CHAPTER 3

METHODOLOGY

3.1 GENERAL

The problem of optimal design of pipe networks essentially involves determination of pipe sizes which will meet the physical and operational requirements imposed on the network at minimum cost. The constraints include the hydraulic laws and operational ones such as the minimum residual pressure requirement, restriction to commercially available diameters and the minimum permissible diameter. The total cost of the network is generally assumed to include the first cost of pipes, pumps and other components and present value of maintenance and operating costs. Several approaches have been suggested for handling this economic design problem over the years. Trial and error methods, hydraulic and electrical models and more recently optimisation and simulation models using computers have been employed for the solution of this problem. Before the advent of computers, a reasonably satisfactory solution had to be based on a few trials because of the extensive labour and time involved in the computation. Even for moderately sized networks the hydraulic balancing with a chosen set of pipe diameters itself was a laborious task and attention had to be paid to devise ways and means of speeding up this operation. With recent advances in mathematical programming techniques and the introduction of high speed digital computer, emphasis has shifted from the balancing part to the economic network design part where powerful and rigorous techniques are being developed.
The problem of analysis and design of water distribution system has been with us for a long time. When we consider that it is still a fertile subject for investigation, we recognise the various levels of complexity involved in it such as determination of diameters of pipes in the networks for one or multiple demand patterns and sizing of total system.

Here, we consider only the main problem of minimum cost design of distribution pipe network subject to the provision of required domestic and fire flows at specific draw-off junctions and the maintenance of minimum residual pressure at critical junctions.

In the present methodology, the problem is cast as one of non-linear programming with the discrete pipe diameters as the decision variable. The mathematical programming problem and its solution using Lagrangian multiplier technique, are discussed in the following paragraphs.

### 3.2 OPTIMISATION

#### 3.2.1 Objective Function

The principal part of the total cost of distribution pipe network is the cost of pipes. The installed cost of a pipe can be related to its diameter by an empirical exponential function of the form,

\[ C = a l D^b \]  

where 
- \( C \) = cost of the pipe, Rs./m,
- \( l \) = length of the pipe, m,
- \( D \) = diameter of the pipe, m,
- \( a \) and \( b \) are pipe cost coefficient and exponent, respectively, derived from pipe cost data.
Hence the objective function can be stated as,

Minimise :

\[ C = a l D^p \]  

(3.2)

It is to be noted that the total cost of the pipes in the network will be the sum of the cost of the individual pipes in it. Also, the cost function vide Equation (3.1) with the known ‘a’ and ‘b’ values will represent the pipe cost data in mathematical form. However, the actual pipe cost evaluation after the selection of diameters is done using the market cost data in the present methodology. Also, the discrete pipe diameters as obtained from the market have as such been treated as the decision variables.

3.2.2 Constraints

The diameters, flows and head losses in the pipe network must meet certain constraints in the form of hydraulic flow formula, and certain operational constraints regarding minimum desirable residual pressure head, commercially available pipe diameters and the minimum pipe diameter. Such constraints can be represented by the following set.

(i) **Head loss equation**

When water flows through a pipe, a part of the total energy of water is spent in maintaining the flow. This is usually expressed in the form of the head of water and therefore called head loss. The head loss in a pipe is classified as head loss due to friction, \( h_f \) and head loss due to appurtenances in pipe. The classification of head loss as major or minor is relative. But in a pipe line of considerable length, as seen in a water distribution network, the head loss due to friction is major head loss and that due to appurtenances is minor head loss.
The designer may or may not consider minor head loss in the design and analysis. If it is considered, one way is to add an extra length to the actual length of pipe to take care of the minor losses. The other option is to ignore the effect of minor losses and consider only the major losses, as is the case in most of the designs. In the present methodology also, the minor losses in pipes have been ignored.

Among the various equations available for velocity computation, the Hazen - Williams formula is widely recommended and used in water supply engineering (Bhave 1991 and CPHEEO 1991). The equation for the loss of head due to friction $h_f$ based on the Hazen - Williams formula can be derived as

$$h_f = \frac{10.68 l Q^{1.852}}{C_{HW}^{1.852} D^{4.87}}$$

(ii) **Minimum Pipe Diameter**

$$D \geq D_{\text{minimum}}$$ (3.4)

where $D_{\text{minimum}}$ is the minimum pipe diameter commercially available.

