DESIGN OF RURAL WATER SUPPLY SYSTEM USING LOOP 4.0

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Abstract— Water is a valuable resource, used as the main raw material by our civilization. This paper concerns for the design of rural water distribution system in developing countries. Approximate 68% population of India is staying in the rural area (census 2011, India). For this study, water supply distribution system is designed for population estimated for future 30 years. The heuristic software LOOP version 4.0 has been used for designing best economical water distribution system. Intermittent water supply planned for the study with considering 100 lpcd water consumption. The economical diameter of water supply distribution system is designed by considering the constraint such as residual nodal pressure, velocity of flow in pipe, pipe material, reservoir level, peak factor and available commercial pipe diameters.

Keywords—Estimated population, Water distribution network design, LOOP version 4.0 software, Economical diameter, Rural water distribution system

I. INTRODUCTION

Water distribution system, a hydraulic infrastructure consisting of elements such as pipes, tanks, reservoirs, pumps and valve etc., is crucial to provide water to the consumers. Effective water supply system is of paramount importance in designing a new water distribution network or expanding the existing one [1]. Pipe water system is one of the best systems to supply water safely, adequately and continuously. To supply adequate, safe and continuous water in rural areas, regional water supply schemes are formed in which more than one village are served from a common water source through pipe system [2], [12]. Distribution networks are also an essential part of all water supply systems. Distribution system costs within any water supply scheme may be equal to or greater than 60 % of the entire cost of the project [1], [13]. Design and analysis of pipe networks are important, because availability of water is an important economical development parameter [3], [14].

Many researchers have used different programming techniques to understand the water supply network and optimize the water supply network viz., Linear programming method, Non – linear programming method, Genetic algorithms, Simulated Annealing and formulated the Hydraulic network design problem as an optimization problem. These methods may not be suitable for network with large number of links and multiples loadings. [4], [5], [6], [7], [8].

II. STUDY AREA

The village Nava Shihora is newly developed area of Shihora village situated at distance of about 15 Km from the Savali Taluka, and the Savli is located at the distance of around 32 km towards North from district head quarter Vadodara as shown in Figure 1. The general topography of the terrain is moderately undulating.
At present, Main water resource of the study area is surface water i.e. Mahi river. There are 136 villages, which forms Savli taluka but regional water supply scheme include only 90 villages of Savli taluka. Shihora village is one of them. In this regional water supply scheme, water is pumped from the main source to the water treatment plant (WTP). From water treatment plant, water conveyed to the master sump, having capacity 41 lakhs liter. water is pumped from the master sump to the elevated service reservoir, having capacity 21 lakh liter. This forms primary network. In the secondary network, water conveyed through pipe from elevated service reservoir to the shihora village sump and then water conveyed to the Shihora village elevated service tank. In tertiary network, water conveyed from elevated service tank to the consumer through pipe system. The village of Shihora is divided into various zones for proper distribution of water. The economical water distribution system is designed in the present study for zone 1 for village of Shihora.

Figure 1. Index map of Vadodara District

Figure 2. Location of Shihora Village

Figure 2 shows Shihora village the state of Gujarat. The area is about 1242 Ha. and population of the village is 6021 people as per 2011 census of india,2011.
III. METHODOLOGY OF LOOP SOFTWARE

A. About Loop

Loop 4.0 is a program that is developed by the World Bank for simulation, design & optimization of looped water distribution networks. The program is free and is in the public domain. The algorithm is applied for determining the economical sizes of pipes. The LOOP is only a tool to provide a good starting solution for the user to further improvement in the solutions. The procedure followed is heuristic and is derived from the work reported by Dixit and Rao (1987). This method has been found to be working quite well when compared to other theoretically rigorous methods and hence expected to result in a quick and good starting solutions [10].

Loop simulates the hydraulic characteristics of a pressurised, looped (closed circuit) water distribution network. The network is characterised by pipes and nodes (points of inputs/demand or pipe junctions) [16]. Data required are the description of the elements of the network such as pipe lengths, diameters, friction coefficients, nodal demands and ground elevation, and data describing the geometry of the network [16]. The program outputs include flows and velocities in the links and pressures at the nodes [16]. It does not accommodate in line booster pumps or pressure reducing valves [16]. Loop 4.0 handles up to 1000 pipes and can simulate and design up to 10 nodes with known hydraulic grade lines (e.g. storage reservoirs) [16]. Loop’s normal use is to simulate and design the hydraulic response of a network to a single or multiple input with at least one known hydraulic gradient line elevation [16]. It also contains a sub-program for generating a cost summary once a final design is completed [16]. Loop network will tend to be a tree network with minimum size connection between tree extremities [15].

