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The Design of Water Supply to Buildings Utilizing Public Mains in Developing Environments

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Abstract- The important aspects of the design of water supply systems for buildings which utilize public mains, namely the determination of water demand and storage tank capacities, distribution pipe layout planning and sizing, determination of height of high level storage, and the rating of the booster pump, are discussed, highlighting preferences for developing environments like Nigeria. An actual water supply system design for a residential building project, consisting of a five-bedroom unit having two floors and a two-bedroom flat on the ground floor, is used to illustrate the design procedures.

Keywords- *Water Supply, Developing Environments*

I. INTRODUCTION

The low system pressure and erratic supply situation of public water supplies experienced in Nigeria, and other developing countries, make it difficult to obtain reliable flow data that can be used for design purposes. It is thus usually difficult to ascertain the height to which water from public mains can rise in pipe work supplying sanitary appliances and other outlets in a building. The way out of this problem is to boost the mains supply by means of pumps before distribution to building premises.

Several arrangements of pump, ancillary equipment and piping for boosting water systems abound (1, 2). Of these, the simplest system which is most times recommended on the ground of ease of maintenance is shown in Figure 1. In this arrangement water flows from the mains into a tank located at ground level. The water pump then raises the water from this level into a high level tank from which distribution to sanitary appliances and other terminal points is achieved by virtue of gravity.

As a contribution towards the proper functioning of this system, this paper presents guidelines for design practice. These guidelines have been adapted from existing standard practice to suit our peculiar developing environment.

To illustrate the application of the presented guidelines, a set of design calculations for an actual residential building project is given.

II. SOME DESIGN CONSIDERATIONS FOR WATER SUPPLY SYSTEMS

A. *Determination of water demand and tank capacities*

The water quantities required to be stored per head are stipulated in codes of practice. For example, the British Standards Code of Practice (CP) 310 (3) stipulates the demands listed in Table 1 based on the use of the building. These demands are expected to cover 24 hours of interruption of supply by British standards. To such domestic uses as are stipulated in Table 1, demands for other uses such as firefighting, agriculture, etc., need to be added, where such uses are planned for.

As water supplies in developing environments are very often interrupted for longer periods, it is suggested that larger capacities be provided for in our designs. Two to three times these storage capacities may be adequate.

The storage capacities so calculated are made up of the low level and high level volumes. The ratio for dividing the total demand between the two tanks would normally consider such factors as construction of a suitable supporting structure for the high level tank (if it is not located on a roof), structural integrity of the roof members (for a roof-mounted tank), available spaces for the tanks, etc. Usually, the low level tank is of higher capacity as it is more stable to locate a larger capacity (or heavier load) at a low level.

B. *Distribution pipe layout planning*

The layout planning of water piping should result in a simple and economical arrangement. For instance, where a single riser can conveniently supply several floors in a multi-story building, it would be uneconomical to use individual risers to supply the different floors. Similarly, where a single horizontal pipe run can supply appliances located in adjacent rooms, it would be uneconomical to have separate horizontal runs to supply the different rooms.

Appropriate pipe fittings should be provided for in the network wherever needed.

C. *Pipe sizing*

This is an important aspect of water supply system design since a wrongly sized pipe can result in interruption of water supply. Procedures for sizing of water supply piping are given in available literature (4, 5). These procedures utilize the available pressure from the supply source (which, in the boosted supply recommended, is the high level tank), the required flow rates and velocities at the terminal points and appliances, as stipulated in design codes such as are given in Table 2 (3), and the pressure losses along the pipe work.

D. Height of water tank

The height of the high level tank must be carefully calculated to ensure water supply in adequate flow rate and pressure at all points in the system. The critical point to consider is the fixture or terminal which is most likely to be starved of water. If the water flow rate and pressure at this point are calculated to be adequate, then all other points in the system would receive adequate supply.

While intending to achieve this, it should be borne in mind that an unnecessarily high elevation of the high level tank would require a higher cost due to the excess construction of the supporting tower and the higher rating of the booster pump.

E. Rating of water booster pump

The head to be overcome by the booster pump is an addition of the height of the high level tank above the pump outlet (the static discharge head); the friction (resistance to water flow) of the internal surface of the pipe; the head loss due to pipe fittings such as bends and tees, and due to valves; the height of the pump above the low level tank (the suction lift); as well as the head due to pressure difference between the low level and high level tanks (the pressure head).

While the head losses due to friction and pipe fittings vary with flow rate, the static discharge head, the suction lift and pressure head do not vary with flow rate in this simple boosted system. Also, the pressure head is usually zero as both the low level and high level water surfaces are at atmospheric pressure.

Pump rating requires determining the discharge rate (which should be a reasonable filling rate of the high level tank) and the total head to be overcome by the pump. The procedure involves generating a graph of total heads to be overcome versus flow rates for the system, and superimposing this graph onto the characteristic head versus flow curves of a particular pump series. The point of intersection represents the operating point which gives the design head and flow rate i.e. the rating of the pump.

In making a choice of pump type, one with a characteristic curve having a wide plateau at the peak efficiency is usually preferred, and the operating point should be near this peak efficiency. Furthermore, cavitation, the detrimental phenomenon of formation and subsequent collapse or condensation of vapor bubbles at normal temperatures (as a result of a low pressure occurring at some point in the flowing fluid) should be avoided in pump selection. The procedure for avoiding this phenomenon is elaborated in available literature (6).

III. A PRACTICAL EXAMPLE

To illustrate the application of the considerations set out so far, the example of an actual residential building, whose water distribution network is shown in the isometric drawing of Figure 2, is taken. There are two building units within the premises: a five-bedroom unit having two floors and a two-bedroom flat on the ground floor.

Water is supplied to the building units from the public mains through an elevated tank which is fed from a ground tank by a pump. The distribution network is of polyvinyl chloride (PVC) pressure piping.

A. Water storage capacities

The building is expected to accommodate 10 residents.

Water storage (using Table 1) = 90 x 10L = 900L

Taking three times this quantity, the total volume to be stored in both tanks is 2700 L. Dividing this volume in the ratio of 2:1 to the low level and high level tanks, then

Low level capacity = $\frac{2}{3} \times 2700 = 1800L$

High level capacity = $\frac{1}{3} \times 2700 = 900L$

B. Distribution pipe sizing

The first index run of pipe i.e. that along which taps are most likely to be starved of water appears to be that made up of pipe sections 1, 2, 3, ..., 12. For the purpose of achieving clarity, this run of pipe is redrawn in Figure 3 in which the pipe sections are numbered (using boxes which touch the relevant sections) as follows: the pipe number is on the left hand side of the box, the actual pipe length on the top right, and the rate of flow is on the bottom right.

