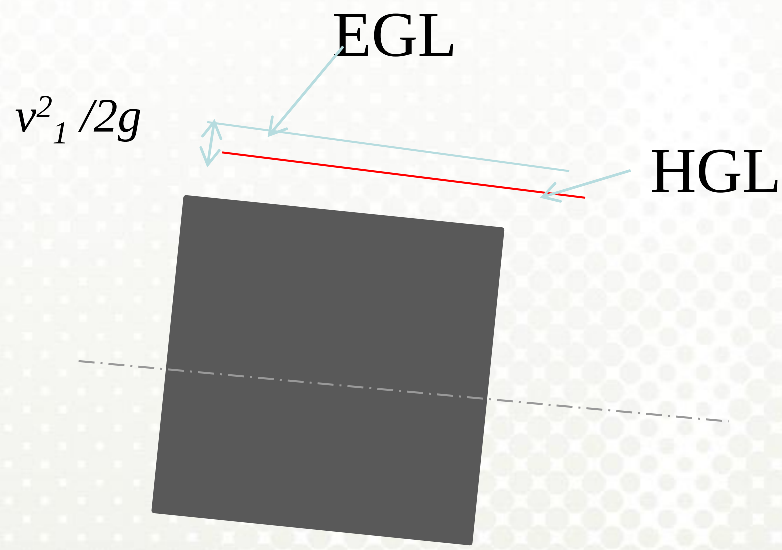
Source: Bhave, 1991

The best formula ?

- Darcy-weisbach – the most accurate
- Hazen-williams- (straight forward and simpler (friction coefficient not function of diameter or velocity), suitable for smooth pipes not attacked by corrosion)
- Mannings- straight forward, suitable for rough pipes, commonly applied for open channel flows

Difference between pressure flow and open channel flow

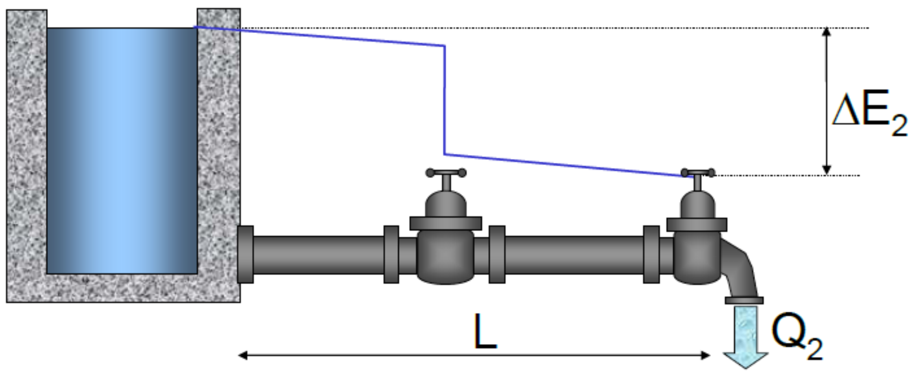




Open channel flow (in large gravity sewer)

Pressure flow

Minor losses



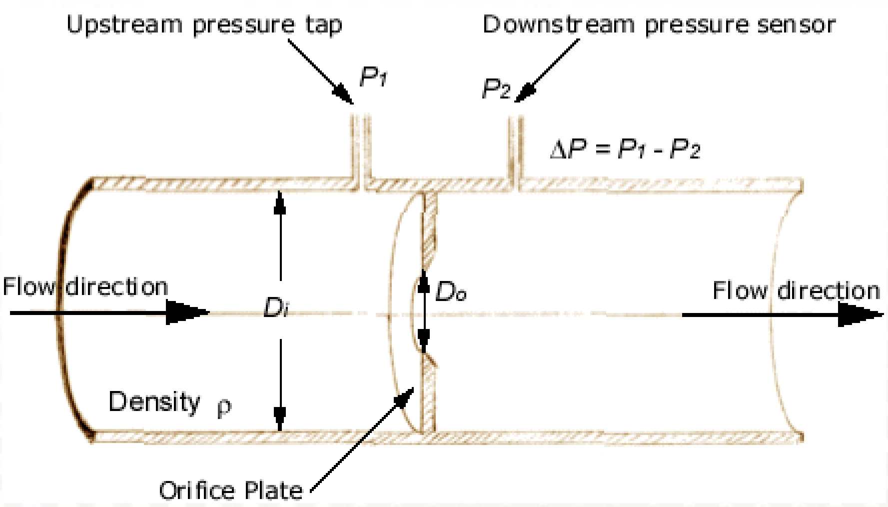
Given by
$h_f = k V^2 / 2g$
K determined experimentally for various fittings

