

Plumbing Systems

Plumbing is a system of piping, apparatus, and fixtures for water distribution and waste disposal within a building. Plumbing also includes the installation and maintenance of this system.

The plumbing constitutes the following:

- 1- The water supply and water distribution. Carries water from the source, street main or a pump to the building.
- 2- The plumbing fixtures that receive the supply water and allow the occupants of the building to use the water.
- 3- The drainage system. The pipe network within the building which conveys from the plumbing fixtures all wastes (sanitary drainage) as well as rainwater to a point of disposal or a treatment facility.

The Demand of Water

- 1- Drinking, cooking, dishwashing
- 2- Personal washing and domestic cleaning.
- 3- Laundry
- 4- Fire fighting
- 5- Swimming
- 6- Boilers and heating plants
- 7- Irrigation

Types of Plumbing Fixtures Used in Residences

- 1- Water closet: A plumbing fixture used to receive human excremental and to discharge it through a waste pipe.
- 2- Flush tank: It holds a supply of water for flushing a fixture such as the water closet. It has a capacity of 5 to 6 gallons .
- 3- lavatory: A fixture designed for the washing of the hands or face. It is also known as wash basin.
- 4- Bath tube: A tube for bathing, usually a fixed plumbing installation designed for one person.

5- Urinal: A sanitary fixture equipped with a water supply and drain for flushing away urine.

6- Kitchen sink: A plumbing fixtures usually consisting of a basin with a water supply connected with a drain.

7- Shower bath: An apparatus for spraying water on the body, usually from above.

Drain is through the shower bath floor drain.

Estimating Water Demand

There are two methods that have been proposed to aid in the design of plumbing water systems.

1- Hunter's Method

Plumbing water distribution systems shall be designed based on the idea of the most Probable peak demand loading, which reflects the worst-case for a system.

Hunter's method is based on assigning a fixture unit weight (f/u) to the plumbing fixtures and then converting these to equivalent gallons per minute, based on the theory of probability of usage. Hunter estimated the flow rates through various fixtures by capturing average flow and the time span of a single operation for different fixtures.

Table 1 lists the demand weights in fixture units as determined by the National Bureau of Standards. It is used in conjunction with Figure 1 or Table 2 in determining the expected normal peak flow for any number or combination of fixtures.

Notes: 1. the fixture unit loading method is used to quantify intermittent demand and could be applied to any of the residential or non-residential facilities. The other continuous water usage requirements such as hose bibs, air conditioning cooling tower makeup, gardening or process cooling requirements, etc. need to carefully added to determine the peak water demand.

2- It is customary engineering practice to employ curve 2 for hot water service pipe sizing and for cold water service when flush tank are involved. The flush valve curve 1 is used only for cold water and total service water flow estimation.

Example: What is the hot, cold and total water flowrate for a group of plumbing fixtures in a small hotel building consisting of 52 flush valve water closets, 30 flush

valve wall urinals, and 40 lavatories? The hotel requires 30 gpm for air-conditioning water makeup and 10 gpm for each of the 3 hose bibs.

Solution

Fixture type	Quantity	F.U	Hot water	Cold water	Total
w.c	52	10	-	520	520
urinals	30	5	-	150	150
lavatories	40	2	-	-	80
lavatories	40	1.5	60	60	-
Sum of f/u			60	730	750

From Table 2 or Fig. 1 , **Hot water** : 60 f/u=32 gpm (for hot water demand read flush tank)

Cold water : 730 f/u=175 gpm (for cold water demand read flush valve)

Total: 750 f/u = 178 gpm

Continuous demand: Hose bibs = $3 \times 10 = 30$ gpm

Air-conditioning= 30 gpm

Total = 60 gpm

Hot water demand= 32 gpm

Cold water demand= 175+60 = 235 gpm

Total water demand = 178+60 = 238 gpm

Example: Building six stories in each story four families dwellings are provided

**A - water closet (flush tank) - bathtube - lavatory - shower head(mix valve)
- urinal (flush tank).**

B - water closet (flush tank) - shower head (mix valve) - lavatory - kitchen sink

Calculate the hot, cold (flush tank), and total water flowrate for total building. The building requires 20 gpm for air-conditioning water cooling and 10 gpm for each of the 5 hose bibs.