(iii) **Commercially available pipe diameters**

$$D \in [D_1, D_2, \ldots, D_n]$$ (3.5)

where $D_1, \ldots, D_n$ are the set of commercially available pipe diameters.
(iv) **Minimum desirable residual pressure head**

The minimum desirable residual pressure head for a network is usually the same for all the draw-off nodes in it. It is fixed by the designer to start with and hence, a known parameter. Similarly, the ground elevations at the nodes of the network are also known. The sum of the ground elevation and the minimum desirable residual pressure head at a node is the minimum desirable Hydraulic Grade Line (HGL) elevation at the node and hence, the minimum desirable HGL elevations at all nodes are also known. Thus, for any pipe excepting the pipe connecting the source node in the network, the minimum desirable HGL elevations at both the ends are known. (At the node where water is fed, the source pressure head and hence, the source HGL elevation are usually known). The difference between the HGL elevations at both the ends of a pipe is the pressure head available for meeting the loss of head due to friction ($h_a$) for the pipe.

In the present methodology, the design exercise always starts with the pipe which connects the source node. The flow in this pipe will be from the source node (with a known HGL elevation) to the other node at which the minimum desirable HGL elevation is known. The difference between the source HGL elevation at one end and the minimum desirable HGL elevation at the other end of the pipe, is $h_a$ for the pipe.

After selecting the diameter for this pipe (by adopting a procedure described later), the head loss due to friction in the pipe is estimated using the Equation (3.3). (For the estimation of the head loss, the flow through the pipe is one of the inputs required which is not known to the designer initially. But, at this stage let us presume that it is known). By deducting the $h_a$ thus calculated from the source node HGL elevation, the HGL elevation at the other end of the pipe (downstream end) is obtained. This downstream HGL elevation is treated as upstream HGL elevation for the next pipe in the series. For the next pipe, the difference between the
upstream HGL elevation and the minimum desirable HGL elevation at the downstream end will be the $h_a$. This logic is followed for the rest of the pipes also in the network. Thus, $h_a$ is made known for each pipe in the network.

Then, the minimum desirable residual pressure head constraint can be stated as,

$$ h_r \leq h_a $$ \hspace{1cm} (3.6) 

From the logic explained above, it is seen that the loss of head due to friction for a pipe directly determines the value of $h_a$ for the succeeding pipe. If $h_r$ for the pipe is more, the succeeding pipe will have a less $h_a$, and vice versa. The succeeding pipe’s $h_r$ will affect $h_a$ for the pipe further downstream and so on. Because of this chain effect, the $h_a$ may become very small for a pipe somewhere in the chain. At this stage, the design of the concerned pipe may not be possible. The reason is that smaller the $h_a$ value, the larger will be the diameter required. Obviously, for a very small $h_a$ value, even the largest diameter in the diameter set considered may prove to be inadequate.

The stage of the design at which this problem will crop up depends upon factors like commercial pipe diameter set considered, pipe flow rate assumptions, source pressure head, size of the network (number of loops and pipes) and the portion of the $h_a$ utilised for meeting the friction losses in a pipe.

The full utilisation of the $h_a$ for pipe design may be theoretically possible only in the case of small networks. As the network becomes larger, only a portion of the $h_a$ will have to be used in the pipe design. The remaining portion is conserved for the downstream pipes. Smaller the size of the network, the greater will be the portion of the $h_a$ utilised and vice versa.
In the present methodology, the portion of the $h_i$ allowed to be utilised is made uniform for all pipes irrespective of their position in the network. It is also proposed to represent the portion utilised by a factor called "Available Residual Pressure Head Utilisation Factor (AHUF)". The AHUF will be chosen by the designer by trial and error and it will be greater than 0 but less than or equal to 1.

