Water supply and sanitation systems

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Chapter 1: Introduction

Main principles of Environment Engineering

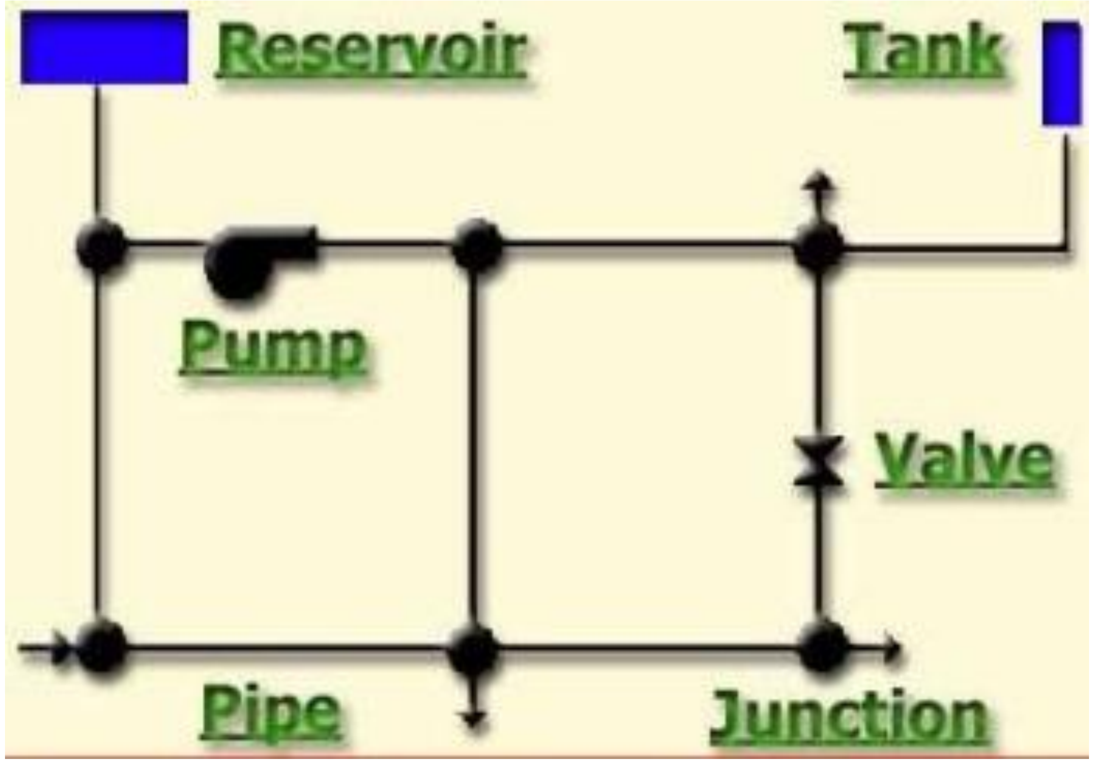
- Provision of safe, tasty and sufficient public water supply.
- Proper handling, disposal or recycling of wastewater and solid waste.
- Control of water, soil, atmospheric pollution and noise pollution.

Water Distribution Networks (WDNs)

A water distribution network (WDN) is comprised of a number of links (mainly pipes) connected together (at nodes) to form loops and/or branches

The links represent in general pipes, pumps, fittings, valves, etc.

Loops: closed circuits that consist of a series of links in which the nodes are supplied from more than one pipe

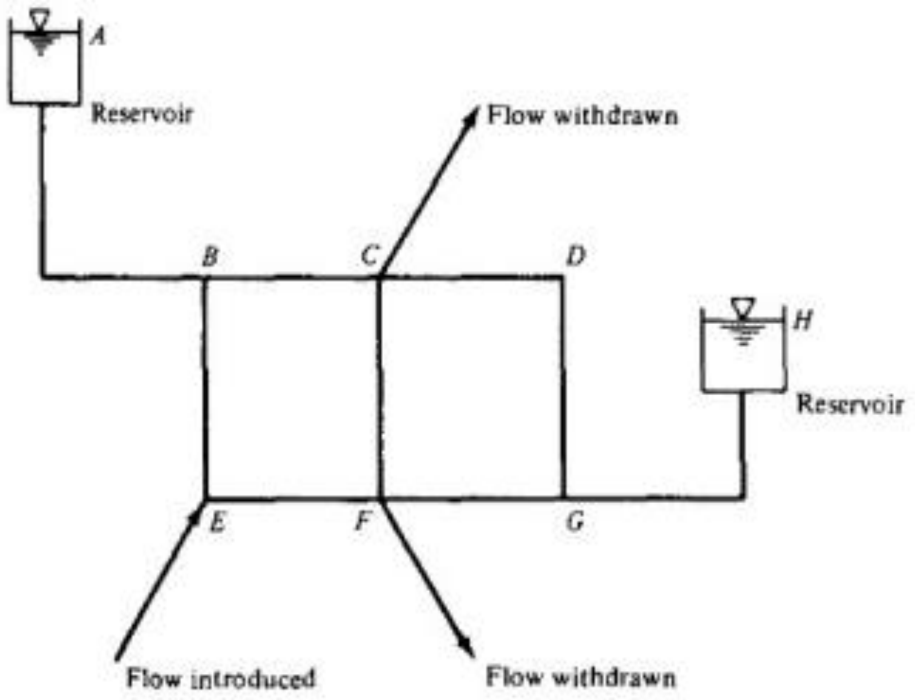


Water Distribution Networks (WDNs)

Nodes: They are the end edges of the pipes where two or more pipes are joined.

Water can enter or leave the network at these nodes.

The reservoirs are considered fixed-head nodes where the head can be assumed constant.



What is the Analysis of WDNs?

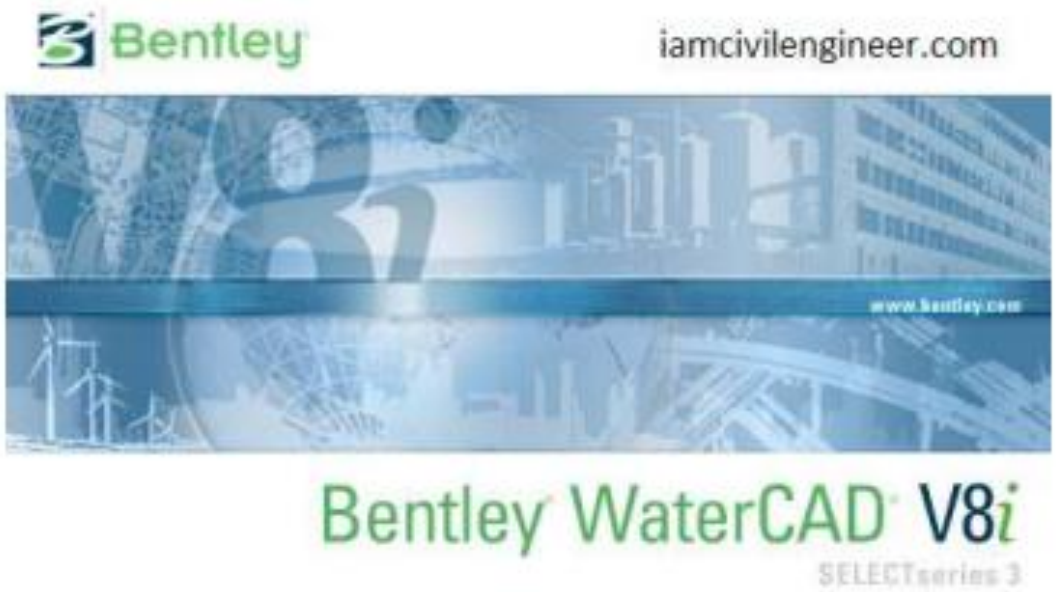
Analysis of WDNs implies obtaining the following:

- **Water velocities in pipes**
- **Water pressure at nodes.**

Network analysis is called simulation.

There are several methods to solve the network equations among which is for instance Hardy Cross Method.

