CHAPTER 5

SUMMARY AND CONCLUSION

5.1 GENERAL

A public water supply scheme has to realise the desirable objectives of adequacy, acceptance, convenience and economy. In realising these objectives, the water distribution system plays a significant role among the various components in the scheme. Also, in general, the distribution network of a water supply system accounts for 40 to 70% of the total cost of the system.

The usual practice of design of water distribution network starts with the assumption of suitable sizes of pipes for various sections of the distribution system followed by checking of the required hydraulic conditions. This trial and error method may not lead to economical design. Also, large investments are made in water supply projects in a developing country like India. Thus, there is a need to develop simple optimisation techniques useful for practicing engineers in the context of maximising service to the population with limited resources.

5.2 SUMMARY

5.2.1 Objective

The objective of the present study was to develop a methodology for selecting the minimum cost combination of pipe diameters for a water supply distribution network of known layout, fed by gravity from a single
source to meet a known single demand pattern. That is, knowing the layout of the network (pipe connectivity), pipe material, nodal demands and the minimum desirable residual pressure head at nodes, the objective was to find the minimum cost combination of the pipe diameters for the network which will meet the nodal demands and maintain the minimum desirable residual pressure head at the nodes.

5.2.2 Methodology

The problem is formulated as one of non-linear programming with the discrete pipe diameters as the decision variables. The problem and its solution using Lagrangian multiplier technique are described in the following paragraphs.

5.2.2.1 Objective Function

Minimise the cost of pipe,

\[ C = a l D^b \]

The total cost of the pipes in the network will be the sum of the cost of the individual pipes in it.

5.2.2.2 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 residual pressure head, commercially available pipe diameters and minimum pipe diameter. These constraints are summarised in the following paragraphs.
(i) **Head loss equation**

The equation for the head loss due to friction in the pipe, $h_f$, based on the Hazen-William formula will be:

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

(ii) **Minimum Pipe Diameter**

$$D \geq D_{\text{minimum}}$$

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

(iii) **Commercially available pipe diameters**

$$D \in [D_1, D_2, \ldots, D_n]$$

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 constraint is

$$\frac{10.68 \times Q^{1.852}}{C_{HW}^{1.852} D^{4.87}} \leq (AHUF) \times h_a$$
The objective function and the constraint equations represent a classical non-linear programming problem in the decision variable, D. Solving the problem using Lagrangian multiplier technique, we get

\[
D = \left[ \frac{10.68 I Q^{1.852}}{C^{1.852} (AHUF) \times h_a} \right]^{1/4.87}
\]

(3.12)

The expression for D stated above is used for calculating the economical pipe diameter in the present study. However, the calculated economical diameter is rounded off to the next higher commercially available pipe diameter to get the recommended diameter for a pipe. Also, if the calculated diameter is smaller than the minimum pipe diameter, the minimum pipe diameter is the recommended pipe diameter.

### 5.2.3 Preparation for design

Like in any other method of design of water supply distribution network, a skeletonised network of pipes is prepared first. For the use of present methodology, only the pipes in loops is considered and the branch pipes excluded (The design of branch pipes can be done separately after completing the design of the pipes in loops). The primary loops, pipes and nodes are then numbered. 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 are marked and so also the ground elevation at the nodes.

### 5.2.4 Computations

Four levels of computations are involved in the proposed methodology. They are:
(i) Level 1 - Assumption of initial conditions: The pipe flow directions and rates are assumed considering the topography. The assumptions should satisfy the Kirchoff's node law.

(ii) Level 2 - Initial Diameter calculation: The initial economical pipe diameters are calculated for the assumed flows using the expression for $D$.

(iii) Level 3 - Simulation and revision of diameters: The network is simulated with the initially chosen flows and pipe diameters, flows are corrected if necessary, by Newton-Raphson method and diameters are revised for the corrected flows until the network is in balance.

(iv) Level 4 - Final simulation and refinement: The network is simulated to determine the actual hydraulic conditions in the network and the design is refined if necessary.

Two design control parameters namely ‘Available Residual Pressure Head Utilisation Factor (AHUF)’ and ‘Minimum Residual Pressure Head Refinement Allowance (MRHRA)’ are incorporated in the design. The designer can start with a lower value of AHUF and move upwards. In addition, a corrective procedure has been built in to obviate any problem arising out of far from realistic assumptions.