In determining flow rates for pipe runs in extensive pipe installations, it is usual practice to account for the fact that not all taps would be opened simultaneously. And so a frequency-of-use estimate expressed as loading units for each appliance is utilized. These units are listed by Barry (5) as 2 for a water closet cistern, 1.5 for a wash basin, 10 for a bath, and 3 to 5 for a sink (an average of 4 being used in this illustration). For appliances whose loading units are not listed, units are assumed by comparison with appliances using similar water quantities and flow rates. The flow rates for different pipe runs are obtained from graphs of loading unit versus flow rate, such as that in Appendix 1 (1).

In situations where the loading units calculated for any section are less than the smallest value for which the graph can be used, i.e. the value of 10, the flow rate is approximated by interpolating linearly between 0 and 10 loading units i.e. by the derived relationship,

Design flow = 0.034 x loading unit

The approximate flow rates so obtained are marked with asterisks in Table 3, which summarizes the pipe sizing calculations for pipe sections 1 to 14. The actual pipe lengths for different pipe sections are measured from the building drawings.

Chosen height of high level tank above ground = 10m

Height of farthest water outlet (i.e. the wash basin at pipe section 12) in first index run (above ground) = 5m

$\therefore$ head available in first index run (above ground)

= 10 – 5 = 5m

To obtain a set of assumed pipe sizes (to enable the estimation of the pressure losses in the pipe fittings) an equivalent pipe length for resistance to flow in fittings of 50% of the length of the first index run is assumed.

Measured pipe length in first index run = 66.5m

$\therefore$ total equivalent length = 66.5 x 1.5 = 99.75m

Thus, permissible rate of head loss per metre

$$(H/L) = \frac{5}{99.5} = 0.0501$$

The chart of Appendix 2 (1) is now used to obtain assumed pipe sizes utilizing this permissible rate of head loss and the flow rate in each section of the first index run.

The pipe numbers, loading units, design flow rates, actual pipe lengths and the assumed diameters are respectively entered in columns 1, 2, 3,4 and 8 in Table 3.

The assumed diameters are now used to calculate, more accurately, the friction losses in terms of equivalent pipe diameters given as (5) 30 pipe diameters for 90^0 elbows, 40 for tees, 20 for gate valves, and 300 for globe valves and taps. For the ball valves, the loss of head is obtained from the graph of head loss versus flow rate given in Appendix 3 (1).

In pipe section 1, for instance, there are 2 elbows, 1 gate valve and I tee and so the corresponding number of pipe diameters equivalent to losses in fittings is 2 x 30 + 1 x 20 + 1 x 40 = 120

The assumed pipe diameter in section 1 = 40mm
$\therefore$ equivalent length of fittings = 120 x 40mm
= 4800mm
= 4.8m

This figure is entered into Column 5. Equivalent lengths of fittings for other sections are obtained in a similar manner. The total equivalent lengths (Column 6) are obtained by the addition of the actual lengths to the equivalent lengths of fittings and valves.

Now, the total of equivalent lengths in Column 6 of the first index run = 101.79m.

Thus, a more accurate permissible rate of loss of head in the first index run (Column 9) = $\frac{5}{101.79} = 0.049$

Final pipe diameters (Column 13) are now selected from the chart in Appendix 2 using this permissible rate of loss of head. The rates of head loss at the interception of the lines of rate of flow and pipe diameter are now the actual rate of head loss values (Column 10). The product of total equivalent length and actual rate of head loss gives the head used (Column 11) in each pipe section. The head of 5m available in pipe section 1 is progressively reduced along the first index run after each section, as shown in Columns 7 and 12. To obtain pipe sizes for runs other than the first index run, pipe numbers, loading units, design flow rates, and actual lengths are tabulated as before.

Now, ratios of total equivalent length to actual pipe length in the first index run = $\frac{101.79}{66.5} = 1.53$

This ratio is used to obtain assumed pipe sizes for runs other than the first index run. For pipe run 13 to 14, for instance, measured total pipe length = 4.0m

$\therefore$ assumed total equivalent length = 4.0 x 1.53
= 6.12m

Head available for this pipe run = that remaining after pipe run 7 less the height of the top of pipe section 14

= 1.4345 - 0.5

= 0.9345m

$\therefore$ permissible H/L value for pipe run 13 to 14

$= \frac{0.9345}{6.12} = 0.152$

Assumed pipe sizes are thus obtained as before. Thus, for pipe section 13 which has a flow rate of 0.35 L/s a 20mm pipe size is obtained. Equivalent lengths of fittings are obtained using these assumed diameters and proceeding as before to obtain final pipe diameters.

For instance, in pipe section 13, there are 1 elbow, 1 gate valve and 1 tee. The corresponding number of pipe diameters equivalent to losses = I x 30 + 1 x 20 + 1 x 40 = 90

$\therefore$ equivalent length of fittings = 90 x 20

=1800mm

= 1.8m

This figure is entered in Column 5. Measured length of section 13 = 1.0m

$\therefore$ total equivalent length of section 13 = 1.8 + 1.0

= 2.8m

This figure is entered in Column 6. Pipe section 14 is treated in the same way as section 13. Now, total of equivalent lengths in Column 6 for pipe run 13 to 14

= 11.65m

Thus, a more accurate permissible H/L for this run of pipe $= \frac{0.9345}{11.65} = 0.080$

Final accurate pipe diameters (Column 13) are now selected from the pipe sizing graph using this permissible rate of loss of head, and the corresponding actual H/L value is recorded in Column 10. Values of head available, head used and head remaining are calculated in the same way as for the first index run.

C. Height of high level storage

The chosen height of the high level storage depends on the availability of a positive remaining head at the end of the first index run of pipe. The availability of the positive head of 0.7004 indicates that water will flow at the required rate to the wash basin at pipe section 12 and so the chosen tank height of 10m above level ground is adequate.

If, on the other hand, a negative (or too low) positive head remained from the calculations, the tank height would have needed to be increased and the pipe sizing calculations repeated, until a comfortable positive remaining head was obtained at the end of the first index run.

D. Booster pump rating

A schematic diagram of the pumping arrangement is shown in Figure 4. Two pumps (one on duty and one on standby) are connected to the high level tank by means of a 25mm PVC pressure pipe, which size of pipe also constitutes the suction pipe from the low level tank.