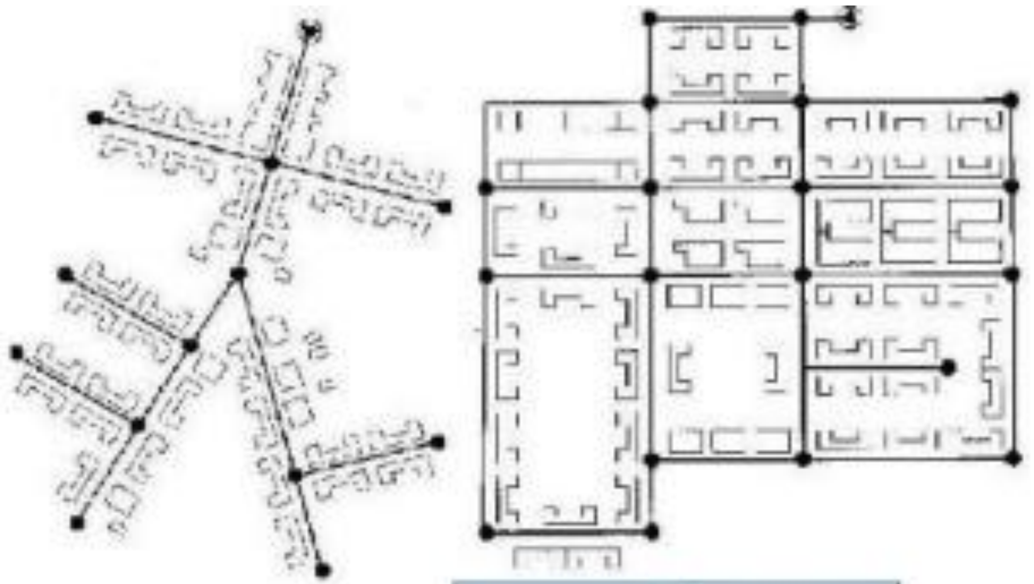
For large number of pipes and nodes, solving these equations manually becomes impractical and unfeasible For that, network simulation (modeling) packages exists such as WaterCAD

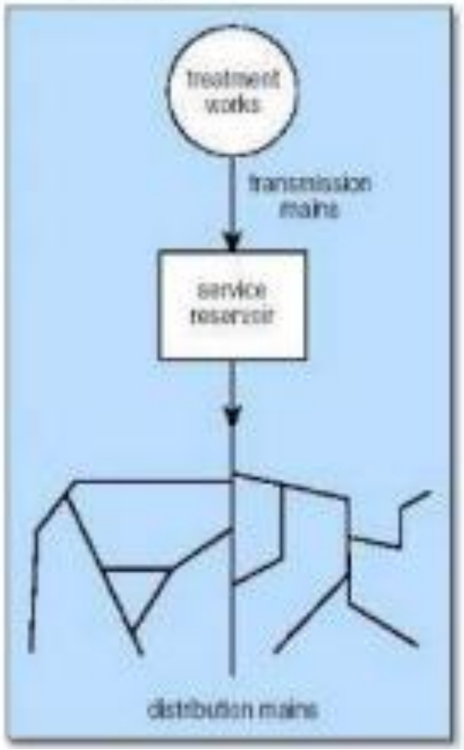


Types of WDNs

WDNs may be classified as looped systems, branching systems, or a combination of the two.

The configuration of the system is influenced by street patterns.





What does a node represent in reality?

What does a reservoir represent in reality?

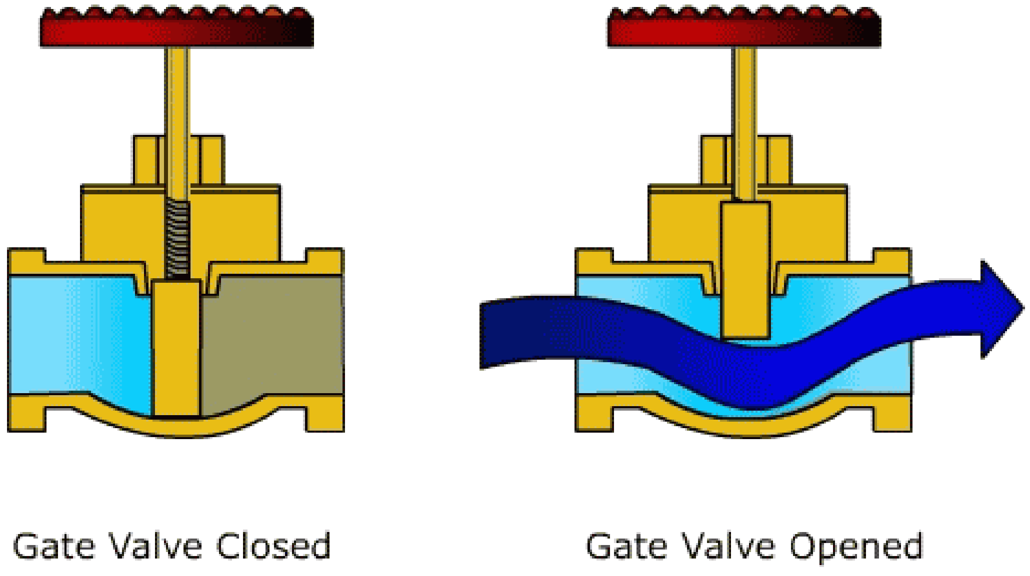
Water pipes

Water valves

Gate Valves

Gate valves are used to throttle flow (reduce, regulate, turn off)

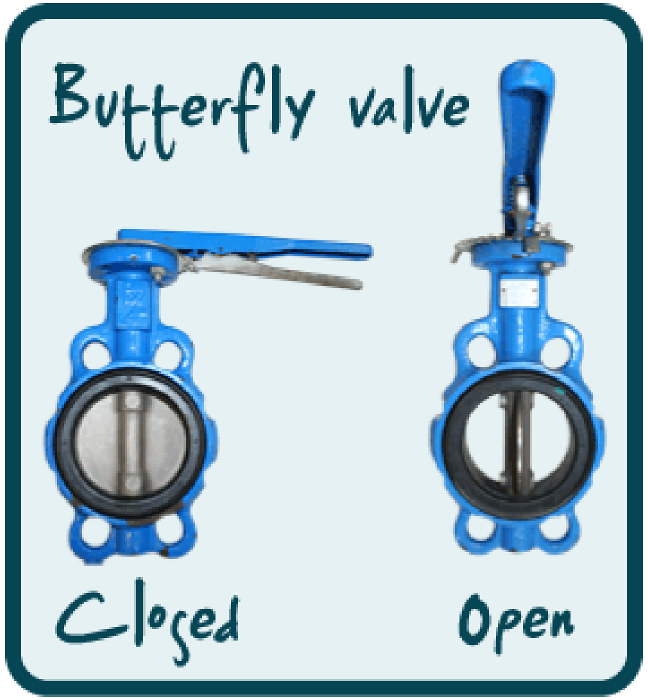
Gate valves function predominantly to isolate a pipe section; a valve block will be installed on an intersection between the pipes. Consequently, these valves normally operate in an open/closed position. Flow regulation is possible but is not common; the disk that is partly exposed to the flow may eventually loosen, causing leakage when it is in the closed position.



Butterfly Valves

(Butterfly valves are used to turn off the flow)

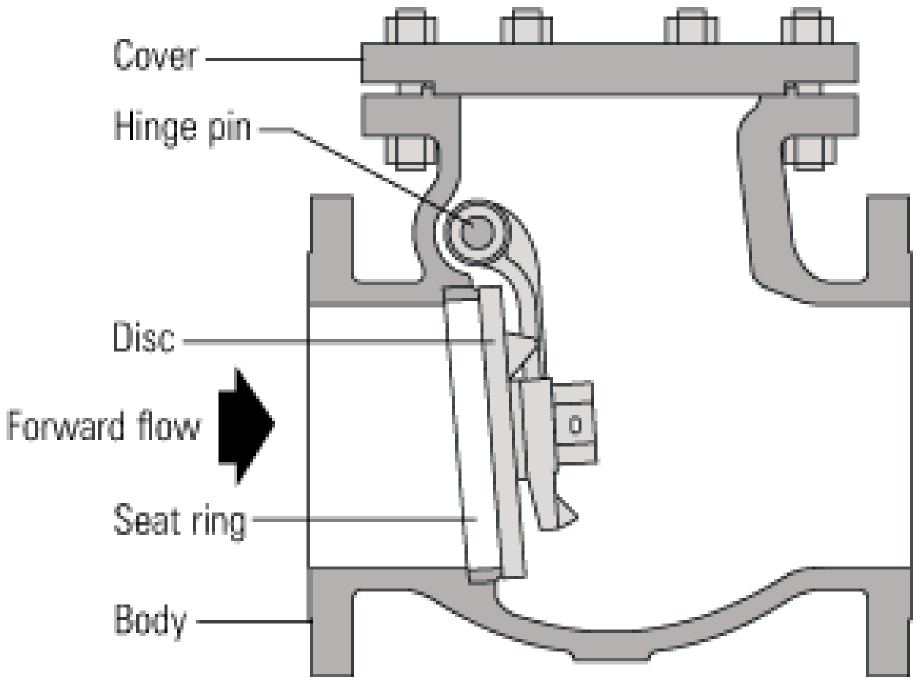
Butterfly valves are widely used in pumping stations as they are compact in size, and easier to operate and cheaper than comparable gate valves