After introducing the AHUF, the Equation (3.6) becomes.

$$h_f \leq \{AHUF\} \times h_a$$

or

$$\left(\frac{10.68 \times Q^{1.862}}{C_{iW}^{1.862} D^{4.87}}\right) \leq \{AHUF\} \times h_a$$

Equation (3.3) is the pipe head loss equation. Equation (3.4) assures that all pipes are equal to or greater than the prescribed minimum diameter. Equation (3.5) specifies that all diameters shall correspond to commercially available ones and Equation (3.7) ensures that the actual loss of head due to friction does not exceed the portion of available pressure head proposed to be utilised.

The objective function specified as Equation (3.2) and the constraints in the Equations (3.3), (3.4), (3.5) and (3.7) represent a classical non-linear programming problem in the decision variable $D$. The constraint in Equation (3.3) is used for estimating the head loss in a pipe. The commercially available pipe diameter set used in the design assures that the constraints in Equations (3.4) and (3.5) are satisfied. The remaining constraint in Equation (3.7) is used directly in solving the mathematical programming problem.

In order to solve the problem using the Lagrangian multiplier technique, the inequality sign in the constraint Equation (3.7) is converted
into an equality sign and the term to the right hand side of the equality sign is set to zero. Thus, the Equation (3.7) becomes

\[
\frac{10.68 \, l \, Q^{1.852}}{C_{11W}^{1.852} \, D^{4.87}} - \{AHUF\} \times h_a = 0 \tag{3.8}
\]

Now, writing the Lagrangian function, we get

\[
L = a / Db + \lambda \left[ \frac{10.68 \, l \, Q^{1.852}}{C_{11W}^{1.852} \, D^{4.87}} - \{AHUF\} \times h_a \right] \tag{3.9}
\]

where \( \lambda \) is the unknown Lagrangian multiplier.

Differentiating the Equation (3.9) partially with respect to \( D \) and equating to 0, we get

\[
\frac{\delta L}{\delta D} = a \, b / D^{b+1} + \lambda \left[ (-4.87) \times \frac{10.68 \, l \, Q^{1.852}}{C_{11W}^{1.852} \, D^{5.87}} \right] = 0 \tag{3.10}
\]

Similarly, differentiating the Equation (3.9) partially with respect to \( \lambda \) and equating to 0, we get,

\[
\frac{\delta L}{\delta \lambda} = \frac{10.68 \, l \, Q^{1.852}}{C_{11W}^{1.852} \, D^{4.87}} - \{AHUF\} \times h_a = 0 \tag{3.11}
\]

or

\[
\frac{10.68 \, l \, Q^{1.852}}{C_{11W}^{1.852} \, D^{4.87}} = \{AHUF\} \times h_a
\]
The Lagrangian function vide Equation (3.9) consists of two variables namely, decision variable $D$ and the unknown Lagrangian multiplier $\lambda$. Normally, the partial derivatives of the function with respect to $D$ and $\lambda$ will lead to two simultaneous equations. By solving these two equations, one can get expressions for $D$ and $\lambda$.

However, in the present case, the expression for $D$ is straight away obtained from the Equation (3.11) without the need to solve the Equations (3.10) and (3.11) simultaneously. Incidentally, it is also possible to derive the expression for $D$ from the constraint Equation (3.7) by changing the inequality sign to equality sign. But, this observation is made only after going through the full exercise of solving the problem by the Lagrangian multiplier technique. Therefore, the credit is given to the technique for finding the solution to the problem.

The right hand side of the Equation (3.12) is the expression used for calculating the economical pipe diameter in the present methodology. However, the calculated economical diameter is rounded off to the next higher commercially available pipe diameter to get the recommended diameter for a pipe. Thus, the constraints namely Equations (3.4) and (3.5) are satisfied.
3.3 PREPARATION FOR THE DESIGN

Preparation of the layout plan of the proposed water supply distribution network is the basic step in the design of the distribution network. Based usually on the projected population and the per capita rate of water supply, the anticipated on-line demand of water for each pipe is computed for an assumed peak factor. The direction of flow in the individual pipe is assumed based on the topographical features and the hydraulic gradient provided by the source of supply. Nodal demands are computed as the sum of the on-line demands of pipes whose downstream end is the node.