Friction loss, h_f, in pipe is given as (6)

$$h_f = \frac{133.4d^{-0.017}}{C^{1.85}}\left(\frac{1}{vd}\right)^{0.15}\left(\frac{l}{d}\right)\frac{v^2}{2g} \quad (1)$$

where d = pipe diameter (in m)

c = Hazen– Williams Coefficient

v = flow velocity (in m/s)

l = pipe length (in m)

g = acceleration due to gravity, 9.81m/s^2

Putting in the values of d = 0.0254m, C = 130 (6) and l = 13.5m (the measured total pipe length for the suction and discharge lines) and substituting for Q by means of the expression

$$V = \frac{\text{Discharge rate}}{\text{Pipe cross-sectional area}}$$

$$= \frac{4Q}{3600 \times \pi \times 0.0254^2} = 0.548Q \quad (2)$$

where Q = Discharge rate (in m^3/h)

results in

$$h_f = 0.2694\,Q^{1.85} \quad (3)$$

Values of h_f for various values of Q are then computed as in Table 4. The losses in pipe fittings and valves are computed for various flow rates. The pipe fittings and their corresponding losses are as given in Table 5 (6).

Total loss through fittings and valves,

$$= \frac{V^2}{2g}\{0.5 + (7 \times 0.75) + (2 \times 2) + (2 \times 0.25) + 30\}$$

$$+ \text{loss through ball valve}$$

$$= 13.25V^2/2g + \text{loss through ball valve} \quad (4)$$

Again substituting for Q from Equation 2 yields the result

$$h_p = 0.2028\,Q^2 + \text{loss through ball valve} \quad (5)$$

The losses through ball valves are obtained from the chart in Appendix 3 (1).

Thus for Q = 1 .0m^3/h (or 0.28 L/s), for instance, loss through the 13mm diameter ball valve orifice

= 0.33m

$\therefore h_p$ = 0.2028 x 1^2 + 0.33

= 0.533m

Values of h_p for various values of Q are as presented in Table 6.

The total static head, h_s = static discharge head + suction lift = difference in elevation between the high and low level tanks (neglecting the depths of the pipe work within the tanks).

And the total system head, $H_t = h_f + h_p + h_s$.

Values of H_t for the various discharge rates are thereby presented in Table 7.

The curve of Q versus H_t is shown superimposed on the performance characteristic curves of 'Grundfos' model pumps in Figure 5. The system head curve cuts the CH4-20 pump performance curve at Q = 2.5m^3/h and H_t = 14.5m; the CH4-30 curve at Q = 3.8m^3/h and H_t = 19.5m; and the CH4-40 curve at Q = 4.7m^3/h and H_t = 25.0m.

The peak efficiency of 72% occurs at Q = 3.5m^3/h which is 1m^3/h higher than 2.5m^3/h (the flow rate at which the system head curve cuts the CH4.20 characteristic curve). It is also 1.2m^3/h less than 4.7m^3/h (the flow rate at which the system head curve cuts the CH4.40 curve. It is, also, 0.3m^3/h less than 3.8m^3/h (the flow rate at which the system curve cuts the CH4.30 curve). On account of the deviation of 0.3m^3/h being the least among the three values, a selection of the CH4.30 pump is made.

In order to avoid pump cavitation, it is necessary to ensure that the available net positive suction head (NPSH) is at least equal to the required NPSH specified by the pump manufacturer (7).

If, for instance, the CH4 -30 pump is selected, then (from the graph of NPSH versus flow rate *Q*, obtained from the manufacturer (8) and shown in Figure 5), the required NPSH is 0.7m. The available NPSH is now calculated.

Applying Bernoulli's equation to points 1 and 2 in Figure 4 under cavitation conditions (i.e. when the pressure at entrance to the pump equals the vapor pressure of the liquid),

$$\frac{P_1}{\rho g}+\frac{V_1^2}{2g}+Z_1=\frac{P_2}{\rho g}+\frac{V_2^2}{2g}+Z_2+\text{ Losses} \quad (6)$$

where P_1 = Pressure at tank = atmospheric pressure of 101kN/m^2

ρ = Density of water at prevailing temperature of 30°C (specific volume at 30°C = 0.001004m^3/kg from steam tables)

V_1 = Velocity at tank = 0 m/s

Z_1 = Elevation of inlet to pipe from tank (relative to a datum level)

P_2 = Vapor pressure at water temperature of 30^{o}C = 4.24kN/m^2 (from steam tables)

V_2 = Flow velocity

Z_2 = Elevation of pump center line relative to datum level

$$Z_2-Z_1=\frac{P_1-P_2}{\rho g}+\frac{V_1^2-V_2^2}{2g}-\text{Losses} \quad (7)$$

Now at Q = 3.8m^3/h

V = 0.548 x 3.8 (from Equation 2) = 2.08m/s

For a pipe length of 13.5m,

h_f = 0.2694 $Q^{1.85}$ (from Equation 3)

Therefore, for the suction pipe length of 1.5m and at the design flow rate of 3.8m/s, friction loss

$$h_f = 0.2694\times 3.8^{1.85}\times\frac{1.5}{13.5}= 0.354\text{m}$$

The loss through pipe fittings and valves (two 90° elbows, one entrance to pipe from tank, one gate valve and one tee)

$$h_p = 2\times\frac{0.75V_2^2}{2g}+\frac{0.5V_2^2}{2g}+\frac{0.25V_2^2}{2g}+\frac{2V_2^2}{2g}=\frac{4.25\times 2.08^2}{2\times 9.81}$$

= 0.937m

∴ total head loss in suction pipe

$= 0.354+0.937$

= 1.291m

Substituting values in Equation 7 results in

$$Z_2-Z_1=\frac{(101-4.24)}{9.81}10^3\times 0.001004+\frac{0-2.08^2}{2\times 9.81}-1.291$$

= 8.39 m

This represents the maximum possible height of the pump above the outlet of the low level tank, to avoid cavitation. As this available NPSH is larger than the required NPSH (0.7m), it is satisfactory. For commonly encountered boosting arrangements such as Figure 4 the available NPSH is usually far greater than that required, as can be observed from this example, and it is usually not necessary to undertake the estimation of the NPSH, for simple water boosting arrangements.

IV. CONCLUSIONS

In addition to proper maintenance and upgrading of water supply systems by both the water authorities and individual house owners, proper engineering design and installation of the systems are necessary for solving the erratic water supply problem.

Such designs should be done according to relevant codes of practice and guidelines, properly applied to suit our peculiar circumstances, especially in the aspects of choice of boosting system, determining water storage capacities and height of high level tank, pump selection, and pipe layout planning and sizing.