Values of K for various fittings:

Valve (fully open) $\longrightarrow$ 2
Tee $\longrightarrow$ 0.2 – 2.0
Bend $\longrightarrow$ 1.2

Flow measurements in pipes

- Orifice plates



$$Q = CA_2\left(2\frac{P_2 - P_1}{\rho}\right)^{0.5}$$

- Where C = discharge coefficient

Flow measurements in open channel flow

- Sharp crested weir

$$Q = \frac{2}{3} C_d L (2g)^{0.5} H^{1.5}$$

- L = Length of weir, m
- C_d = discharge coefficient

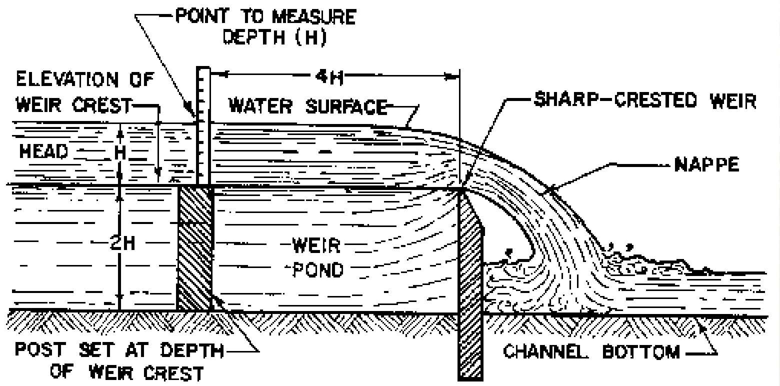


FIGURE 1.– PROFILE OF A SHARP-CRESTED WEIR

Small diameter sewer collection system

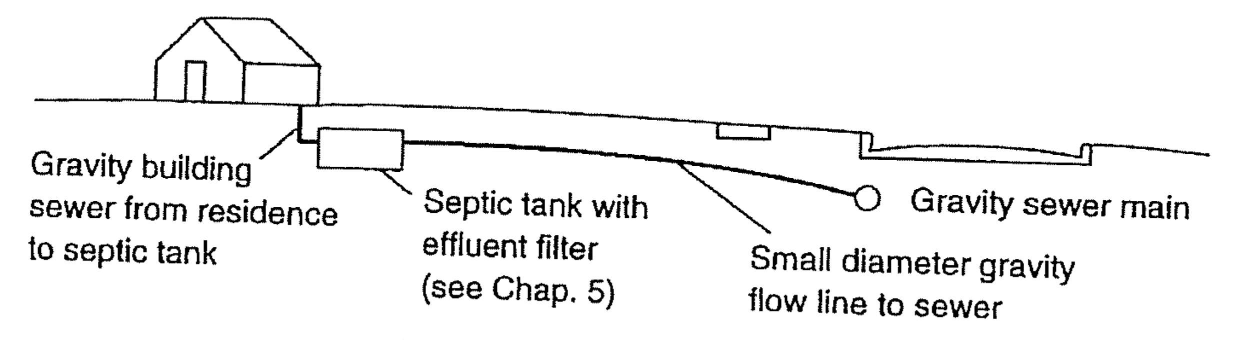
- Transport sewage to treatment or disposal point