Fixture type	Quantity	F.U	Hot water	Cold water	Total
w.c	2	5	-	10	10
bathtube	1	3	3	3	-
bathtube	1	4	-	-	4
lavatory	2	1.5	3	3	-
lavatory	2	2	-	-	4
shower	2	3	6	6	-
shower	2	4	-	-	8
urinal	1	3	-	3	3
Kitchen sink	1	3	3	3	-
Kitchen sink	1	4	-	-	4
Total of each story/all building			15/90	28/168	33/198

From Fig. **Hot water** : 15 f/u =10 gpm for each story

90 f/u = 41 gpm for total building

Cold water: 28 f/u = 18 gpm for each story

168 f/u = 60 gpm for total building

Total : 33 f/u = 44 gpm for each story

198 f/u = 92 gpm for total story

Continuous demand : Hose bibs = $5 \times 10 = 50$ gpm

Air-conditioning = 20 gpm

Total = 70 gpm

For each story

Hot water = 10 gpm

Cold water = 18 + 70 = 88 gpm

Total water = 44 + 70 = 114 gpm

For total building

Hot water = 41 gpm

Cold water = 60 + 70 = 130 gpm

Total water = 92 + 70 = 162 gpm

2- Demand at Individual Water Outlets

The total water demand may be calculated by adding the maximum flows at all points of use and applying a factor less than unity to account for the probability that only some of the fixtures will be operated simultaneously. Table 3 lists demand rates flow from individual water outlets at various plumbing fixtures.

Using the following equation to compute the required design flow

$$Q = 8 \sqrt{Q_d}$$

Q_d = demand flowrate given in Table 3 in Lpm

Q = design required water supply in Lpm

Hot water can be estimated using Table (4) for different building.

Example: Building four stories in each story two families dwellings are provided

2 water closet (flush tank)

2 bathtube

2 shower head (mix valve)

4 ordinary lavatory

2 kitchen sink(faucet $\frac{3''}{4}$)

Calculate the hot, cold (flush tank), and total water flowrate for each story and total building using the individual water outlets and Hunter's methods. The building requires 30 gpm for air-conditioning water cooling and 10 gpm of each 2 hose bibs.

Solution: **Individual Water Outlets**

Fixture type	Quantity	Demand gpm	Cold water	Hot water
w.c	2	3	6	-
bathtub	2	5	10	-
bathtub	2	0.333	-	0.667
shower	2	5	10	-
shower	2	0.5	-	1
Lavatory	4	2	8	-
Kitchen sink	2	6	12	-
Kitchen sink	2	0.17	-	0.333
Total			46	2

Cold Water

$$Q = 8\sqrt{Q_d}$$

$$Q = 8\sqrt{46 \times 3.786} = 105.6 \frac{l}{min} \quad \text{for each story}$$

$$Q = 8\sqrt{46 \times 3.786 \times 4} = 211.1 \frac{l}{min} \quad \text{for total building}$$

Continuous water demand = $30 + 10 \times 2 = 50$ gpm

$$105.6 + 50 \times 3.786 = 294.9 \frac{l}{min} \quad \text{for each story}$$

$$211.1 + 50 \times 3.786 = 400.4 \frac{l}{min} \quad \text{for total building}$$

Hot Water

$$Q = 2 \times 0.3 = 0.6 \frac{g}{min} = 2.272 \frac{l}{min} \quad \text{for each story}$$

$$Q = 0.6 \times 4 = 2.4 \frac{g}{min} = 9.1 \frac{l}{min} \quad \text{for total building}$$

For total flow (hot + cold) = $Q_d = 46 + 2 = 48$ gpm

$$Q = 8\sqrt{48 \times 3.786} = 107.85 \frac{l}{min}$$

$$107.85 + 50 \times 3.786 = 297.15 \frac{l}{min} \quad \text{for each story}$$

$$Q = 8\sqrt{48 \times 3.786 \times 4} = 215.7 \frac{l}{min}$$

$$215.7 + 50 \times 3.786 = 405 \frac{l}{min} \quad \text{for total building}$$

2- Hinter's method

Fixture type	Quantity	F.U	Hot water	Cold water	Total
w.c	2	5	-	10	10
bathtub	2	3	6	6	-

bathtub	2	4	-	-	8
shower	2	3	6	6	-
shower	2	4	-	-	8
lavatory	4	1.5	6	6	-
lavatory	4	2	-	-	8
Kitchen sink	2	3	6	6	-
Kitchen sink	2	4	-	-	8
Total of each story			24	34	42