For the use of present methodology, only the pipes in loops should be considered and the branch pipes should be excluded from the layout. However, the design of branch pipes can be done separately after completing the design of pipes in loops. Then, the primary loops, pipes and nodes including the source node is numbered using integers. Every pipe including the common pipe is assigned only one number. The loops, pipes and nodes can be numbered in any order or sequence. The demand at various draw-off nodes is marked and so also the ground elevation at the nodes.

3.4 COMPUTATIONS

The computations involved in the present methodology are schematically shown in Figure 3.1. There are four levels of computations involved as described below.

3.4.1 Level 1 - Assumption of initial conditions

The initial conditions to be assumed in the present methodology are pipe flow directions and pipe flow rates.
Figure 3.1 Schematic of Computations

- Assume flows in pipes to satisfy Kirchhoff's node law.
- Assume AHUF as 1 and MRHRA as 0.
- Start with the loop containing the source node, design the pipes and calculate HGL elevations.

Is the AHUF adequate to design all the pipes?

If yes, check if the Kirchhoff's loop law is satisfied.

If yes, simulate the network with the chosen pipe diameters, estimate actual HGL elevations and residual pressure heads.

If no, correct the assumed flows.

If no, choose another AHUF.

Is the minimum pressure head requirement met?

If yes, note the total cost and AHUF value.

Has the range of AHUF values been covered?

If yes, choose another MRHRA.

For the least cost design, is the actual minimum residual pressure head close enough to the prescribed minimum?

If yes, tabulate the results.
In the normal case, the designer while preparing the basic layout map would enumerate all details including the nodal demand. While estimating the nodal demand, the pipe flow directions are assigned based on the topography. These flow directions can be retained for the next step of designing the network. Instead, if the designer is starting straightway with the known nodal demands, then he has to assume flow directions taking into consideration the topography.

Next, the pipe flow rates are assumed in such a way that they satisfy the Kirchoff's node law at all nodes. Even though the designer is free to assume any flow rate for a pipe, it would be better to avoid far from realistic assumptions. A way to do this is to start from the pipes feeding the farthest node in the network and move towards the source node. An easy option would be to assign nearly equal flow rates for the pipes feeding a node to satisfy the Kirchoff's node law.

As already stated, a little care in assuming the pipe flow rates and directions is necessary because far from realistic assumptions may make value of $h_a$ in the Equation (3.12) so small for a pipe that the diameter for the pipe can not be estimated. However, if such a problem arises, a corrective procedure built-up in the methodology is invoked to obviate the problem. As per this procedure, the immediate upstream pipe diameter is incremented to the next larger diameter making the $h_a$ for the pipe in question larger and the design of the pipe is attempted again. If the value of $h_a$ is still insufficient, then the second pipe in the flow path upstream is selected and its diameter incremented. Incrementing the upstream pipes by one diameter is continued until the value of $h_a$ is sufficiently larger to complete the design of the pipe or all the pipes in the upstream flow path have been incremented, whichever is earlier. The upstream pipes selected for this exercise are the ones which lie in the path leading to the source node. If, even after incrementing all the relevant pipes, the value of $h_a$ is still small, then the flow rate and / or flow direction assigned are far from
realistic for a pipe in the path upstream of the pipe in question. The assumed flow direction and flow rates are revised and the design exercise restarted. (A provision has been made in the computer software to indicate the pipe for which this problem occurs).

3.4.2 Level 2 - Initial Diameter Calculation

In the present methodology of optimal design of a looped type network, every loop is considered to be made of two series. Therefore, the two series of pipes constituting a loop are first identified. Both the series will start at a common node and end at another common node. The direction of flow in the two series will counter each other.

The identified series of pipes in a loop are designed one after the other. In a series, the pipes are designed starting from the most upstream pipe and then moving downwards in the direction of flow. The diameter computation starts from a loop containing the source node and then moves to an adjacent loop containing a node where the HGL elevation (not the minimum desirable HGL elevation) is known, and so on. In the computation, the value of $h_a$ is estimated as per the procedure outlined in Section 3.2.2.

The Level 1 and Level 2 computations are further explained with the help of a pipe network (Figure 3.2).