- Size and length of sewer depends upon the type of sewerage system (centralised or decentralised)

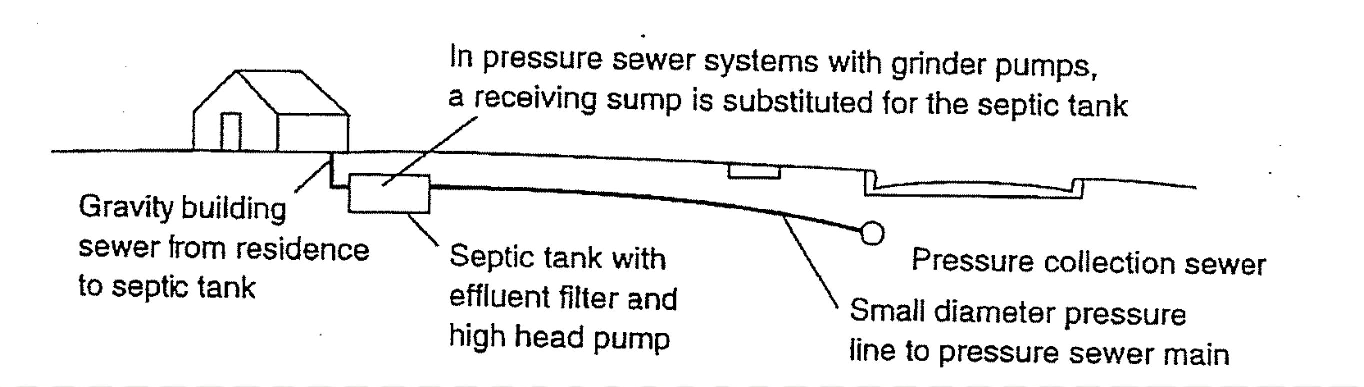
- Need sufficient velocity to transport sewage

Small diameter sewer network

- Septic tank effluent gravity (STEG)

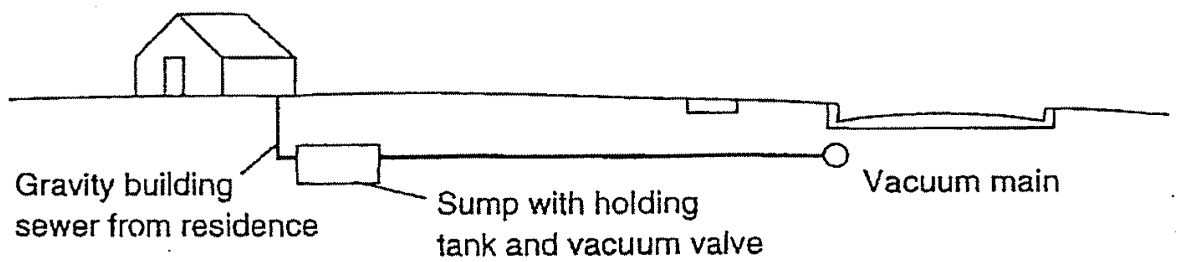


- Septic tank effluent pump (STEP) and pressure sewer with grinder pumps



Small diameter sewer network

- Vacuum sewer



Friction losses

Hazen –Williams formula based on actual flow area- so inside pipe diameter is used.

Hazen –Williams

$$h_f = R_f Q^{n_f} = \frac{10.68L}{C^{1.852} D^{4.87}} Q^{1.852}$$

Or

$$V = 0.85 \times C \times R^{0.63} \times S^{0.54}$$

L = Pipe length (m)
C = Hazen-Williams factor
D = Pipe diameter (m)
Q = Pipe flow (m^3 /s)
R = Hydrualic Radius (flow area/wetted perimeter)
S = Slope of energy grade line = h_f /L

Design and layout of collection system

- Information required
  - –Topography of the area
  - –Depth of soil
  - –Depth of water table
  - –Depth of freezing zone
  - –Amount (daily minimum, average and peak flow rates)
  - –Population growth rate