Check Valves

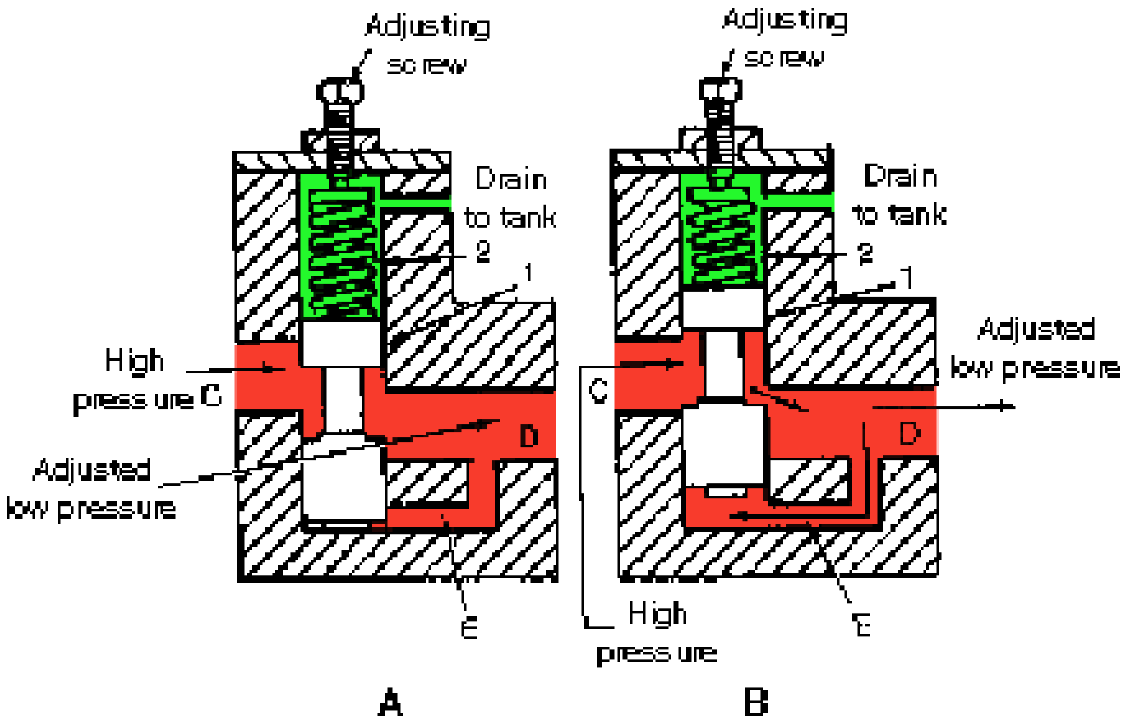
Check valves: or One way valves are used to maintain flow in one direction. An opposite flow direction causes the valve to close and remain closed until the flow is re-established in its original direction. There are two types: ball valves and swing gate valves

Check valve working animation:
https://youtu.be/RZZjNv1EgGo?si=NR_g7u1E7_ggVuVE



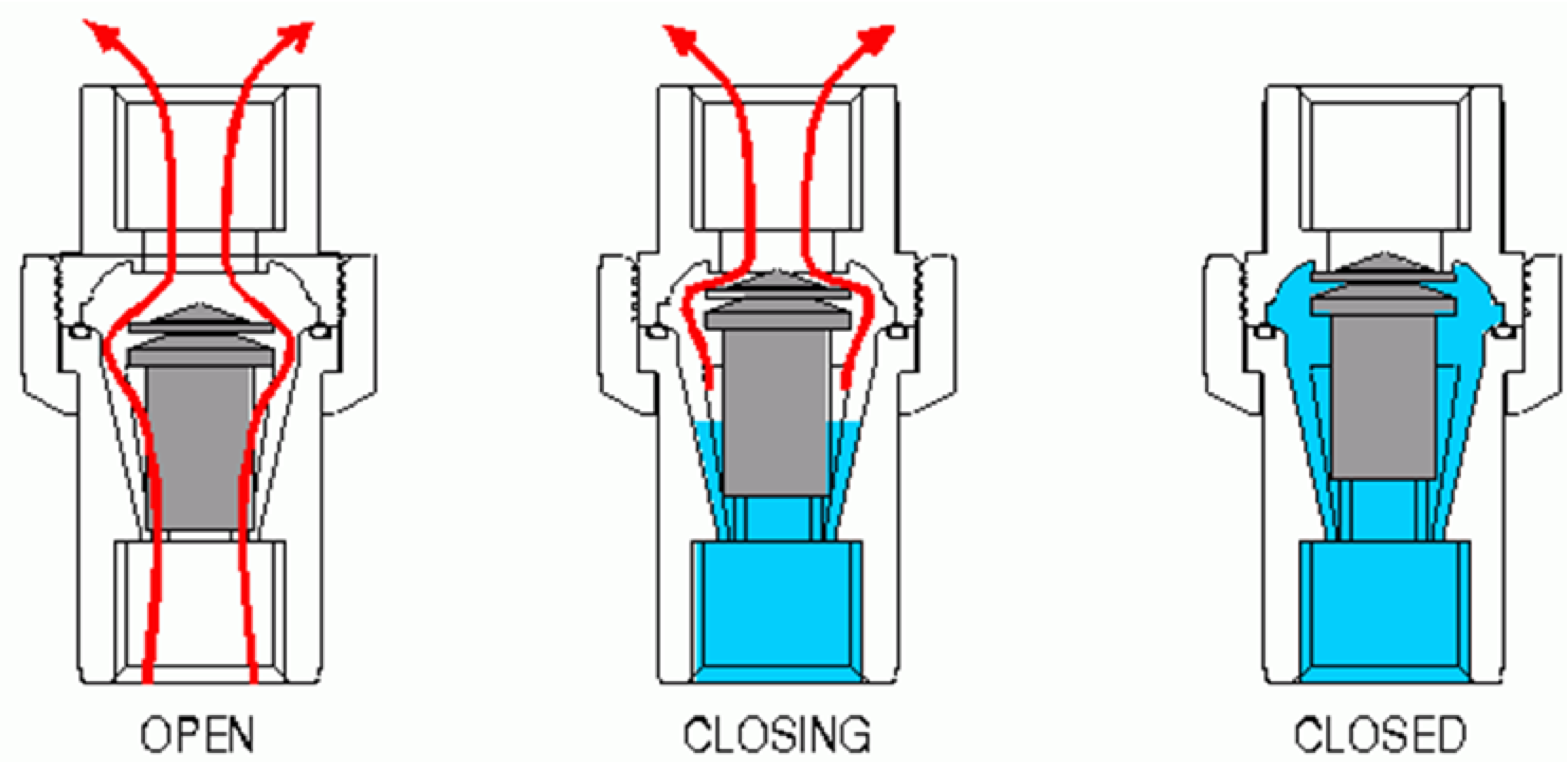
Pressure Reducing Valves

PRV are normally used to control the pressure in isolated parts of networks if it becomes too high. When the pressure upstream of the valve rises above the pre-set value, the valve will start closing until the downstream pressure is equal to the pre-set pressure. If the upstream pressure is below the pre-set value, the valve operates fully opened