To ensure that such codes and guidelines are applied, building and planning approval authorities should ensure that qualified personnel carry out all water supply system designs. They should also monitor the execution of the supply installations to ensure conformity with approved designs.

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TABLE I.

Types of Building	**Storage in Liters**	
Dwelling houses and flats	Per resident	90
Hostels	Per resident	90
Hotels	Per resident	135
Offices without canteens	Per head	35
Offices with canteens	Per head	45
Restaurants	Per head per meal	8
Day schools	Per head	27
Boarding schools	Per resident	90
Nurses homes and medical quarters	Per resident	110

TABLE II. RECOMMENDED FLOW RATES FROM FULLY OPEN HOT AND COLD WATER TAPS

Sanitary Appliance	Flow Rate in Liters/Second
Water closet flushing cistern	0.11
Lavatory basin	0.15
Bath	0.30
Sink	0.30

TABLE III. SUMMARY OF PIPE SIZING CALCULATIONS

1	2	3	4	5	6	7	8	9	10	11	12	13	14
Pipe No.	Loading Unit	Design Flow Rate (L/s)	Actual Pipe Length (m)	Equiv. Length of Fittings (m)	Total Equiv. Length (m)	Head Available (mm)	Assumed Diam. (mm)	Permissible H/L Value	Actual H/L Value	Head Used (m)	Head Remaining (m)	Final Diameter (mm)	Types and Nos. of Fittings and Valves
1	122.0	1.47	10.50	4.80	15.30	5.0000	40	0.049	0.047	0.7191	4.2809	40	2 elbows I gate valve 1 tee
2	91.0	1.17	4.00	2.40	6.40	4.0761	40	0.049	0.032	0.2048	3.8713	40	I gate valve 1 tee
3	70.0	1.00	4.50	2.40	6.90	3.8713	40	0.049	0.025	0.1725	3.6988	40	I gate valve 1 tee
4	60.0	0.90	2.00	2.40	4.40	3.6988	40	0.049	0.022	0.0968	3.6020	40	I gate valve 1 tee
5	52.0	0.82	5.00	1.92	6.92	3.6020	32	0.049	0.045	0.3114	3.2906	32	I gate valve 1 tee
6	26.5	0.55	1.00	1.92	2.92	3.2906	32	0.049	0.024	0.0701	3.2205	32	I gate valve 1 tee
7	21.0	0.46	30.00	8.00	38.00	3.2205	25	0.049	0.047	1.7860	1.4345	25	8 elbows 2 gate valves 1 tee
8	17.5	0.40	4.00	3.00	7.00	1.4345	25	0.049	0.038	0.2590	1.1755	25	2 elbows I gate valve 1 tee
9	15.5	0.39	0.50	1.00	1.50	1.1755	25	0.049	0.037	0.0555	1.1200	25	1 tee
10	5.5	0.19*	1.00	0.80	1.80	1.1200	20	0.049	0.042	0.0756	1.0444	20	1 tee
11	3.5	0.12*	1.00	0.80	1.80	1.0444	20	0.049	0.019	0.0342	1.0102	20	1 tee
12	1.5	0.05*	3.00	5.85	8.85	1.0102	15	0.049	0.035	0.3098	0.7004	15	3 elbows, 1 tap
13	11.0	0.35	1.00	1.80	2.80	0.9345	20	0.080	0.030	0.0840	0.8505	25	1 elbow 1 gate valve 1 tee
14	1.5	0.05*	3.00	5.85	8.85	0.8505	15	0.080	0.035	0.3098	0.5407	15	3 elbows 1 tap

TABLE IV. CALCULATED PIPE FRICTION LOSS FOR VARIOUS FLOW RATES

Q (m^3/h)	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0
h_f (m)	0.27	0.57	0.97	1.47	2.06	2.73	3.50	4.35	5.29

TABLE V. FORMULA FOR HEAD LOSS IN PIPE FITTINGS

Type of Fitting	Head Loss Formula	Number of Fittings
Entrance to pipe from tank	$0.50\frac{v^2}{2g}$	1
90° elbow	$0.75\frac{v^2}{2g}$	7
Tee	$2.00\frac{v^2}{2g}$	2
Gate valve	$0.25\frac{v^2}{2g}$	2
Check valve	$3.00\frac{v^2}{2g}$	1
Ball valve with 13mm Orifice	Values obtainable from graph in Appendix 3	1

TABLE VI. CALCULATED HEAD LOSS FOR PIPE FITTING FOR VARIOUS FLOW RATES

Q (m^3/h)	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0
h_p (m)	1.53	1.21	2.06	2.82	4.33	5.78	7.05	9.11	10.57

TABLE VII. CALCULATED TOTAL SYSTEM HEAD, FOR VARIOUS FLOW RATES

Q (m^3/h)	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0
h_f (m)	0.27	0.57	0.97	1.47	2.06	2.73	3.50	4.35	5.29
h_p (m)	1.53	1.21	2.06	2.82	4.33	5.78	7.05	9.11	10.57
H_s (m)	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00
H_t (m)	10.80	11.78	13.03	14.29	16.39	18.51	20.55	23.46	25.86