Excersise-Sewer collection system

- Prepare a profile
- Select a pipe size
- Calculate the velocity
- Calculate the pipe cross sectional area and determine the actual capacity
- Check for the surcharged condition

NORWEGIAN UNIVERSITY OF LIFE SCIENCES

Friction Losses

Hazen –Williams

$$h_f = R_f Q^{n_f} = \frac{10.68L}{C^{1.852} D^{4.87}} Q^{1.852}$$

Or

$$V = 0.85 \times C \times R^{0.63} \times S^{0.54}$$

L = Pipe length (m)
C = Hazen-Williams factor
D = Pipe diameter (m)
Q = Pipe flow (m^3 /s)
R = Hydrualic Radius (flow area/wetted perimeter)
S = Slope of energy grade line = h_f /L

Pipe selection

TABLE 6-4

Nominal pipe sizes with outside and inside diameters for PVC pipe

Nominal pipe size, in	Outside diameter, in	Inside diameter, in		
		Schedule 40	Schedule 80	Class 200
$\frac{1}{2}$	0.840	0.622	0.546	
$\frac{3}{4}$	1.050	0.824	0.742	0.930
1	1.315	1.049	0.957	1.189
$1\frac{1}{2}$	1.900	1.610	1.500	1.720
2	2.375	2.067	1.939	2.149
$2\frac{1}{2}$	2.875	2.469	2.323	2.601
3	3.500	3.068	2.900	3.166
4	4.500	4.026	3.826	4.072
6	6.625	6.065	5.761	5.993
8	8.625	7.981	7.625	7.805
10	10.750	10.020	9.564	9.728
12	12.750	11.938	11.376	11.538

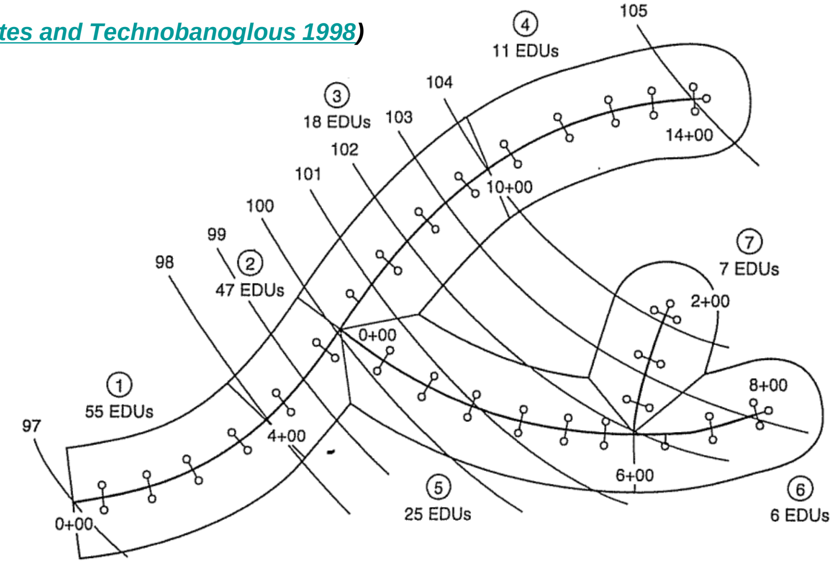
Crites and Technobanoglous 1998)

NORWEGIAN UNIVERSITY OF LIFE SCIENCES

EXAMPLE 6-1. LAYOUT AND DESIGN OF STEG SEWER COLLECTION MAIN. Design a STEG sewer collection main to serve a small development of 55 EDUs (equivalent dwelling units), as shown in the plan view given below. Septic tank effluent will flow by gravity through the small-diameter gravity collection system. Assume the following conditions apply:

1. Design peak flowrate = (0.5 gal/EDU·min)(number of EDUs)
2. Pipeline material = Class 200 PVC pipe (see Tables 6-4 and 6-5)
3. Hazen-Williams coefficient = 150
4. Minimum nominal pipe size = 2 in

Crites and Technobanoglous 1998)

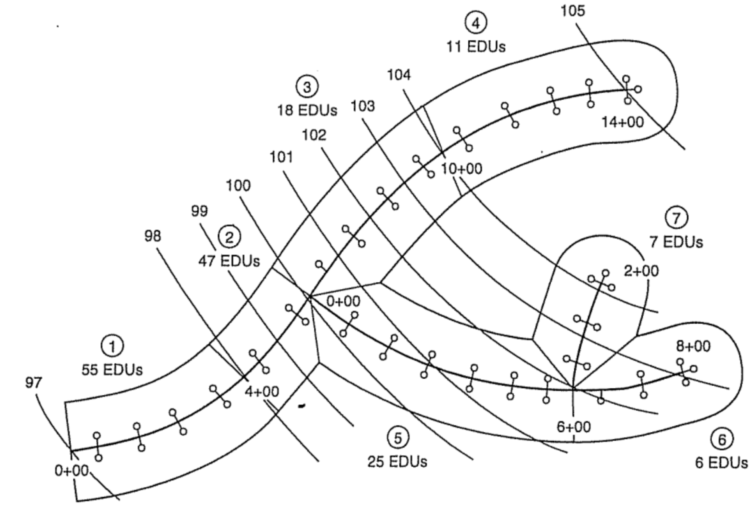


Design of STEP sewer

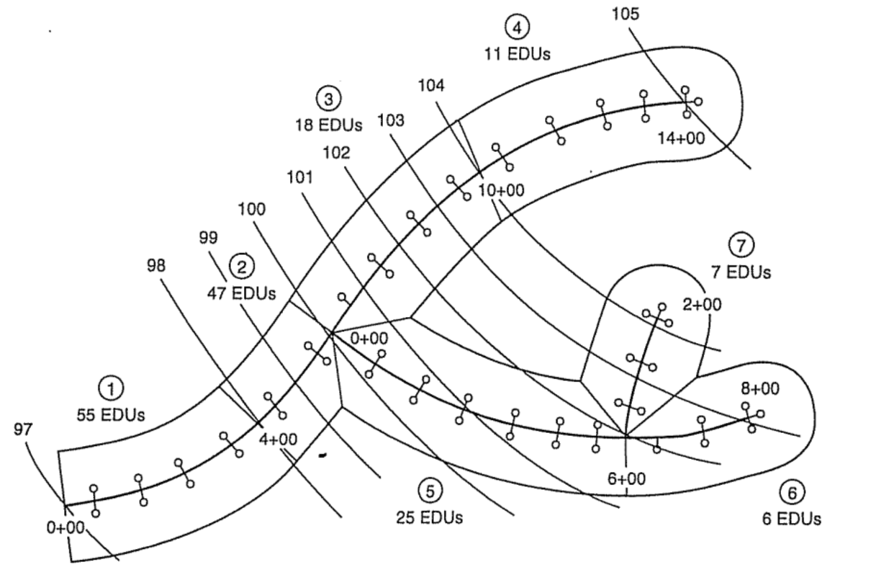
Design of STEP for a small community as shown in plan view below.