5.2.5 Application

The proposed methodology was used to design several water supply distribution networks. A description of the outcome is presented in respect of three networks called example networks 1, 2 and 3.
The example network 1 consists of 2 loops, 8 pipes and 7 nodes. The total cost for the example network 1 as per the present design methodology is 4.56 lakhs. The AHUF selected are 0.90 and 1.00 both for a MRHRA of 0.

The example networks 2 and 3 are field problems with fairly undulating ground elevations. The example network 2 has 15 loops, 50 pipes and 36 nodes whereas the example network 3 has 31 loops, 82 pipes and 52 nodes.

The example network 2 is designed for a cost of Rs.199.93 lakhs. The AHUF and MRHRA concerned are 0.40 and 5 m respectively. The example network 3 is designed for a cost of Rs.655.32 lakhs. The AHUF and MRHRA concerned are 0.20 and 4.50 m respectively.

A comparison of the costs for the example network 1 adopting different approaches reported in the literature, is:

<table>
<thead>
<tr>
<th>Sl.No.</th>
<th>Designer / Software</th>
<th>Cost lakhs</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Alperovits and Shamir (1977)</td>
<td>4.79</td>
</tr>
<tr>
<td>2</td>
<td>Quindry et al (1979)</td>
<td>4.41</td>
</tr>
<tr>
<td>3</td>
<td>Goulter et al (1986)</td>
<td>4.25</td>
</tr>
<tr>
<td>4</td>
<td>Fujiwara et al (1987)</td>
<td>4.15</td>
</tr>
<tr>
<td>5</td>
<td>Kessler and Shamir (1989)</td>
<td>4.00</td>
</tr>
<tr>
<td>6</td>
<td>LOOP Version 4.0</td>
<td>4.63</td>
</tr>
<tr>
<td>7</td>
<td>Present Study</td>
<td>4.56</td>
</tr>
</tbody>
</table>
Similarly, a comparison of costs for all the three networks as per the present methodology and as per UNDP / World Bank software LOOP Version 4.0 (Modak and Dhoondia 1991), is:

<table>
<thead>
<tr>
<th>Sl.No.</th>
<th>Network</th>
<th>Cost, lakhs</th>
<th>As per LOOP Version 4.0</th>
<th>As per the present methodology</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Example Network 1</td>
<td>4.63</td>
<td>4.56</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Example Network 2</td>
<td>Rs.200.16</td>
<td>Rs.199.93</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Example Network 3</td>
<td>Rs.597.73</td>
<td>Rs.665.32</td>
<td></td>
</tr>
</tbody>
</table>

From these results, it is inferred that the present methodology while being the simplest involving the least mathematical complexity, is comparable to other methods in terms of efficiency in the design of water supply distribution networks. Specifically, with reference to LOOP Version 4.0, the present methodology proves to be marginally better for designing the example networks 1 and 2 (networks with two and fifteen loops respectively). However, in the case of the large network (example network 3 with 31 loops), the LOOP Version 4.0 proves to be superior. Therefore, it is felt that refinement of the present methodology is necessary to make it more effective in case of large networks.

In order to ascertain the effect of flow assumption on the total cost of the pipes in the network, design is carried out for several assumed flow sets and variation in the cost is found to be marginal at 4.60%.

### 5.2.6 Computer software

A computer software written in 'C' language is used in Personal Computer PC/AT - 486 for the present study. The computation time required
is 3 seconds for the example network 1, 10 seconds for the example network 2 and 15 seconds for the example network 3.

5.3 CONCLUSION

1. The methodology proposed in the present study is the simplest involving the least mathematical complexity in optimisation.

2. The methodology is robust with respect to the assumption relating to the flow direction and flow rate.

3. The software developed supports the design of real world large water supply distribution networks using a Personal Computer itself.

4. The methodology proved to be marginally superior in designing a network with fifteen loops, when compared with LOOP Version 4.0. However, refinement of the methodology is necessary to design large networks.

5.4 SCOPE FOR FURTHER STUDY

Further investigation is necessary to refine the methodology in the case of design of large networks. The possibility of availing the user interaction in adopting smaller diameters in selected cases is to be looked into. Also, the capability of the software could be further improved to design more complex networks.