Hot Water For each story $24 \text{ f/u} = 16 \text{ gpm}$

for total building $96 \text{ f/u} = 43 \text{ gpm}$

Cold Water for each story $34 \text{ f/u} = 22 \text{ gpm}$

for total building $136 \text{ f/u} = 52 \text{ gpm}$

Total flow for each story $42 \text{ f/u} = 48 \text{ gpm}$

for total building $168 \text{ f/u} = 84 \text{ gpm}$

Continuous demand $30 + 2 \times 10 = 50 \text{ gpm}$

Hot water = **16 gpm** for each story

= **43 gpm** for total building

Cold water $22 + 50 = 72 \text{ gpm}$ for each story

$52 + 50 = 102 \text{ gpm}$ for total building

Total flow $48 + 50 = 98 \text{ gpm}$ for each story

$84 + 50 = 134 \text{ gpm}$ for total building

Example:

Determine heater and storage tank size for an apartment building from a following number of fixtures.

Quantity	Flow per fixture gal/hr	Hot water demand gal/hr
60 Lavatories (private)	2	120
30 bathtubs	20	600
30 showers	30	900
60 kitchen sink	10	600
15 laundry tubs	20	300
		2520

Probable maximum demand = 0.3×2520

= 756 gph

Storage tank capacity = 1.25×756

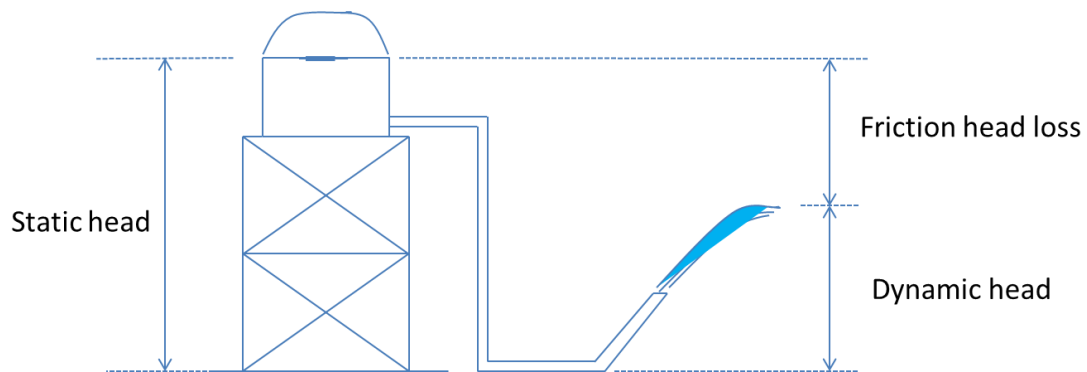
= 945 gal

Static head

It is the measure of elevation of water above a reference point.

Dynamic head

It is static head minus the friction loss of a flowing liquid, expressed as shown in Fig



The water distribution system must be always be designed on basis of the minimum pressure available. Generally, the minimum pressure to be provided at most fixture is 8 psi (55 kpa) and from 15 to 25 psi for water closet.

Friction head loss

Water piping must be sized to limit the friction head losses in the piping system so that the highest and most remote water outlet will have the required minimum pressure head for adequate flow during periods of peak demand. The maximum friction head loss that can therefore be tolerated in the system during peak demand is the difference between the static pressure at the highest and most remote outlet at no flow conditions and the minimum flow pressure required at that outlet.

For brass, copper, or plastic piping

$$h_f = 0.000623 q^2 \frac{L}{d^5}$$

or
$$p_f = 0.00027 q^2 \frac{L}{d^5}$$

For galvanized-steel and wrought-iron piping

$$h_f = 0.001246 q^2 \frac{L}{d^5}$$

or
$$p_f = 0.000539 q^2 \frac{L}{d^5}$$

h_f = head loss due to friction ft

p_f = pressure loss, psi

q = quantity of flow, gpm

L = equivalent length of piping, ft

$$L_e = 1.5 \times L$$

d = diameter of piping, in.