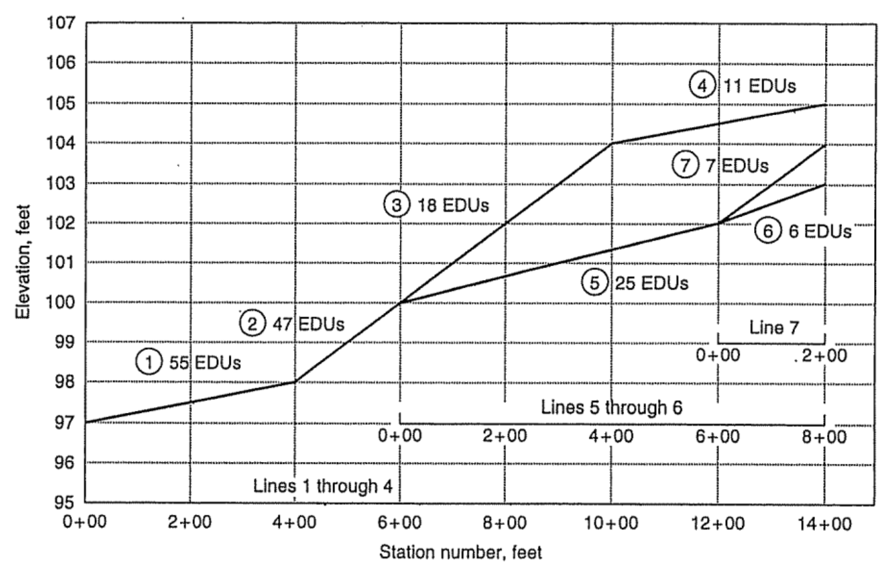
The informations given are:

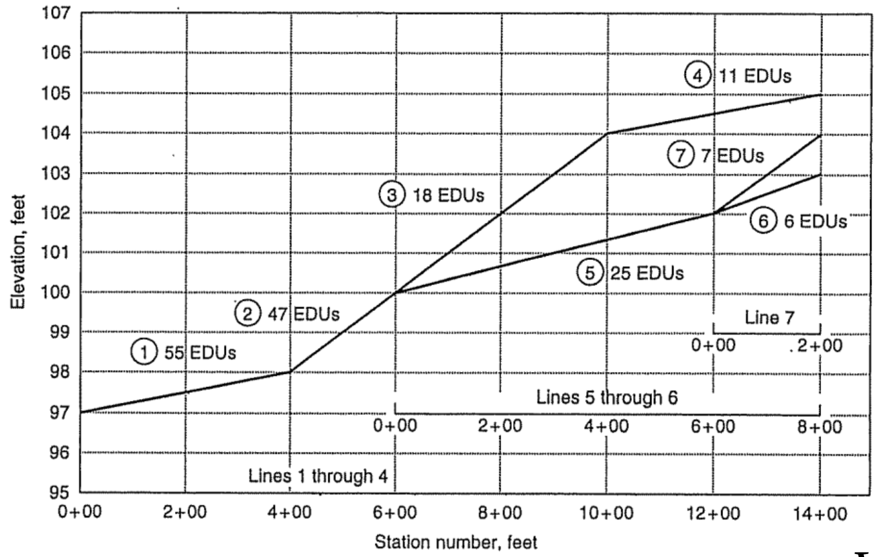
1. Design peak flowrate = (0.5 gal/EDU·min)(number of EDUs)
2. Pipeline material = Class 200 PVC pipe (see Tables 6-4 and 6-5)
3. Hazen-Williams coefficient = 150
4. Minimum nominal pipe size = 2 in



NORWEGIAN UNIVERSITY OF LIFE SCIENCES







1.31English unit !!!!!!!!

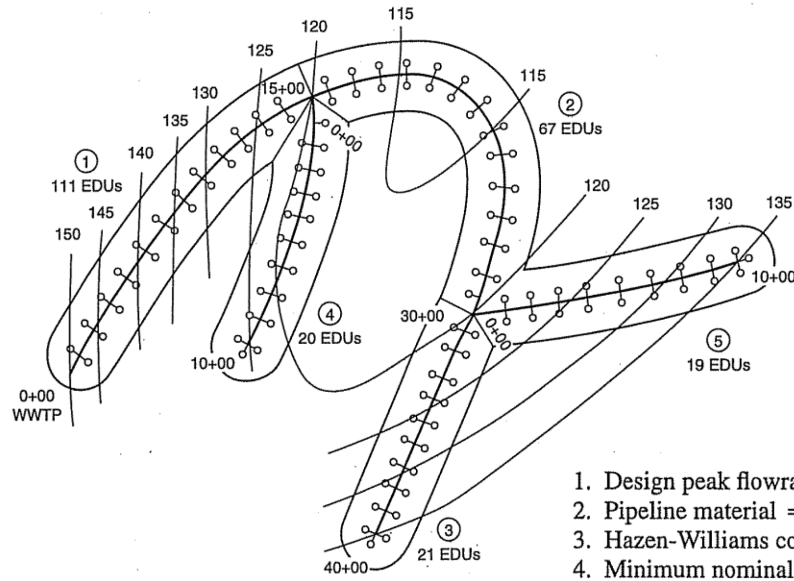
$$V = 0.85 \times C \times R^{0.63} \times S^{0.54}$$