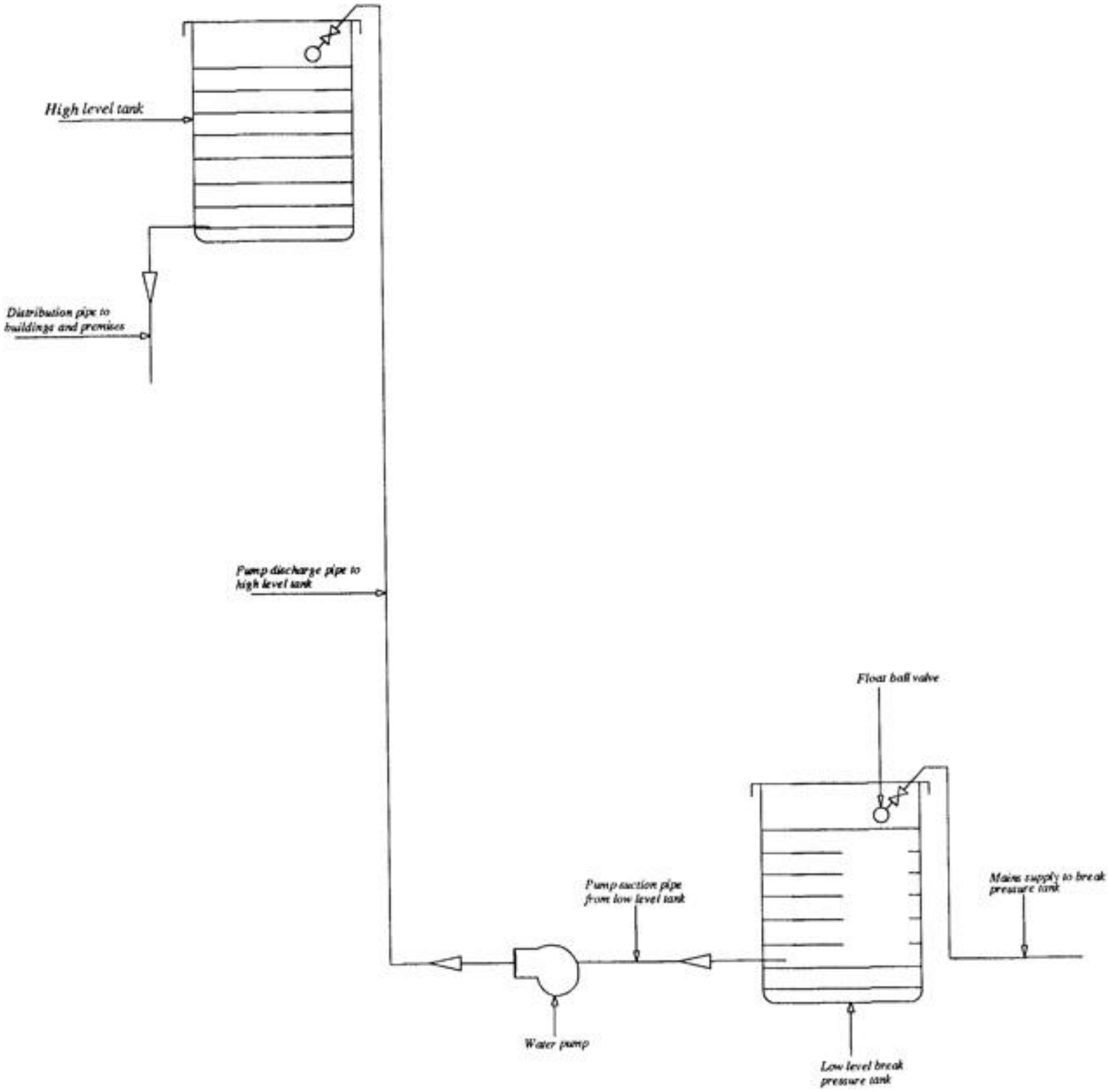


Figure 1. Sketch of simple boosted water distribution system (Accessories and pipe fittings not shown)