Using Hazen-Williams Eq.

$$q = 0.2784 C D^{2.63} S^{0.54} \quad , \quad m^3/s$$

For greater accuracy , it was suggested that water supply pipe be considered in four classes as to hydraulic roughness:

$$\text{For smooth pipe} \quad q = 4.93 P^{0.571} d^{2.714}$$

$$\text{For fairly smooth pipe} \quad q = 4.57 P^{0.546} d^{2.64}$$

$$\text{For fairly rough pipe} \quad q = 4.29 P^{0.521} d^{2.562}$$

$$\text{For rough pipe} \quad q = 3.7 P^{0.5} d^{2.5}$$

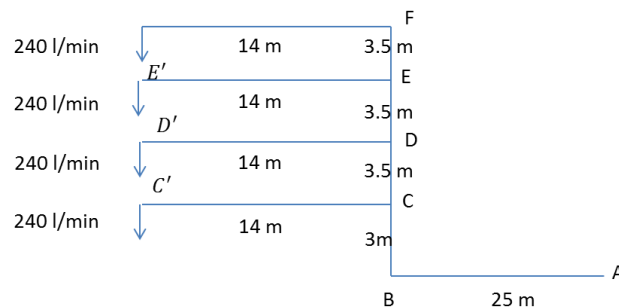
q = quantity rate of flow, gpm

P = pressure loss due to friction, $\frac{\text{psi}}{100}$ ft pipe length

d = diameter of pipe, in.

Example

There is 4-story building where the street pressure is reported as 22 m. Design the pipes of water supply network shown in Fig. if the pipes are galvanized-steel piping.



$$h_f = 0.001246 q^2 \frac{L}{d^5}$$

$$h_f = 22 - 13.5 - 5.61 = 2.89 \text{ m}$$

$$L_e = 1.5 \times 52.5 = 78.75 \text{ m}$$

$$\text{Slope of hydraulic pressure} = \frac{h_f}{L} = 0.037$$

To find slope of hydraulic pressure of branches CC' , DD' , EE' , and FF' as follows:

Point C : $h_f = 22 - 28 \times 0.037 - 3 - 5.61 = 12.354 \text{ m}$

$$L_e = 14 \times 1.5 = 21 \text{ m} \rightarrow S = 0.588$$

Point D: $h_f = 22 - 31.5 \times 0.037 - 6.5 - 5.61 = 8.725 \text{ m}$

$$L_e = 1.5 \times 14 = 21 \text{ m} \rightarrow S = 0.415$$

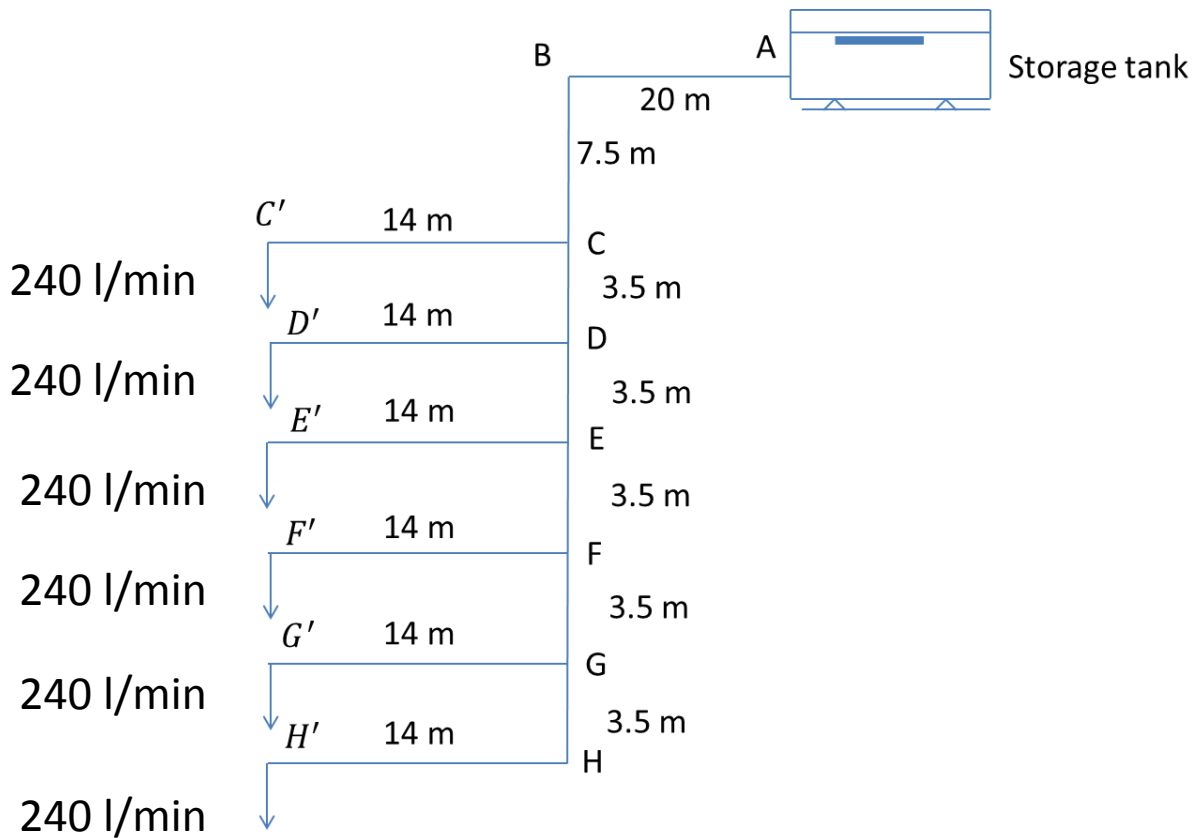
Point	h_f	L	S
C	12.354	21	0.588
D	8.725	21	0.415
E	5.095	21	0.243
F	1.466	21	0.07