R = D/4

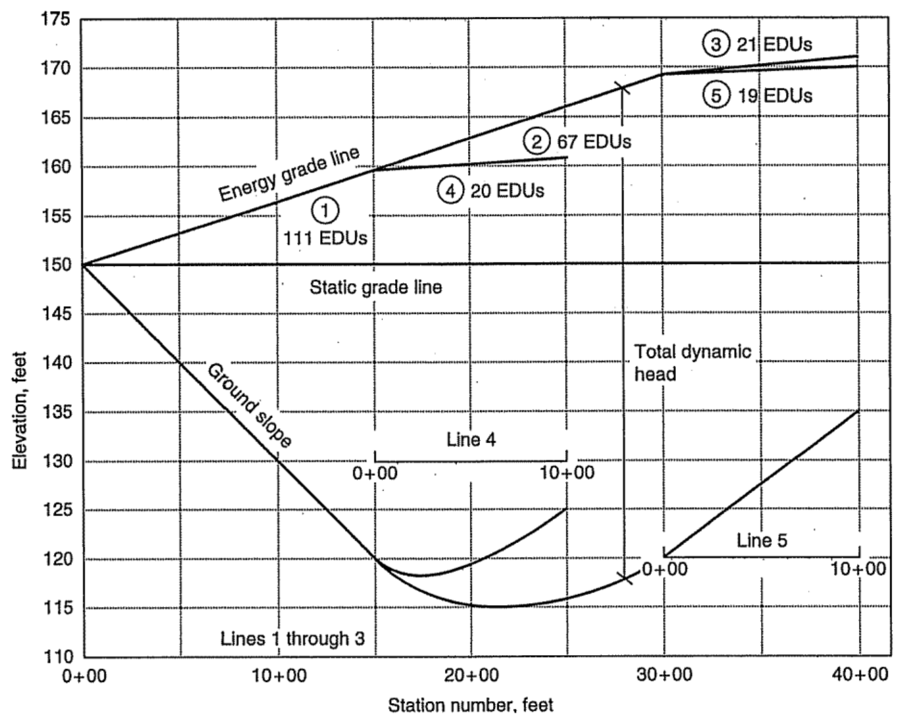
Hydraulic computations for a STEG sewer collection system

Pipe number (1)	Cumulative EDUs (2)	Design flow, gal/min (3)	Upstream station (4)	Downstream station (5)	Length, ft (6)	Upstream elevation, ft (7)	Downstream elevation, ft (8)
1	55	27.5	4+00	0+00	400	98	97
2	47	23.5	6+00	4+00	200	100	98
3	18	9.0	10+00	6+00	400	104	100
4	11	5.5	14+00	10+00	400	105	104
5	25	12.5	12+00	6+00	600	102	100
6	6	3.0	8+00	6+00	200	103	102
7	7	3.5	2+00	0+00	200	104	102