3.4.2.1 Illustration

In the pipe network shown in Figure 3.2, there are two loops, numbered as 1 and 2, seven pipes, numbered as 2 to 8 and six nodes, numbered as 2 to 7. The source node is 2. All the data needed for the design such as the pipe lengths, ground elevations at the nodes, nodal demands, and the assumed flow directions and rates are as marked in the Figure. First, loop 1 is considered for design as it contains the source node 2.
Pressure Head = 53.40m
HGL Elevation = 203.40 m

**LEGEND**

1. Loop number
2. Pipe number
3. Node number
4. Nodal demand, lps
5. Length of pipe, m
6. Ground elevation, m
7. Assumed rate of flow, lps
8. Hazen - Williams $C_{HW}$ for all pipes = 130
9. Minimum desirable residual pressure head at all nodes = 30 m

**Figure 3.2** Network for methodology illustration
Design of pipes in Loop 1

The two series of pipes in the loop 1 for the assumed direction of flow are 2 - 7 and 3 - 4. Design may start either with the series 2 - 7 or 3 - 4. For illustration, the design is started with the series 2 - 7.

In the series 2 - 7, the water flows from the pipe 2 to 7. Therefore, the upstream pipe in the series is 2 and the downstream pipe is 7. Hence, in the series 2 - 7, pipe 2 is designed first and then, the pipe 7.

For the pipe 2, the upstream HGL elevation (source node HGL elevation), the minimum desirable HGL elevation at the downstream node 3, pipe length, flow rate (assumed), and the Hazen-Williams Coefficient are known. A value is chosen for the AHUF. Using the AHUF chosen and other data, the pipe diameter is calculated by the Equation (3.12) and is rounded off to the next higher commercially available diameter. For this pipe diameter, $h_f$ is calculated by the Equation (3.3). Then, the HGL elevation corresponding to the chosen pipe diameter is estimated at the downstream node (node 3) by deducting the $h_f$ from the upstream HGL elevation at node 2.

Now, the pipe 7 is considered for design. For the pipe 7, the upstream HGL elevation is the downstream HGL elevation of pipe 2. As in the case of the pipe 2, pipe 7 is designed and $h_f$ for the pipe 7 and HGL elevation at node 5 are estimated. Thus, the initial diameters for the pipes 2 and 7 and the corresponding HGL elevations at nodes 3 and 5 are determined.

Next, the pipe series 3 - 4 is considered. The design exercise described for the series 2 - 7 is repeated for the series 3 - 4 and the
diameters for the pipes 3 and 4 are estimated along with the HGL elevations at the nodes 4 and 5. With this, the design of pipes in loop 1 is complete. It is to be noted that for the node 5, two different HGL elevations, one relevant to the series 2 - 7 and the other to the series 3 - 4 are applicable.

**Design of pipes in loop 2**

The next loop considered for the design will be loop 2 as that is the only loop remaining to be designed in the network. In general the 'next loop' selected will be the one containing at least one node where the HGL elevation (not the minimum desirable HGL elevation) is known. In this case, loop 2 contains nodes 4 and 5 where the HGL elevations are known.

As usual, the pipe series in loop 2 are identified. These are 5 - 6 and 4 - 8. First the series 5 - 6 is considered. The pipe 5 is designed using the HGL elevation known at node 4 and the HGL elevation at node 6 is estimated. Then, the pipe 6 is designed and the HGL elevation at node 7 is estimated.

Then, the pipe series 4 - 8 is considered. The pipe 4 is common to the loops 1 and 2 and it has already been designed as a part of the loop 1. Hence, only the pipe 8 is taken up for design. For the pipe 8, there are two upstream HGL elevations at the node 5. Out of these two, the lower elevation is used in the design of the pipe 8. With this, the design of pipes in loop 2 is also over. Thus, the initially selected pipe diameters are known for the entire network.
3.4.3  **Level 3 - Simulation and revision of diameters**

The flow rates used in the computation of initial diameters are the assumed flow rates which satisfy only the Kirchoff's node law. For a network to be "balanced", the Kirchoff's loop law should also be satisfied. Therefore, the next step is to test for this requirement for all the loops in the network by simulating the network. If the algebraic sum of the head losses in a loop is equal to 0 or a pre-set tolerance limit for unbalanced head in a loop, the network is considered to be in "balance" and computations proceed to the next level. If not, the assumed flows are corrected. The correction to the flows in pipes in every loop is estimated using the Newton Raphson method and the corrected flows for the pipes are estimated. The sign convention adopted for the flow and head loss is that clockwise flows and associated head losses are positive and anticlockwise flows and associated head losses are negative. The tolerance limit for the unbalanced head in a loop adopted in the present methodology is ± 0.01 m.