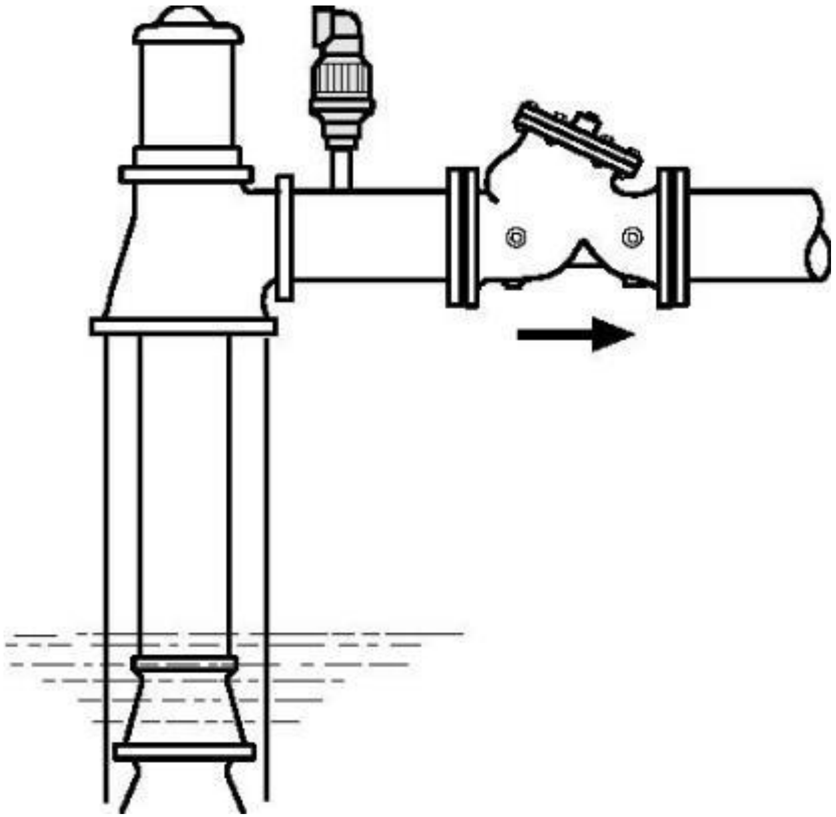


Air Release Valve

is a special type of valve that helps to release air from pipelines, which prevents reduction of the conveying capacity.



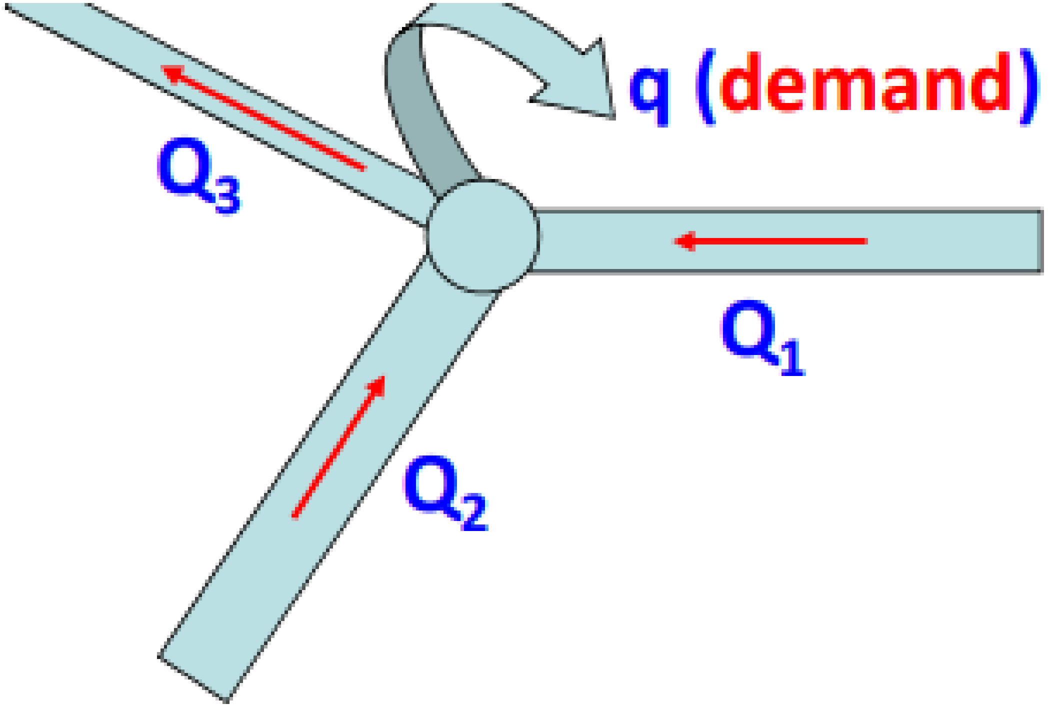
Air Release Valve



Main Principles of WDN Analysis

Continuity: The algebraic sum of the flow rates in the pipes meeting at a node together with any external flows is zero.

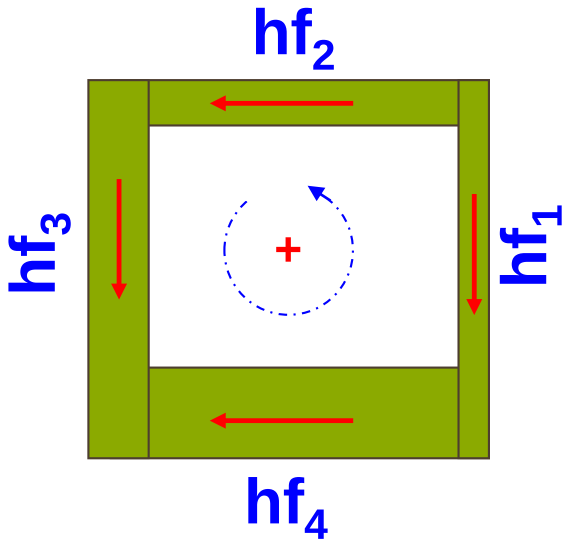
$$Q1 + Q2 = Q3 + q$$



Main Principles of WDN Analysis

Energy conservation: For all paths around closed loops, the accumulated energy loss including minor losses minus any energy gain or heads generated by pumps must be *zero*

A part of a looped network
Closed loop
Given total headloss for each link (pipe) as h_f

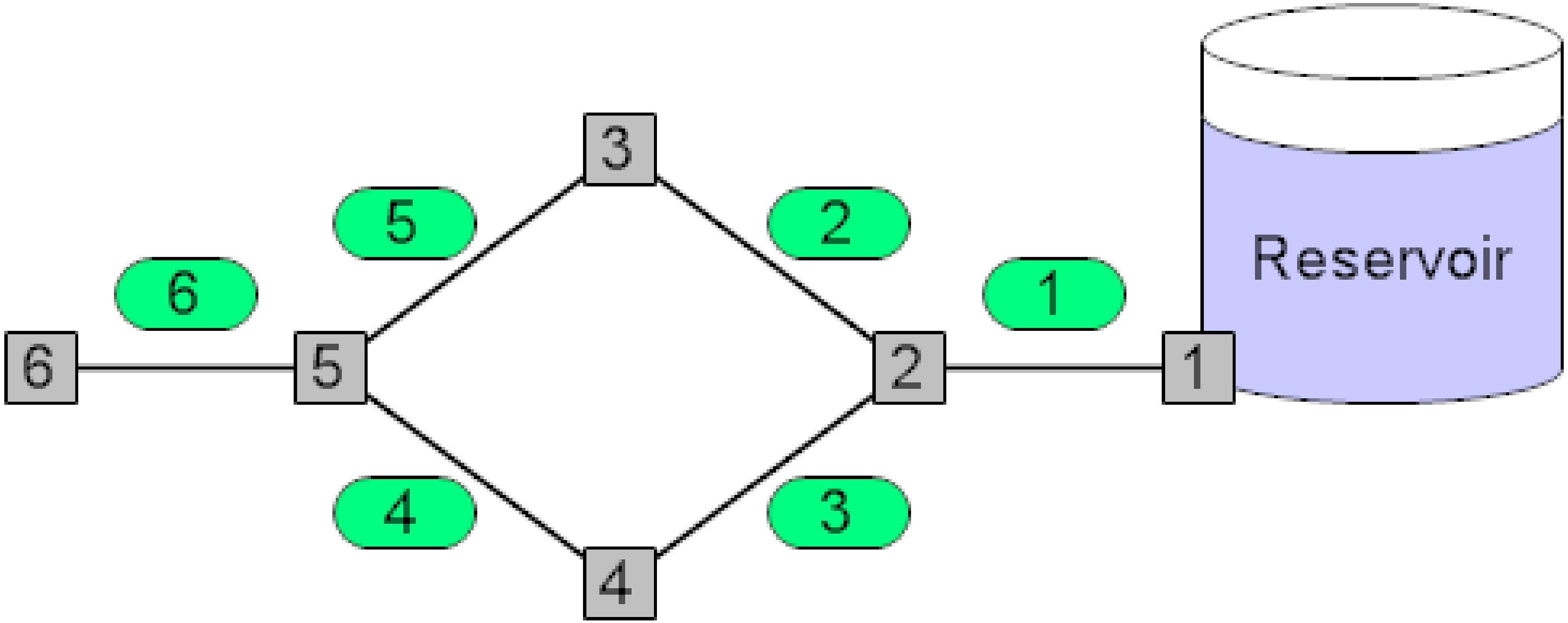


Assume counterclockwise to be positive

$-hf_1 - hf_4 + hf_3 + hf_2 = 0$

Example 1

Write the *continuity* and *energy conservation* equations for the following network:



Example 1

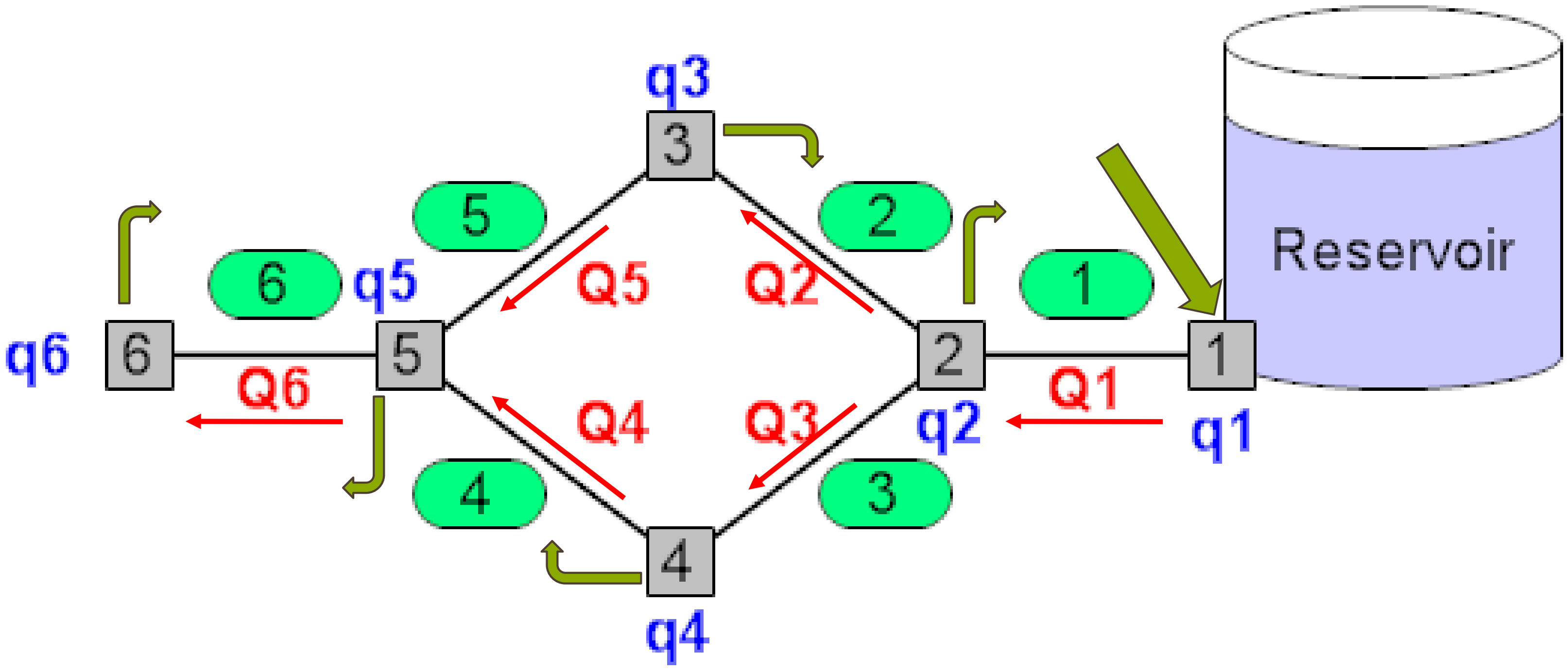
- First of all, keep in mind two issues:
    - Nodes provide water or receive water
    - Links (pipes) convey water to nodes or from nodes

- General input data includes:
    - Ground surface elevation (z)
    - Nodal demand or supply (q)
    - Total head at the source
    - Pipe diameter (D)
    - Pipe length (L)
    - Hazen-Williams coefficients

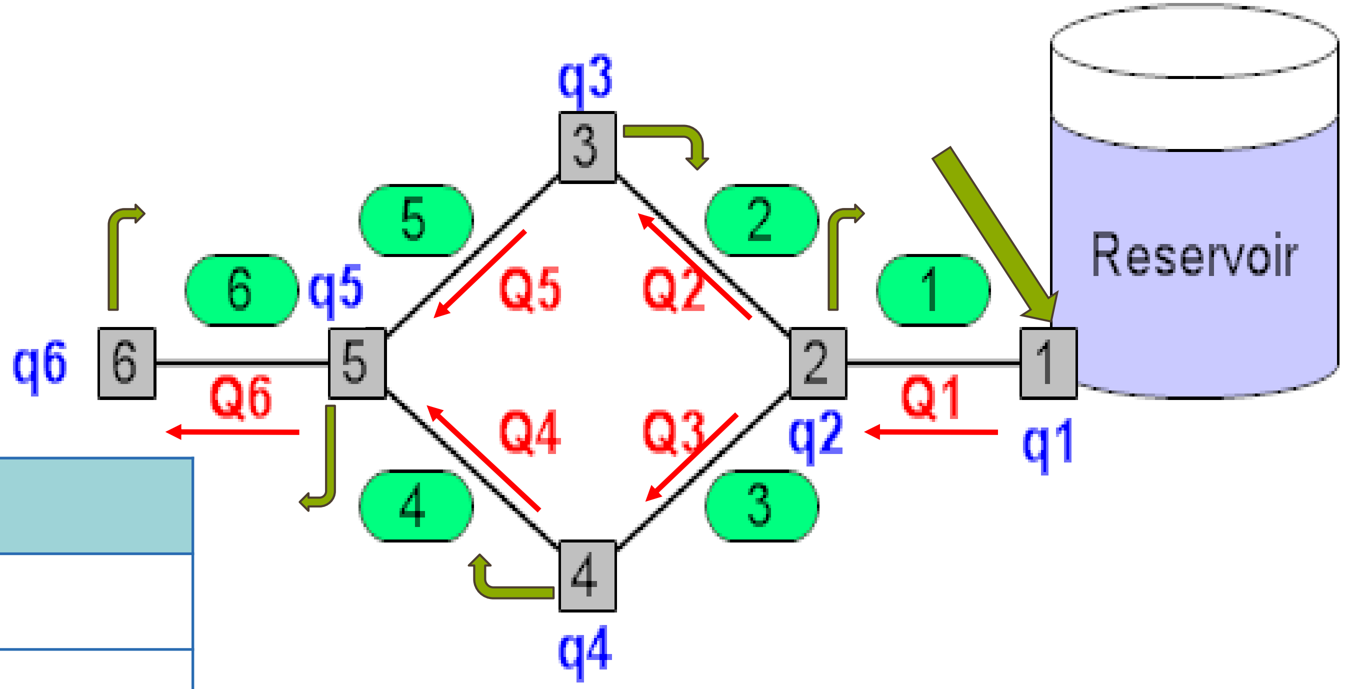
Example 1

- Label the nodal demands and pipe flows in the figure and assume flow directions

- This is necessary to be able to formulate the equations needed to analyze the network



Example 1



Node ID	Continuity
1	$Q_1 = q_1$
2	$Q_1 = Q_2 + Q_3 + q_2$
3	$Q_2 = q_3 + Q_5$
4	$Q_3 = q_4 + Q_4$
5	$Q_4 + Q_5 = q_5 + Q_6$
6	$Q_6 = q_6$
Loop	***Energy Conservation***
2 – 5 – 4 – 3	$hf_2 + hf_5 - hf_4 - hf_3 = 0$