Pipe	Slope	Total Discharge l/min	Design Discharge, l/min	Cal. Diameter, mm	Sel. Diameter, mm
ABC	0.037	960	248	68.7	70
CD	0.037	720	215	64.9	70
DE	0.037	480	175	59.8	60
EF	0.037	240	124	52.1	55
CC'	0.588	240	124	29.9	30
DD'	0.415	240	124	32.1	35
EE'	0.243	240	124	35.7	40
FF'	0.07	240	124	45.8	50

Example:

Design pipes of water supply network shown in Fig. Using Hazen-Williams Eq. for steel Pipes

$$q = 0.2784 C D^{2.63} S^{0.54} , C=100$$



Solution: Calculation of friction loss and slope of pressure hydraulic

$$\text{Line } ABCC' \quad h_f = 7.5 - 5.61 = 1.89 \text{ m}$$

$$L = 41.5 \times 1.5 = 62.25 \text{ m}$$

$$S = \frac{1.89}{62.25} = 0.03$$

Line	h_f	L	S
ABCC'	1.89	62.25	0.03
ABDD'	5.39	67.5	0.08
ABEE'	8.89	72.75	0.122
ABFF'	12.39	78.0	0.159
ABGG'	15.89	83.25	0.191
ABHH'	19.39	88.5	0.219

Minimum $S = 0.03$

Calculation h_f at points and slopes of pressure

Point C: $h_f = 7.5 - 0.03 \times 27.5 - 5.61 = 1.065 \text{ m}$

$$L = 14 \times 1.5 = 21 \text{ m}$$

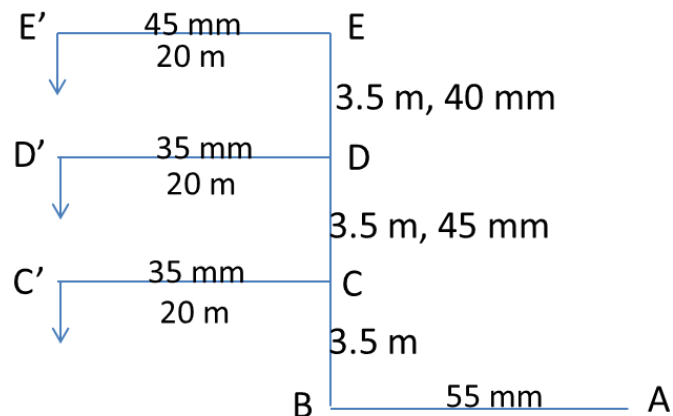
$$S = 0.051$$

Points	h_f	L	S
C	1.065	21	0.051
D	4.46	21	0.212
E	7.855	21	0.374
F	11.25	21	0.536
G	14.645	21	0.697
H	18.04	21	0.859