For the corrected flows, revised pipe diameters are estimated as in level 2 computation. In this process, the minimum desirable HGL elevations used in level 2 computations will continue to be the downstream HGL elevations. The revised pipe diameters are used in balancing the network which will yield yet another corrected flows set. These corrected flows in turn are used for estimating the next set of revised pipe diameters. Thus, at every iteration in balancing, a new set of flows are obtained for which a new set of diameters are estimated. This process of flow correction and diameter revision is continued until the network is in "balance". The pipe diameters obtained at this stage are the recommended diameters for the AHUF chosen.
3.4.4 Level 4 - Final simulation and refinement

After the completion of the level 3 computations, the actual HGI elevations at the nodes in the network are not available. This is because, the values and HGL elevations computed in balancing are not retained. Also, to enable the revision of pipe diameters, the minimum desirable HGL elevations are kept intact for all nodes. Therefore, there is a need to go for a final simulation of the network to estimate the actual HGL elevations corresponding to the pipe diameters chosen in the level 3 computations. This is done again by the Newton - Raphson method with the chosen diameters as one of the inputs.

At the end of the final simulation, the recommended pipe diameters and the associated total cost of pipes, the actual HGL elevations and the actual residual pressure heads are determined for the chosen AHUF. Now, the actual residual pressure heads are reviewed to identify the minimum value. If the identified minimum is satisfactory, the AHUF chosen is considered as feasible. Then, it is checked whether the identified minimum is close enough to the prescribed minimum. If yes, the design is considered to be satisfactory in terms of residual pressure head and the best possible in terms of cost. Therefore, any further refinement of the design is not necessary. The design exercise is treated as complete and the results are tabulated.

If the identified minimum is not satisfactory, then the AHUF chosen is considered as infeasible. The design as per this AHUF is ignored and a revised value is adopted. For a feasible AHUF, if the identified minimum is not close enough to the prescribed minimum, a refinement of the design is necessary. The objective in the refinement exercise is to bring
the identified minimum close enough to the prescribed minimum resulting in further reduction in the cost.

The refinement is achieved by designing the network for a provisional prescribed minimum which is less than the one originally prescribed. The difference between the originally prescribed minimum and the provisional minimum is termed as "Minimum Residual Pressure Head Refinement Allowance (MRHRA)". This allowance (expressed in m and chosen by the designer by trial and error) is deducted from the prescribed minimum and the resulting figure is used as the provisional minimum for the network and the whole exercise is repeated until the identified minimum is close enough to the prescribed minimum. For a given network there may be more than one feasible AHUF value. Either all the feasible AHUF values are identified and then, the one leading to the lowest total cost is selected for refinement or any feasible AHUF is chosen for refinement. It is advisable to follow the former procedure. And by default the initial value of the MRHRA will be 0.

3.5 DATA FORMATS

3.5.1 Input Data

After numbering the loops, pipes and nodes and marking the flow directions and rates on the layout map, the data required for feeding the computer are prepared as per the following formats.

3.5.1.1 General Information

Title of the project : A description to identify the project.
<table>
<thead>
<tr>
<th>Description</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of loops</td>
<td>Total number of primary loops in the network.</td>
</tr>
<tr>
<td>Number of pipes</td>
<td>Total number of pipes in the network.</td>
</tr>
<tr>
<td>Number of pipes as for present method</td>
<td>Total number of pipes in the network when the common pipe is counted twice, once each for the loops to which it is common.</td>
</tr>
<tr>
<td>Number of nodes</td>
<td>Total number of nodes including the source node in the network.</td>
</tr>
<tr>
<td>Source node No.</td>
<td>Node number assigned to the source of supply.</td>
</tr>
<tr>
<td>Source pressure head, m</td>
<td>Pressure head maintained at the source.</td>
</tr>
<tr>
<td>Minimum Desirable Pressure Head, m</td>
<td>Value may range from 7 - 10 m; Treated as uniform for all nodes in the present methodology.</td>
</tr>
<tr>
<td>Type of pipe material used</td>
<td>Single pipe material proposed to be used.</td>
</tr>
<tr>
<td>Number of commercial diameters</td>
<td>For the chosen pipe material, the number of standard pipe diameters considered for design.</td>
</tr>
</tbody>
</table>
Newton-Raphson Stopping criterion, m : The maximum permissible unbalanced head (numerically) in a loop; the value used in the present methodology, ± 0.01 m.