Hydraulics review

Reynolds Number

$$Re = \frac{\rho V_{avg} D}{\mu} = \frac{V_{avg} D}{\nu}$$

Vavg: average flow velocity (m/s)
D: diameter in the case of pipes (m)
μ: dynamic viscosity (kg/m.s)
ν: kinematic viscosity (m2 /s)
ρ: density (kg/m3)

$Re \leq 2{,}000$ Laminar
$2{,}000 \leq Re \leq 4{,}000$ Transitional
$Re \geq 4{,}000$ Turbulent

ρ: density (kg/m3)

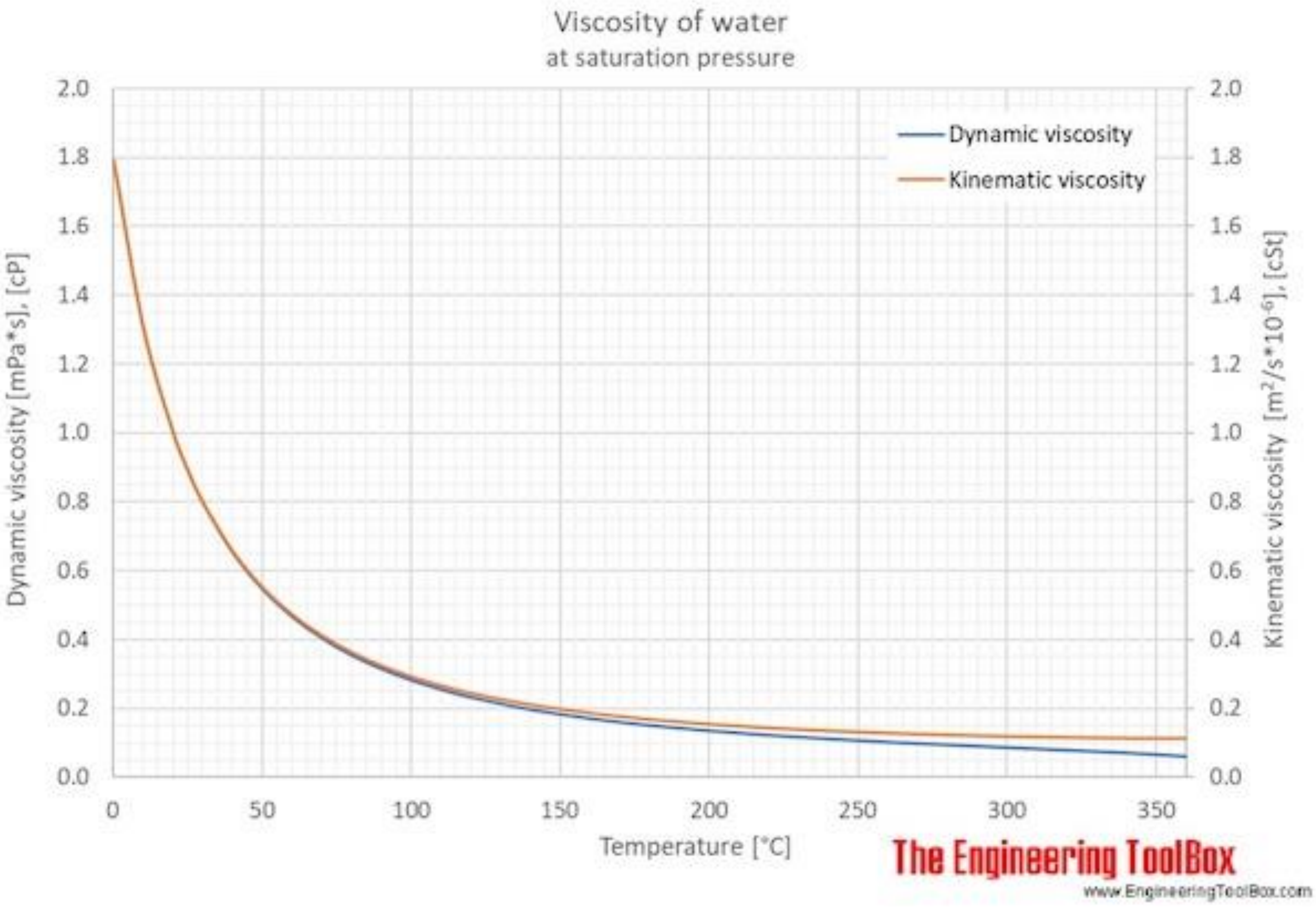
Density Of Liquid Water From 0°C to 100°C

External pressure: 1 atm = 101 325 Pa

Temperature °C	Density kg/m³	Temperature °C	Density kg/m³	Temperature °C	Density kg/m³
0 (ice)	917.00	33	994.76	67	979.34
0	999.82	34	994.43	68	978.78
1	999.89	35	994.08	69	978.21
2	999.94	36	993.73	70	977.63
3	999.98	37	993.37	71	977.05
4	1000.00	38	993.00	72	976.47
5	1000.00	39	992.63	73	975.88
6	999.99	40	992.25	74	975.28
7	999.96	41	991.86	75	974.68
8	999.91	42	991.46	76	974.08
9	999.85	43	991.05	77	973.46
10	999.77	44	990.64	78	972.85
11	999.68	45	990.22	79	972.23
12	999.58	46	989.80	80	971.60
13	999.46	47	989.36	81	970.97
14	999.33	48	988.92	82	970.33
15	999.19	49	988.47	83	969.69
16	999.03	50	988.02	84	969.04
17	998.86	51	987.56	85	968.39
18	998.68	52	987.09	86	967.73
19	998.49	53	986.62	87	967.07
20	998.29	54	986.14	88	966.41
21	998.08	55	985.65	89	965.74
22	997.86	56	985.16	90	965.06
23	997.62	57	984.66	91	964.38
24	997.38	58	984.16	92	963.70
25	997.13	59	983.64	93	963.01
26	996.86	60	983.13	94	962.31
27	996.59	61	982.60	95	961.62
28	996.31	62	982.07	96	960.91
29	996.02	63	981.54	97	960.20
30	995.71	64	981.00	98	959.49
31	995.41	65	980.45	99	958.78
32	995.09	66	979.90	100	958.05

μ: dynamic viscosity (kg/m.s)

ν: kinematic viscosity (m2 /s)



Example2

Determine whether the flow is laminar or turbulent if water at 70°C flows in a 1-in pipe with a flow rate of 285 L/min

$$Re = \frac{\rho V_{avg} D}{\mu} = \frac{V_{avg} D}{v}$$

Example2

ν: kinematic viscosity (m2 /s) from the chart = 0.42×10^{-6}

D = 1 in = 0.0254 m

$$V = \frac{Q}{A} = \frac{0.0475\, m^3/sec}{5.067\times10^{-4}} = 9.37\, m/s$$

$$Re = \frac{9.37\frac{m}{s}\times0.0254\, m}{0.42\times10^{-6}\, m^2/s} = 566662$$

Then the flow is turbulent

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Hazen Williams for frictional head loss

$$h_f = 162.5 \times \left(\frac{Q}{C_{hw}}\right)^{1.852} \times D^{-4.87} \times L$$

Q in $(\frac{m^3}{h})$

D in (in).

C_{hw} = Hazen Williams friction coefficient,

L = pipeline length in (m)

h_f = frictional head loss (m).

The Hazen-Williams coefficient (C_{hw}) is usually taken as 140-150 for plastic and new steel pipes as shown in the following table.