Pipes	S	$Q_T, l/min$	$Q_D, l/min$	Dia. Cal. , mm	Dia. sel. , mm
ABC	0.03	1440	303.6	78	80
CD	0.03	1200	277.1	75.2	80
DE	0.03	960	247.9	72.1	75
EF	0.03	720	214.7	68.2	70
FG	0.03	480	175.3	63.2	65
GH	0.03	240	123.9	55.3	60
CC'	0.051	240	123.9	49.6	50
DD'	0.212	240	123.9	37.1	40

Pipes	S	$Q_T, l/min$	$Q_D, l/min$	Dia. Cal. , mm	Dia. Sel. , mm
EE'	0.374	240	123.9	33.0	35
FF'	0.536	240	123.9	30.6	35
GG'	0.697	240	123.9	29.03	30
HH'	0.859	240	123.9	27.8	30

Example: There is a 3-story building where the street pressure is reported as 20 m. Calculate the required discharge in network, if the pipes are steel material using Hazen-Williamz Eq. $q = 0.2784 C D^{2.63} S^{0.54}$, C=100



Solution : Calculation slope of pressure (minimum)

Line	h_f	L	S
ABCC'	10.89	57.75	0.189
ABDD'	7.39	63	0.117
ABEE'	3.89	68.25	0.057

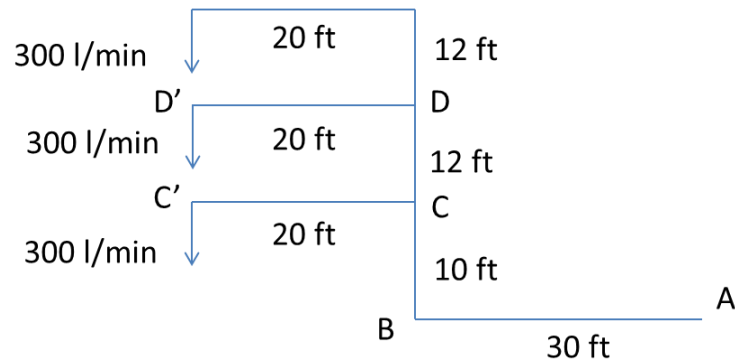
Using Min. S=0.057

Points	h_f	L	S
C	9.836	30	0.328
D	6.136	30	0.205
E	2.437	30	0.081

Pipes	Slope	Dia. mm	$q, m^3/s$	$q, l/min$	$q, l/min$ in network
ABC	0.057	55	0.00288	173	468
CD	0.057	45	0.0017	102	163/312
DE	0.057	40	0.00125	75	88/156
CC'	0.328	35	0.00226	136/305	287/156
DD'	0.205	35			156
EE'	0.081	45			156

Example: There are 3- story building where the street is reported as 32 psi. Design the pipes of water network shown in figure. If the pipes are galvanized-steel smooth pipe

$$q = 4.93 P^{0.571} d^{2.714}$$



Pressure or head loss

The pressure required must be adequate for all pipes. The minimum pressure is along path ABEE' is

$$P = 32 - \frac{34 \times 62.4}{144} - 8 = 9.27 \text{ psi along } 84 \text{ ft}$$

$$P \text{ of } \frac{\text{psi}}{100} = \frac{9.27 \times 100}{84} = 11.04 \text{ psi}$$