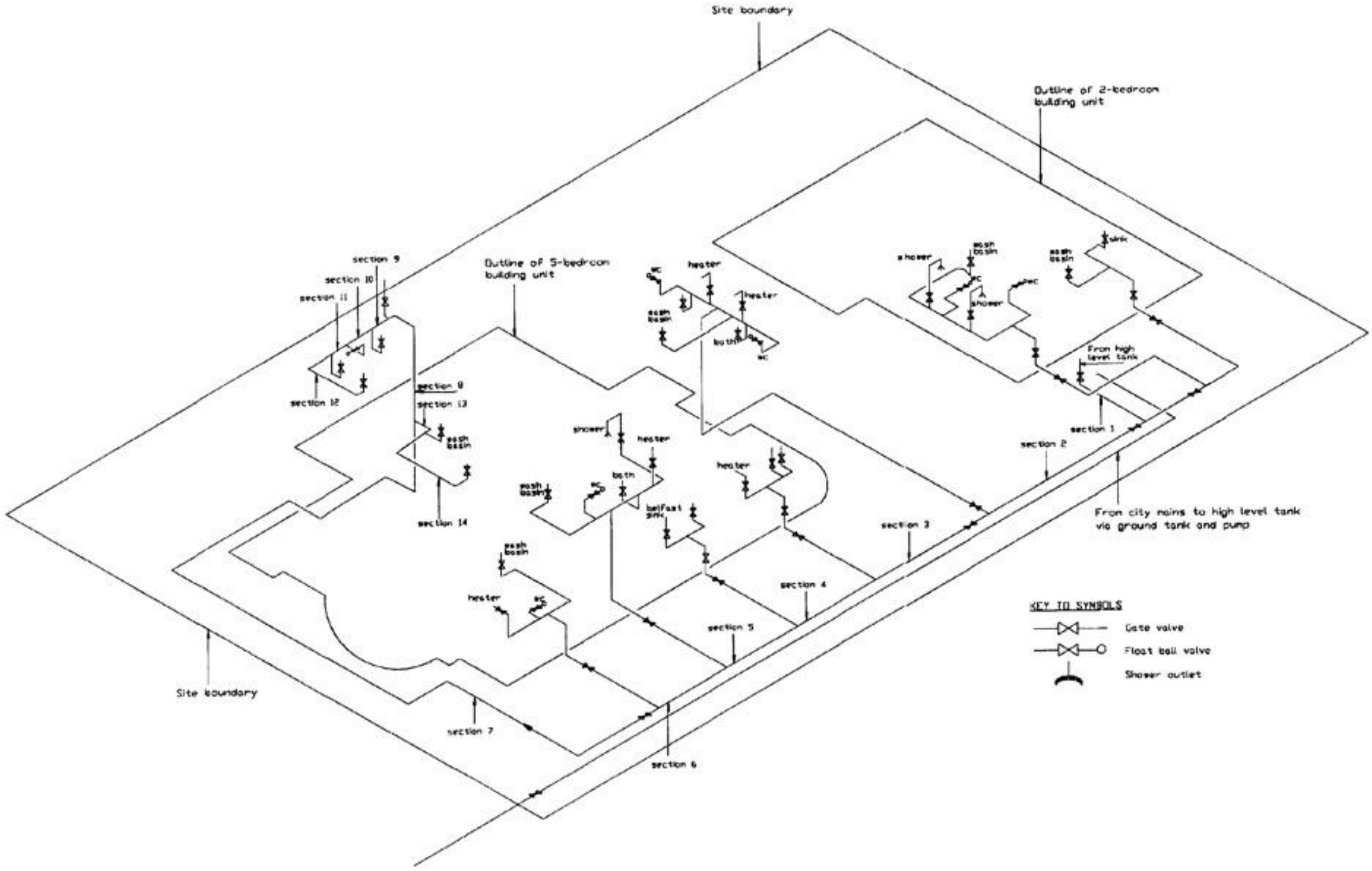


Figure 2. Isometric sketch of water distribution piping

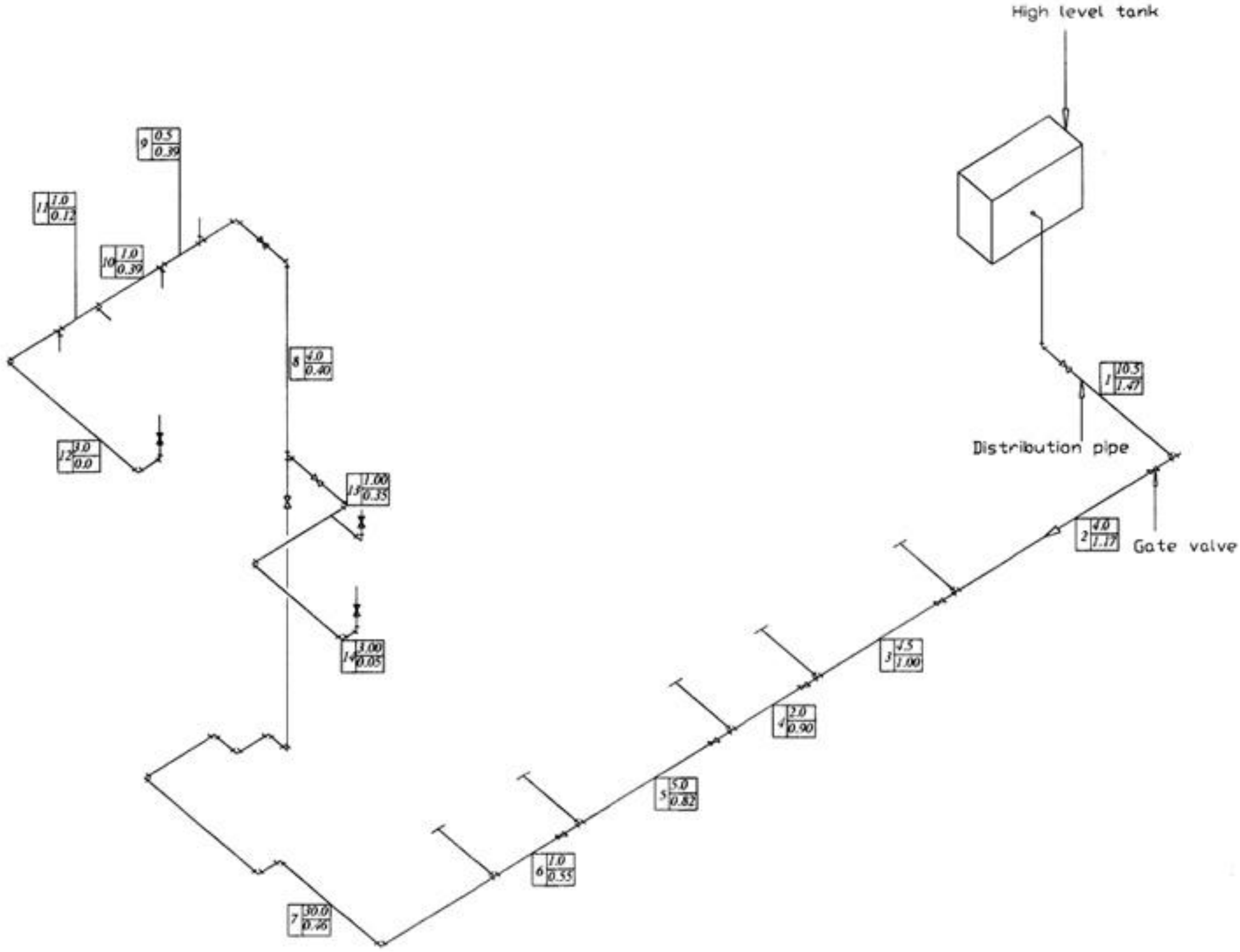


Figure 3. Isometric drawing of first index pipe run