B. Collection of Data

The following data is required for design of water distribution network using LOOP software and it has been collected from WASMO (Water and Sanitation Management Organization), Vadodara, India. WASMO have also prepared detail map of study area by conducting level surveying and linear measurement of length of streets of the study area.

The data required can be classified into five categories: geometric data, hydraulic data, water source data, data of cost estimation parameters and historical population data.

Geometric data - Node to node connectivity of pipe, Length of pipes, Reduce levels of nodes in a study area.

Hydraulic data - Average water demands at all the relevant nodes, Pipe resistance coefficient in terms of Hazen William's C, Hydraulic gradient desired.

Water Source data - Elevations of service reservoir.

Data of cost estimation parameters - Available commercial diameters with data on unit cost and allowable working pressure, Newton-Raphson stopping criterion (viz. Maximum allowable error in flow balance), Maximum and minimum pressure at nodes. For distribution network in Shihora village, material of pipe PVC is used.

Historical population data – The population of Shihora village of year 2011 have been collected from census of India, 2011. The population of 2011 is 6201 and the population of zone 1 is 1325 people.

C. Input of data for network design in Loop 4.0

Estimation of the population

Present and future population can be predicted as under

\[ P_n = P_0 (1 + GR)^n \]  \[ \text{ (1) } \]

where,

- \( P_n \) = the projected population after nth year from initial year
- \( P_0 \) = the population in the initial year of the period concerned
- \( GR \) = average annual growth rate considered 1.7 % for the village as per the Gujarat Water Sewage Supply Board (GWSSB, Gujarat, India) guide lines.
n = number of years

Present population the year 2016 is estimated 6550 people from the above equation number (1) by using the population of year 2011. From present population obtained from equation (1) as above the population of year 2046 i.e. after 30 years have been estimated as 9983.

**Estimation of water demand**

Total water demand (Q) for each node can be calculated as under.

\[ Q = 1.5 \times P_n \times D_{pc} \times C_f \]  

where,

- \( P_n \) = population catered for each node
- \( D_{pc} \) = water demand in liter per capita per day
- \( C_f \) = conversion factor \((1/24 \times 60 \times 60)\)

The above mentioned data such as geometric data, hydraulic data, water sources data, cost estimates parameters data, water demand data are incorporated into Loop 4.0 software to distribution network design for zone- 1 of Shihora village. Input data file for water distribution system is shown in Table 1 is run into the software.

| Table 1. Input Data          |
|------------------------------|
| **Title of the Project**    | shihora zone 1              |
| **Name of the User**        | Vidhi                       |
| Number of Pipes in a network | 33                          |
| Number of Nodes in a network | 33                          |
| Type of Pipe Material Used  | PVC                         |
| Peak Design Factor          | 3                           |
| Newton-Raphson Stopping Criterion in lps | 0.001 |
| Minimum residual Pressure (m) | 7                           |
| Maximum allowable Pressure (m) | 60                          |
| Design Hydraulic Gradient (m in km) | 1                         |
| Simulate or Design? (S/D)   | D                           |
| Type of Formula             | Hazen’s                     |

In the above table, peak design factor is taken as per Central Public Health and Environmental Engineering Organization (CPHEEO) manual and Minimum and Maximum pressure is taken as per the Rural water supply manual.

The Pipe input data & Node input data is shown in Table 2.

**Loop Water Distribution Network Design Input**

In the above table, -ve sign indicate that required water demand catered at each specific node. As per the rural water supply manual, Hazen’s constant C recommended 140 for PVC pipe. The cost estimate parameters data have been shown in Table 3. The water source data have been shown in Table 4.
Table 2. Input data for Pipe and Node (Zone-1)