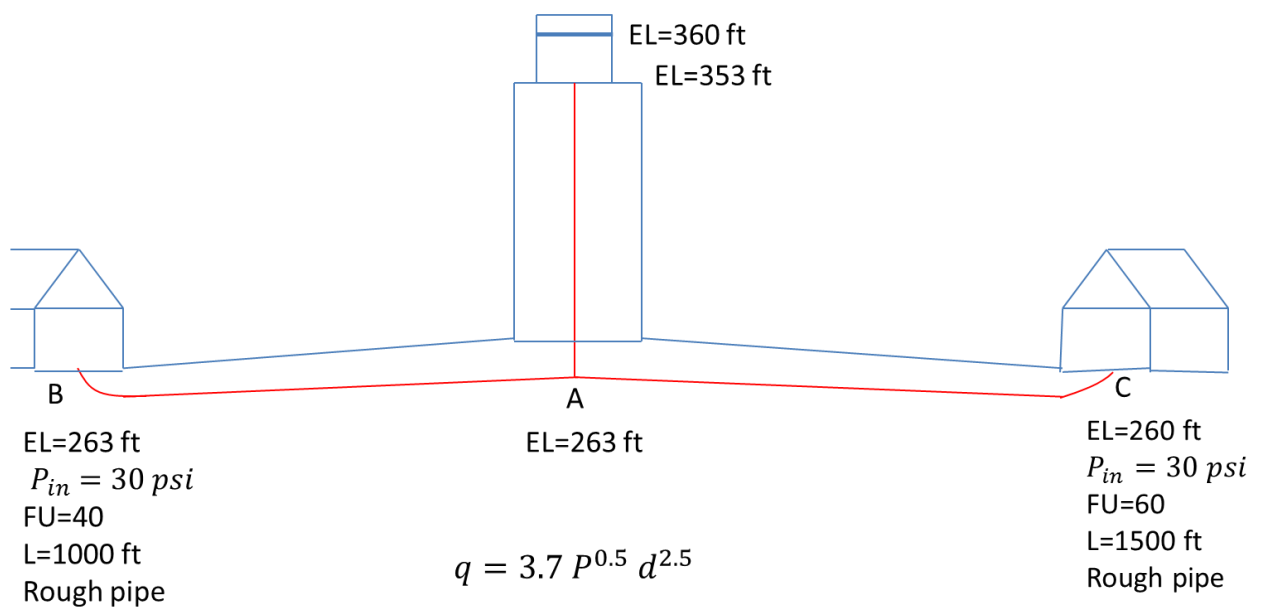
Pressure of points: $P_c = 32 - \frac{10 \times 62.4}{144} - 8 - \frac{9.27 \times 40}{84} = 15.252 \text{ psi}$

$$P \text{ at } CC' = \frac{15.252 \times 100}{20} = 76.26 \text{ psi}$$

Points	P	P/100
C	15.252	76.26
D	8.73	43.65
E	2.2	11

Pipes	P/100	$q_{dem}, l/min$	$q_{des} l/min$	Dia. Cal. mm	Dia. Sel. mm
ABC	11.04	900	240	39	40
CD	11.04	600	196	36	40
DE	11.04	300	139	32	35
CC'	76.26	300	139	21	25
DD'	43.65	300	139	24	25
EE'	11	300	139	32	35

Example : Design water lines shown in figure



For F.U = 40 $\rightarrow$ $q = 47 \text{ gpm}$

$$P_{toB} = (353 - 263) \times \frac{62.4}{144} - 30 = 9 \text{ psi}$$

$$P_{toB} \text{ in } 100 \text{ ft} = \frac{9 \times 100}{1000} = 0.9 \text{ psi}$$

$$47 = 3.7 \times 0.9^{0.5} \times d^{2.5} \quad \rightarrow \quad d = 2.8 \text{ in.} \quad \text{use } d = 3 \text{ in.}$$

For F.U= 60 → $q = 55 \text{ gpm}$

$$P_{to C} = (353 - 260) \times \frac{62.4}{144} - 30 = 10.3 \text{ psi}$$

$$P_{to C} \text{ in } 100 \text{ ft} = \frac{10.3 \times 100}{1500} = 0.687 \text{ psi}$$

$$55 = 3.7 \times 0.687^{0.5} \times d^{2.5}$$

$$d = 3.2 \text{ in.} \quad \text{use } d = 3.5 \text{ in.}$$

Design from tank to A

$$q = 47 + 55 = 102 \text{ gpm}$$

Using the minimum pressure from tank to C = 0.687 psi

$$102 = 3.7 \times 0.687^{0.5} \times d^{2.5}$$

$$d = 4.1 \text{ in} \quad \text{use } d = 4.5 \text{ in}$$

Example: There is a 16-story building where the street pressure is reported as 45 psi. The highest outlet is 180 ft above the level of the pumps and the pumps are at the same level as the street main. The building has flush valve water closets and the required pressure at the highest fixture is 20 psi. The total combined cold and hot water fixture count for the building is 4840 F.U. The length of run from the pumps to the farthest and highest fixture is 350 ft. Material for the water service into the building will be type copper piping. Calculate the pump capacity in psi and design the main pipe(head loss through pump is 5 psi).