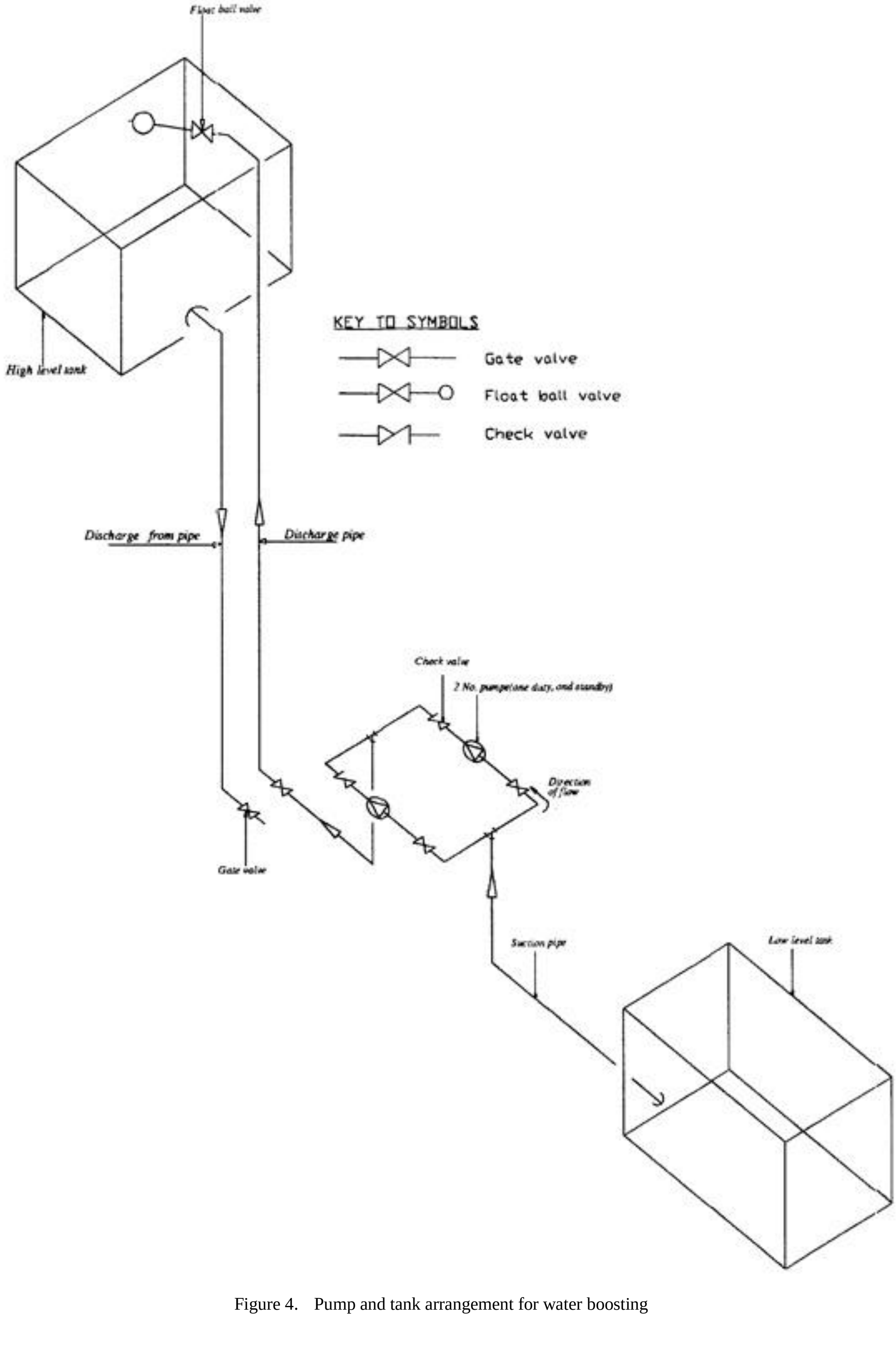


Figure 4. Pump and tank arrangement for water boosting

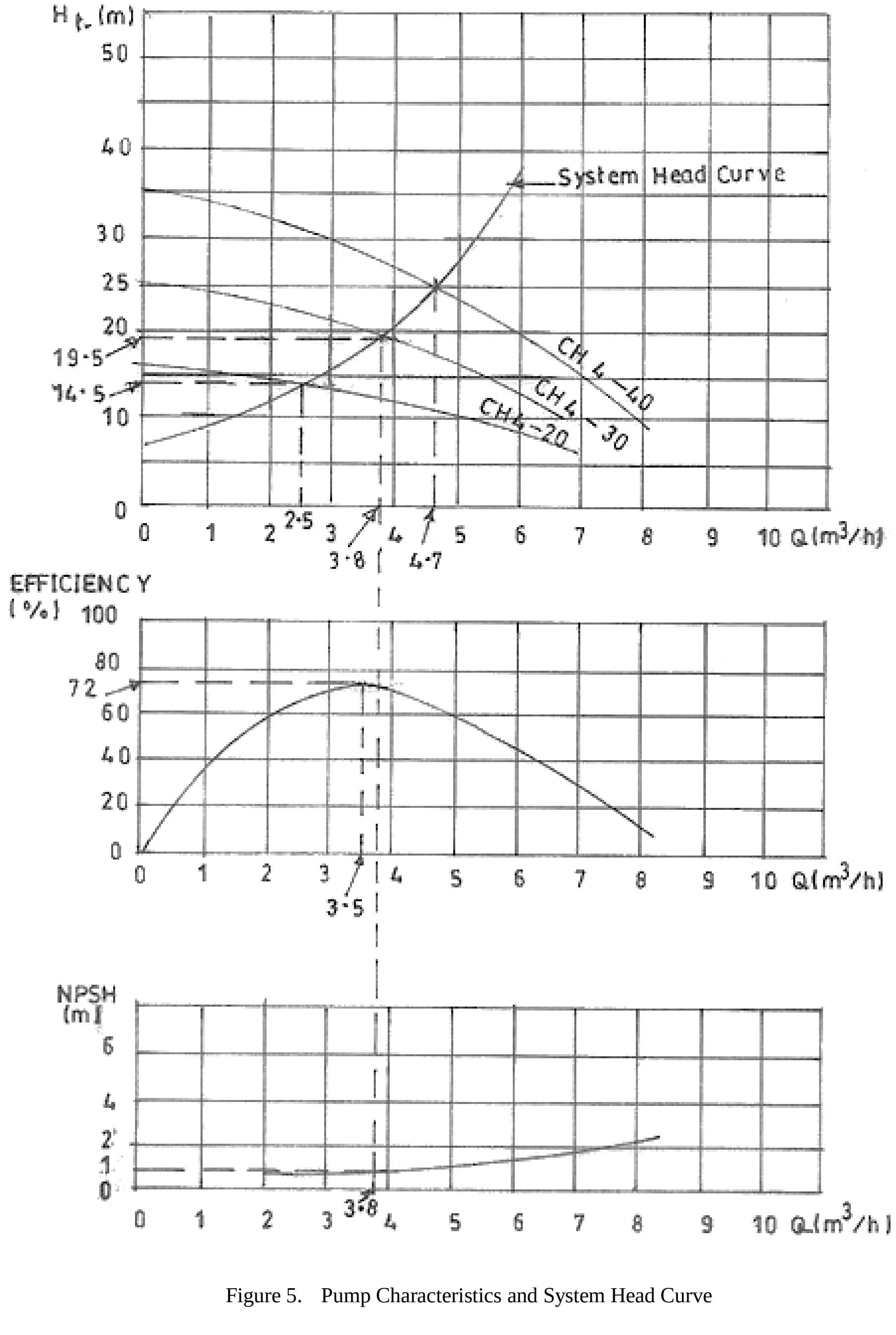
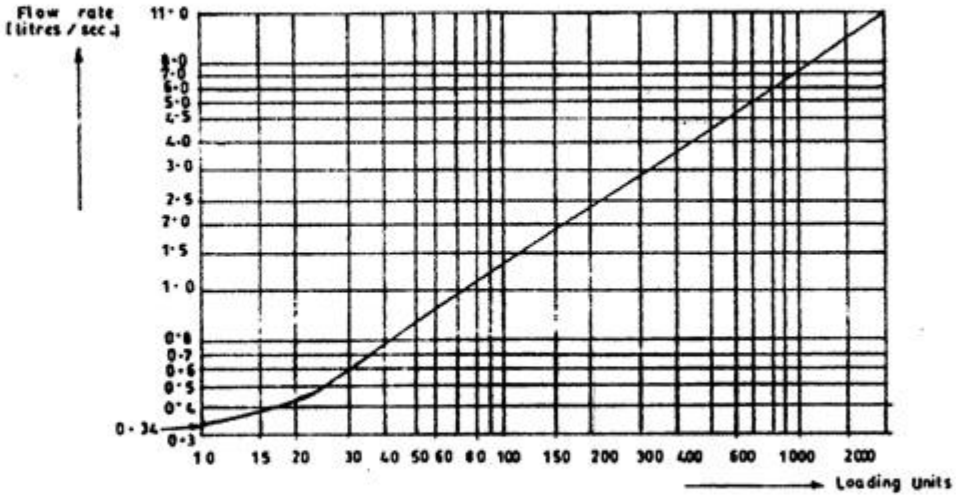
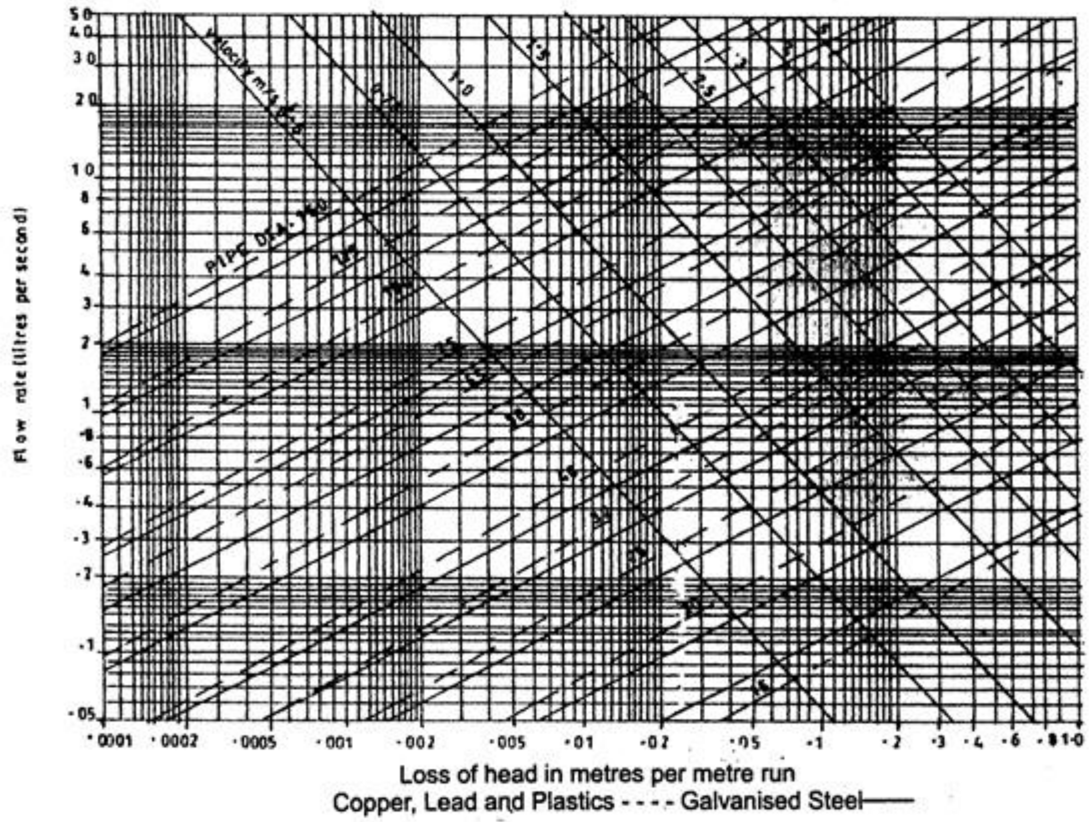