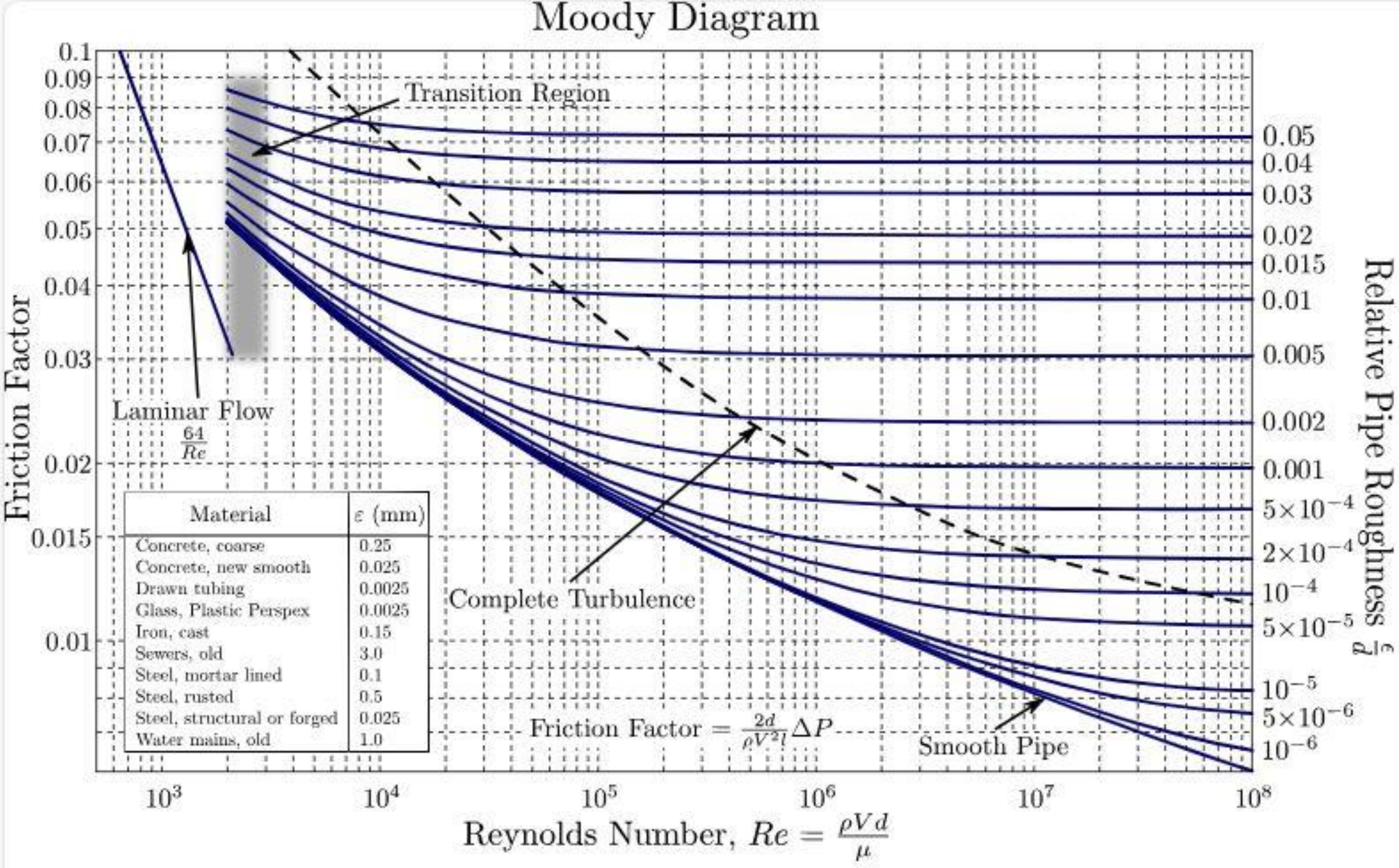
Material	Hazen-Williams Coefficient	Material	Hazen-Williams Coefficient
ABS - Acrylonite Butadiene Styrene	130	Ductile Iron Pipe (DIP)	140
Aluminum	130 - 150	Ductile Iron, cement lined	120
Asbestos Cement	140	Fiber	140
Asphalt Lining	130 - 140	Fiber Glass Pipe – FRP	150
Brass	130 - 140	Galvanized iron	120
Brick sewer	90 - 100	Glass	130
Cast-Iron - new unlined (CIP)	130	Lead	130 - 140
Cast-Iron 10 years old	107 - 113	Metal Pipes - Very to extremely smooth	130 - 140
Cast-Iron 20 years old	89 - 100	Plastic	130 - 150
Cast-Iron 30 years old	75 - 90	Polyethylene, PE, PEH	140
Cast-Iron 40 years old	64-83	Polyvinyl chloride, PVC, CPVC	150
Cast-Iron, asphalt coated	100	Smooth Pipes	140
Cast-Iron, cement lined	140	Steel new unlined	140 - 150
Cast-Iron, bituminous lined	140	Steel, corrugated	60
Cast-Iron, sea-coated	120	Steel, welded and seamless	100
Cast-Iron, wrought plain	100	Steel, interior riveted, no projecting rivets	110
Cement lining	130 - 140	Steel, projecting girth and horizontal rivets	100
Concrete	100 - 140	Steel, vitrified, spiral-riveted	90 - 110
Concrete lined, steel forms	140	Steel, welded and seamless	100
Concrete lined, wooden forms	120	Tin	130
Concrete, old	100 - 110	Vitrified Clay	110
Copper	130 - 140	Wrought iron, plain	100
Corrugated Metal	60	Wooden or Masonry Pipe – Smooth	120
		Wood Stave	110 - 120

Darcy-Weisbach Equation

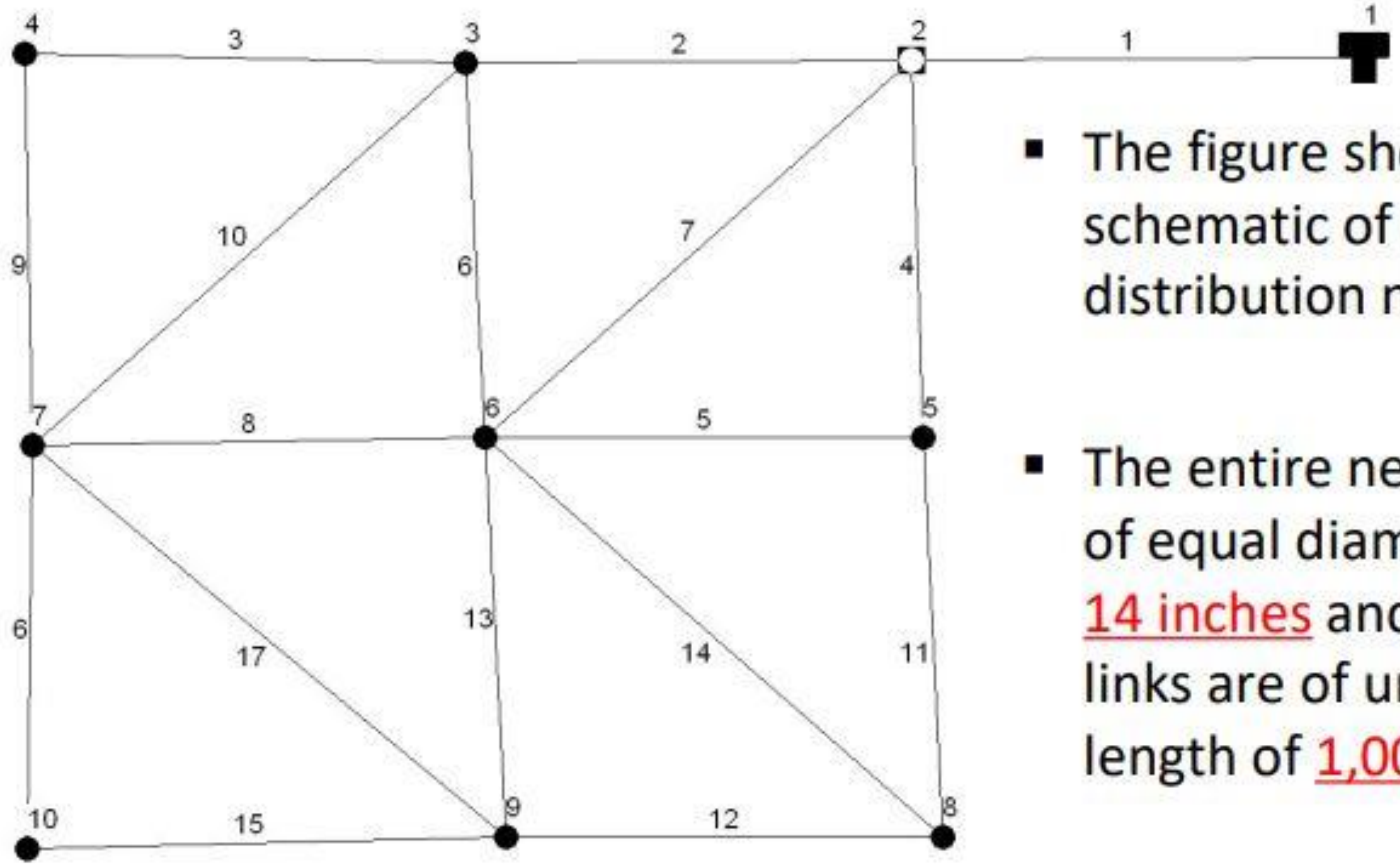
$$h_f = f\frac{L}{D}\frac{V^2}{2g}$$

Darcy Friction Factor, f
Duct Length, L (m)
Duct Diameter, D (m)
Velocity, V (m/s)
Major Loss, h_f (m)
g = acceleration due to gravity = 9.806 m/s^2.