Default value for AHUF : 1.00
Default value for MRHRA, m: 0.00
Design (D)/Simulation (S) : D to be chosen for design and S for simulation.

3.5.1.2. Pipe Data

The pipe data are prepared in the format presented in Table 3.1

<table>
<thead>
<tr>
<th>Loop Number</th>
<th>Pipe Number</th>
<th>From Node</th>
<th>To Node</th>
<th>Pipe length, m</th>
<th>HWC</th>
<th>Pipe flow, lps</th>
</tr>
</thead>
</table>

Loop Number : Data entry starts with any loop in the network. But, data for the loop chosen is completed before proceeding to the next loop. Loop number is repeated for all the pipes in a loop.
Pipe Number: The pipe number is entered in the order of the position of the pipe in the series identified in a loop. The rule is that the most upstream pipe is entered first and other pipe(s) downstream follow. Once the listing of pipes in a series is completed, then the most upstream pipe in the second series in that loop is listed.

From Node - To Node: This indicates from which node to which node the flow occurs in a pipe based on the flow direction assumed for a pipe.

Pipe length, m: Length of pipe between the two nodes defining the pipe.

HWC: Hazen - Williams Coefficient for the chosen pipe material; only single material can be chosen for the present methodology.

Pipe flows, lps: The initially assumed rate of flow for a pipe is entered with a sign; if the flow is clockwise in the loop, then it bears a positive sign and if otherwise, a negative sign.

3.5.1.3 Node Data

The format for the preparation of the node data is presented in Table 3.2.
Table 3.2
Format for node data

<table>
<thead>
<tr>
<th>Node No.</th>
<th>Ground Elevation, m</th>
</tr>
</thead>
</table>

3.5.1.4 Cost Data

The format for the preparation of cost data is presented in Table 3.3.

Table 3.3
Format for cost data

<table>
<thead>
<tr>
<th>Pipe diameter, mm</th>
<th>Unit Cost, Rs/m</th>
</tr>
</thead>
</table>

Pipe Diameter, mm : Commercially available pipe diameters considered for design.

Unit Cost, Rs/m : Installed unit cost of pipes.
3.5.2 Output

The output consists of general information, pipe details, node details and pipe cost details.

3.5.2.1 General Information

Title of the project : 
Final value of AHUF used : 
Final value of MRHRA used, m : 
Type of pipe material used :

3.5.2.2 Pipe Details

The format for the pipe details is presented in Tables 3.4.

| Table 3.4 |
| Format for pipe details |

<table>
<thead>
<tr>
<th>Loop No.</th>
<th>Pipe No.</th>
<th>From Node</th>
<th>To Node</th>
<th>Length m</th>
<th>Flow lps</th>
<th>Diameter mm</th>
<th>Head loss, m</th>
<th>Velocity m/s</th>
</tr>
</thead>
</table>
3.5.2.3 Node details

The format for the node details is presented in Table 3.5.

Table 3.5  
Format for node details

<table>
<thead>
<tr>
<th>Node No.</th>
<th>Ground Elevation, m</th>
<th>HGL, m</th>
<th>Pressure head</th>
</tr>
</thead>
</table>

3.5.2.4 Pipe cost details

The format for the pipe cost details is presented in Table 3.6

Table 3.6  
Format for pipe cost details

<table>
<thead>
<tr>
<th>Pipe No.</th>
<th>HWC</th>
<th>Diameter, mm</th>
<th>Length, m</th>
<th>Cost, Rs. lakhs</th>
</tr>
</thead>
</table>

Total Cost of Pipes =