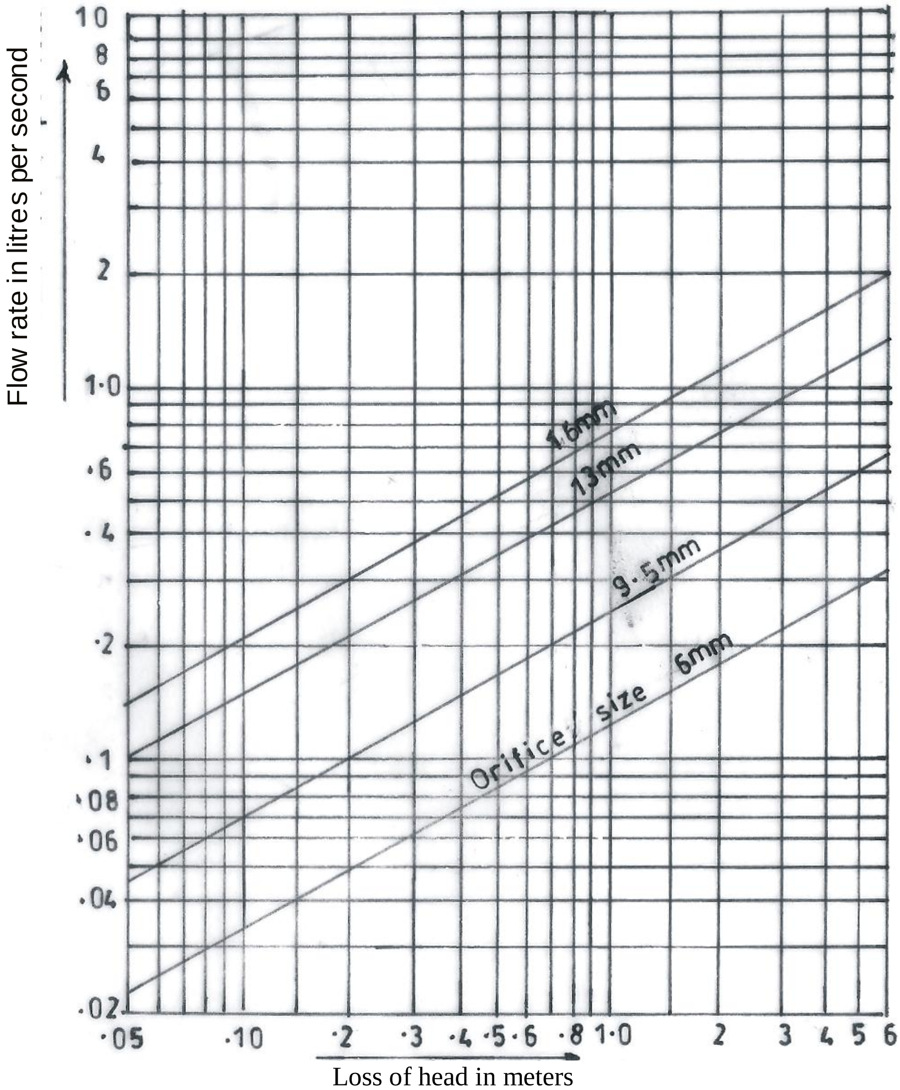
Figure 5. Pump Characteristics and System Head Curve



Appendix 1: Loading Units and Design Flow Rates (1)



Appendix 2: Pipe Sizing Graph (1)



Appendix 3: Head Loss through Ball Valve Orifices