The Darcy-Weisbach method is generally considered more accurate than the Hazen-Williams method. Additionally, the Darcy-Weisbach method is valid for any liquid or gas; Hazen-Williams is only valid for water at ordinary temperatures (40 to 75 ^{o}F). The Hazen-Williams method is very popular, especially among civil engineers, since its friction coefficient (C) is not a function of velocity or duct diameter. Hazen-Williams is simpler than Darcy-Weisbach for calculations where you are solving for flowrate, velocity, or diameter. More Discussion and References.


Moody Diagram
Transition Region
Laminar Flow
64/Re
Complete Turbulence
Friction Factor = (2d/ρV²l) ΔP
Smooth Pipe
Friction Factor
Reynolds Number, Re = ρVd/μ
Relative Pipe Roughness ε/d
0.1
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.015
0.01
10^3
10^4
10^5
10^6
10^7
10^8
0.05
0.04
0.03
0.02
0.015
0.01
0.005
0.002
0.001
5×10^-4
2×10^-4
10^-4
5×10^-5
10^-5
5×10^-6
10^-6
Material | ε (mm)
Concrete, coarse | 0.25
Concrete, new smooth | 0.025
Drawn tubing | 0.0025
Glass, Plastic Perspex | 0.0025
Iron, cast | 0.15
Sewers, old | 3.0
Steel, mortar lined | 0.1
Steel, rusted | 0.5
Steel, structural or forged | 0.025
Water mains, old | 1.0

Example 3



- The figure shows a schematic of a water distribution network
- The entire network is of equal diameters of 14 inches and the links are of uniform length of 1,000 m

A hydraulic analysis was carried out for this network and the results of the pressure head and the total head at each node are summarized in the table

The pipes are at least 15 years old

Network Table - Nodes

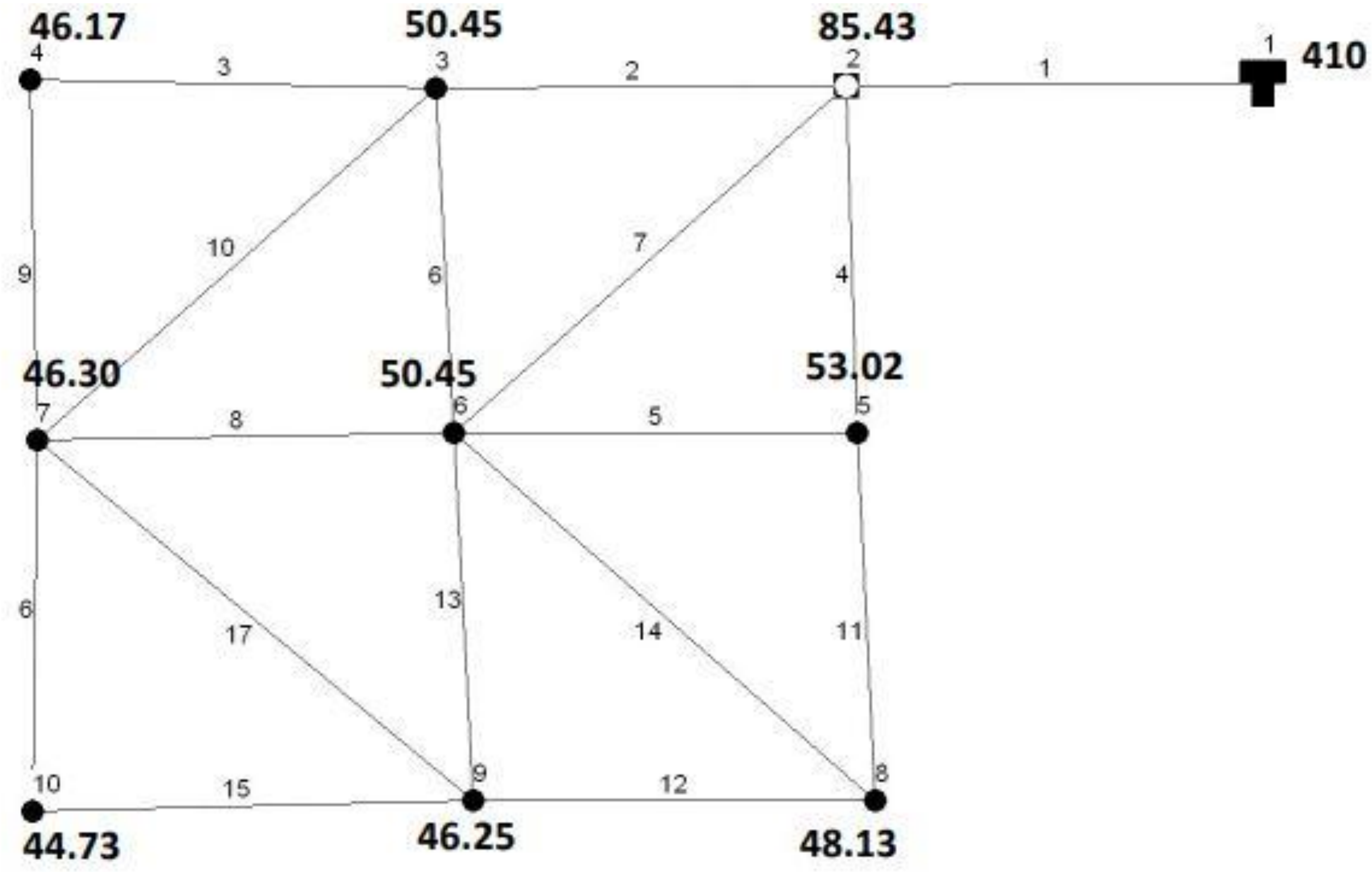
Node ID	Head m	Pressure m
Junc 2	85.43	85.43
Junc 3	50.45	50.45
Junc 4	46.17	46.17
Junc 5	53.02	53.02
Junc 6	50.45	50.45
Junc 7	46.30	46.30
Junc 8	48.13	48.13
Junc 9	46.25	46.25
Junc 10	44.73	44.73
Tank 1	410.00	10.00

[1] Determine the direction of flow in links 8, 13, 15, 16, and 17

[2] What is the net total water supply at node 6?

[3] Where is the maximum link flow in the network and why?

[4] What is the velocity in link 17?


46.17
50.45
85.43
410
4
3
2
1
3
2
1
9
10
6
7
4
46.30
50.45
53.02
7
6
5
8
5
6
17
13
14
11
10
9
8
15
12
44.73
46.25
48.13

[1] The main premise here is that water flows from the node of the higher total head to the node of lower total head. As such, link 8 (6→7), link 13 (6→9), link 15 (9→10), link 16 (7→10), and link 17 (7→9)

[2] We know that

$$h_f = 162.5\left(\frac{Q}{C_{HW}}\right)^{1.852} D^{-4.87} L \rightarrow Q = \left(\frac{h_f}{162.5 \times D^{4.87} L}\right)^{1/1.852} C_{HW}$$

We determine for each link connected to node 6 the headloss value and then from the above equation we can find out the flow. What you need to assume is the value of Hazen-Williams coefficient which was taken here as 100. As such, the following table was prepared:

	m	m	m	m^3/h	m^3/h
Link	Initial head	Final head	h_f	Q	Flow
5	53.02	50.45	2.57	263.97	263.97
6	50.45	50.45	0	0	0
7	85.43	50.45	34.98	1,080.95	1,080.95
8	50.45	46.3	4.15	341.92	-341.92
13	50.45	46.25	4.2	344.14	-344.14
14	50.45	48.13	2.32	249.78	-249.78
				Total	**409.08**

[3] The maximum flow is in link 1 because all the water to the nodes comes from the tank and thus the maximum flow is the total flow supplied by the network. The maximum must come at first from the tank through link 1

[4] The flow through the link is 31.45 m^3/hr. This gives a velocity of 316.67 m/h