| Pipe Number | From Node | To Node | Length (m) | Hazen Constant | Node Number | Peak Factor | Flow (lps) | Reduce level (m) | Min. Press. (m) |
|-------------|-----------|---------|------------|----------------|--------------|-------------|------------|------------------|----------------|
| 1           | 1         | 2       | 205        | 140            | 1            | 3           | 0.000      | 100 (Benchmark) | 7              |
| 2           | 2         | 3       | 40         | 140            | 2            | 3           | 0.000      | 99.987           | 7              |
| 3           | 3         | 4       | 40         | 140            | 3            | 3           | -0.061     | 101.112          | 7              |
| 4           | 4         | 5       | 30         | 140            | 4            | 3           | -0.035     | 101.210          | 7              |
| 5           | 4         | 6       | 144        | 140            | 5            | 3           | -0.035     | 101.074          | 7              |
| 6           | 4         | 7       | 35         | 140            | 6            | 3           | -0.139     | 100.920          | 7              |
| 7           | 4         | 8       | 130        | 140            | 7            | 3           | -0.043     | 101.270          | 7              |
| 8           | 8         | 9       | 139        | 140            | 8            | 3           | -0.148     | 101.588          | 7              |
| 9           | 8         | 10      | 118        | 140            | 9            | 3           | -0.148     | 101.596          | 7              |
| 10          | 8         | 11      | 45         | 140            | 10           | 3           | -0.148     | 102.321          | 7              |
| 11          | 11        | 12      | 79         | 140            | 11           | 3           | -0.078     | 101.001          | 7              |
| 12          | 11        | 13      | 89         | 140            | 12           | 3           | -0.087     | 99.543           | 7              |
| 13          | 3         | 14      | 65         | 140            | 13           | 3           | -0.087     | 99.109           | 7              |
| 14          | 4         | 15      | 129        | 140            | 14           | 3           | -0.095     | 99.112           | 7              |
| 15          | 4         | 16      | 158        | 140            | 15           | 3           | -0.078     | 99.465           | 7              |
| 16          | 4         | 17      | 50         | 140            | 16           | 3           | -0.165     | 99.404           | 7              |
| 17          | 4         | 18      | 108        | 140            | 17           | 3           | -0.069     | 99.987           | 7              |
| 18          | 4         | 19      | 23         | 140            | 18           | 3           | -0.139     | 100.587          | 7              |
| 19          | 4         | 20      | 98         | 140            | 19           | 3           | -0.043     | 100.857          | 7              |
| 20          | 4         | 21      | 40         | 140            | 20           | 3           | -0.113     | 101.588          | 7              |
| 21          | 4         | 22      | 48         | 140            | 21           | 3           | -0.078     | 101.565          | 7              |
| 22          | 4         | 23      | 35         | 140            | 22           | 3           | -0.061     | 101.854          | 7              |
| 23          | 4         | 24      | 20         | 140            | 23           | 3           | -0.043     | 101.909          | 7              |
| 24          | 4         | 25      | 14         | 140            | 24           | 3           | -0.026     | 102.012          | 7              |
| 25          | 4         | 26      | 22         | 140            | 25           | 3           | -0.043     | 102.574          | 7              |
| 26          | 4         | 27      | 20         | 140            | 26           | 3           | -0.043     | 102.742          | 7              |
| 27          | 4         | 28      | 43         | 140            | 27           | 3           | -0.043     | 102.985          | 7              |
| 28          | 4         | 29      | 78         | 140            | 28           | 3           | -0.113     | 103.554          | 7              |
| 29          | 4         | 30      | 20         | 140            | 29           | 3           | -0.026     | 103.849          | 7              |
| 30          | 4         | 31      | 55         | 140            | 30           | 3           | -0.043     | 104.578          | 7              |
| 31          | 4         | 32      | 40         | 140            | 31           | 3           | -0.026     | 104.786          | 7              |
| 32          | 4         | 33      | 37         | 140            | 32           | 3           | -0.017     | 104.556          | 7              |
| 33          | 4         | 34      | 36         | 140            | 33           | 3           | -0.026     | 104.585          | 7              |
Table 3. Commercial Pipe Diameter Data

| Pipe internal diameter (mm) | Hazen’s constant | Unit cost Rs/m length | Allowable Pressure (m) | Pipe material |
|-----------------------------|------------------|-----------------------|------------------------|---------------|
| 63.9                        | 140              | 87.1                  | 60                     | PVC           |
| 83.2                        | 140              | 124.72                | 60                     | PVC           |
| 102                         | 140              | 177.89                | 60                     | PVC           |
| 129.7                       | 140              | 294.12                | 60                     | PVC           |
| 148.4                       | 140              | 378.78                | 60                     | PVC           |

Table 4. Fixed Head at Reservoir Data

| Source Node | Head (m) | Ref Reservoir |
|-------------|----------|---------------|
| 1           | 115.00   | R             |

In the above table, head 115m is summation of base elevation plus height of tank.

D. Result of Output

Output data obtained from LOOP software 4.0 is shown below.