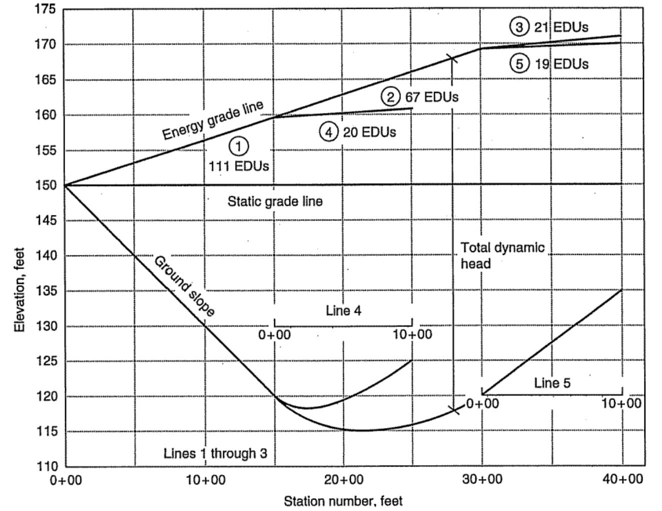
Pipe number (1)	Elevation drop, ft (9)	Slope, ft/ft (10)	Nominal diameter, in (11)	Inside diameter, in (12)	Velocity, ft/s (13)	Cross-sectional area, in^2 (14)	Pipe capacity, gal/min (15)	Ratio of design flow to pipe capacity (16)
1	1.0	0.0025	3.0	3.166	1.40	7.87	34.4	0.80
2	2.0	0.0100	2.0	2.149	2.32	3.63	26.3	0.89
3	4.0	0.0100	2.0	2.149	2.32	3.63	26.3	0.34
4	1.0	0.0025	2.0	2.149	1.10	3.63	12.4	0.44
5	2.0	0.0033	2.0	2.149	1.28	3.63	14.5	0.86
6	1.0	0.0050	2.0	2.149	1.60	3.63	18.1	0.17
7	2.0	0.0100	2.0	2.149	2.32	3.63	26.3	0.13



1. Design peak flowrate = (0.5 gal/EDU·min)(number of EDUs)
2. Pipeline material = Class 200 PVC pipe (see Tables 6-4 and 6-5)
3. Hazen-Williams coefficient = 150
4. Minimum nominal pipe size = 2 in



NORWEGIAN UNIVERSITY OF LIFE SCIENCES



$$h_f = \frac{10.68L}{C^{1.852}D^{4.87}}Q^{1.852}$$

L

Slope should be 0.5 to 1.5 %

If too low -pipe is oversized

Hydraulic computations for a STEP pressure collection system

Pipe number (1)	Cumulative EDUs (2)	Design flow, gal/min (3)	Upstream station (4)	Downstream station (5)	Length, ft (6)	Nominal diameter, in (7)
1	111	55.5	15+00	0+00	1500	3.0
2	67	33.5	30+00	15+00	1500	2.5
3	21	10.5	40+00	30+00	1000	2.0
4	20	10.0	10+00	0+00	1000	2.0
5	19	9.5	10+00	0+00	1000	2.0

Pipe number (1)	Inside diameter, in (8)	Slope of EGL, % (9)	Cross-sectional area, in² (10)	Velocity, ft/s (11)	Headloss, ft (12)
1	3.166	0.61	7.87	2.26	9.1
2	2.601	0.62	5.31	2.02	9.4
3	2.149	0.18	3.63	0.93	1.8
4	2.149	0.17	3.63	0.88	1.7
5	2.149	0.15	3.63	0.84	1.5

Design flow/CA of pipe

EGL/100 *L

Plot EGL – begin from D/S

References

Water supply and Sewerage – Terence J McGhee
Chapter 3 (Page 24 – 61) (IHNALibrary catlog No. 628.1 MCG)

Crites, R. and G. Technobanoglous (1998). Small and decentralized wastewater management systems, McGraw-Hill. (Chapter 6)

Advanced Water Distribution Modelling and Management by Haestad and et al. (Chapter 2.3, 2.4, 2.5, 2.6)
(IHNALibrary catlog No. 628.1)

THANK YOU