$$\text{static pressure} = \frac{180 \times 62.4}{144} = 78 \text{ psi}$$

$$\text{dynamic pressure} = 20 \text{ psi}$$

$$\text{head loss in pump} = 5 \text{ psi}$$

$$\text{total pressure} = 103 \text{ psi}$$

$$\text{Pump Capacity} = 103 - 45 = 58 \text{ psi}$$

$$p_f = 0.00027 q^2 \frac{L}{d^5}$$

$$F.U. = 4840 \quad \rightarrow \quad q = 582 \text{ gpm}$$

$$L_e = 1.5 \times 350 = 525 \text{ ft}$$

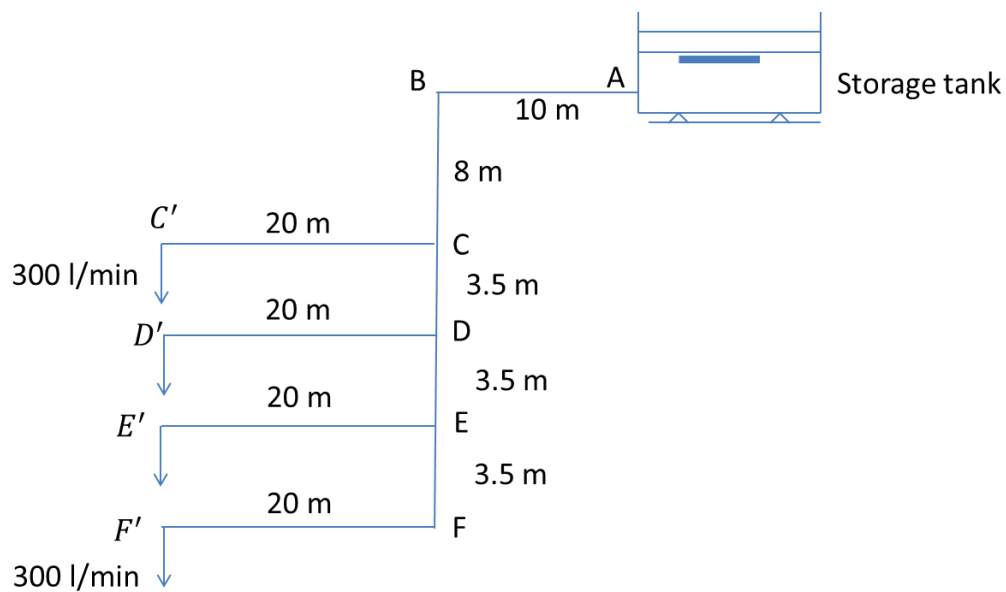
$$58 = 0.00027 \times 582^2 \times \frac{525}{d^5}$$

$$d = 3.83 \text{ in.} \quad \text{use} \quad d = 4 \text{ in.}$$

Example : Design pipes of water supply network shown in Fig. using

$$h_f = 0.000623 q^2 \frac{L}{d^5}$$

$$\text{or} \quad p_f = 0.00027 q^2 \frac{L}{d^5}$$



$$h_f = 8 - 5.61 = 2.39 \text{ m}$$

$$L_e = 38 \times 1.5 = 57 \text{ m}$$

$$S = \frac{2.39}{57} = 0.042$$

$$\text{Point c :} \quad h_f = 8 - 0.042 \times 18 - 5.61 = 1.634 \text{ m}$$

$$L_e = 20 \times 1.5 = 30 \text{ m}$$

$$S = \frac{1.634}{30} = 0.054$$

Points	h_f	L	S
C	1.634	30	0.054
D	4.987	30	0.166
E	8.34	30	0.278
F	11.693	30	0.39

Pipes	S	$Q_T, l/min$	$Q_D, l/min$	Dia. Cal. , in	Dia. sel. , in
ABC	0.042	1200	277	2.4	2.5
CD	0.042	900	240	2.3	2.5
DE	0.042	600	196	2.1	2.5
EF	0.042	300	139	1.8	2.0
CC'	0.054	300	139	1.7	2.0
DD'	0.166	300	139	1.4	1.5
EE'	0.278	300	139	1.25	1.5
FF'	0.39	300	139	1.2	1.5