Table 5 shows the number of iterations run for obtaining the design output. Table 6 shows the output for pipe i.e. available flow (lps) in each pipe, economical diameter (mm), head loss (m), head loss (m/km) and available velocity (m/s). Table 7 shows the output for each of nodes i.e. the available flow (lps) at the node, hydraulic gradient line (m) and pressure (m). Table 8 shows the output for cost of PVC pipe i.e. diameter (mm), length (m), cost (1000 Rs.) and cumulative cost (1000 Rs.).

Table 5. Design Output

| Band Width | 1 |
|------------|---|
| Number of Loops | 1 |
| Newton Raphson Iteration | 2 |

Table 6. Output for Pipe

| Pipe No. | Flow (lps) | Dia. (mm) | HL (m) | HL per 1000 m (m) | Length (m) | Velocity (m/s) |
|----------|------------|-----------|--------|-------------------|------------|----------------|
| 1        | 6.897      | 148.4     | 0.25   | 1.22              | 205        | 0.4            |
| 2        | 6.897      | 148.4     | 0.05   | 1.22              | 40         | 0.4            |
| 3        | 2.844      | 102       | 0.06   | 1.47              | 40         | 0.35           |
| 4        | 0.105      | 63.9      | 0.0    | 0.03              | 30         | 0.03           |
| 5        | 0.417      | 63.9      | 0.06   | 0.41              | 144        | 0.13           |
| 6        | 0.129      | 63.9      | 0.0    | 0.05              | 35         | 0.04           |
| 7        | 2.088      | 102       | 0.11   | 0.83              | 130        | 0.26           |
| 8        | 0.444      | 63.9      | 0.06   | 0.46              | 139        | 0.14           |
| 9        | 0.444      | 63.9      | 0.05   | 0.46              | 118        | 0.14           |
| 10       | 0.756      | 63.9      | 0.06   | 1.23              | 45         | 0.24           |
| 11       | 0.261      | 63.9      | 0.01   | 0.17              | 79         | 0.08           |
| 12       | 0.261      | 63.9      | 0.02   | 0.17              | 89         | 0.08           |
| NO. DE No. | Flow (LPS) | Reduce level (m) | HGL (m) | Press. (m) |
|------------|------------|------------------|---------|------------|
| 1          | 6.897      | 100.0            | 115.0   | 15.0       |
| 2          | 0.00       | 99.99            | 114.75  | 14.76      |
| 3          | -0.183     | 101.11           | 114.70  | 13.59      |
| 4          | -0.105     | 101.21           | 114.64  | 13.43      |
| 5          | -0.105     | 101.07           | 114.64  | 13.57      |
| 6          | -0.417     | 100.92           | 114.58  | 13.66      |
| 7          | -0.129     | 101.27           | 114.64  | 13.37      |
| 8          | -0.444     | 101.59           | 114.53  | 12.94      |
| 9          | -0.444     | 101.60           | 114.47  | 12.87      |
| 10         | -0.444     | 102.32           | 114.48  | 12.16      |
| 11         | -0.234     | 101.00           | 114.48  | 13.48      |
| 12         | -0.261     | 99.54            | 114.46  | 14.92      |
| 13         | -0.261     | 99.11            | 114.46  | 15.35      |
| 14         | -0.285     | 99.11            | 114.65  | 15.54      |
| 15         | -0.234     | 99.46            | 114.63  | 15.17      |
| 16         | -0.495     | 99.40            | 114.55  | 15.15      |
| 17         | -0.207     | 99.99            | 114.48  | 14.49      |
| 18         | -0.417     | 100.59           | 114.34  | 13.75      |
In above table, -ve sign indicate that node getting supply from source.

### Table 8. Output Pipe Cost (For PVC pipes)

| Outer Diameter (mm) | Pipe Material | Length (m) | Cost (1000 Rs.) | Cumulative Cost (1000 Rs.) |
|--------------------|---------------|------------|-----------------|----------------------------|
| 75                 | PVC           | 1362       | 118.63          | 118.63                     |
| 90                 | PVC           | 75         | 9.35            | 127.98                     |
| 110                | PVC           | 328        | 58.35           | 186.33                     |
| 140                | PVC           | 223        | 65.59           | 251.92                     |
| 160                | PVC           | 245        | 92.8            | 344.72                     |

**IV. CONCLUSION**

The Loop 4.0 software provides successful solutions for economical water supply distribution system design. This paper describes the simulations through Loop 4.0 software for the hydraulic design of the regional water supply scheme of a Nava Sihora village of Savli taluka of Vadodara district of the state of Gujarat. The program results include flows and velocities in the links and pressures at the nodes in water supply system.

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