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Design of Water Supply Distribution Networks for Two Rural Villages using LOOP Software

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Abstract—

Old, leaking pipe networks leave many villages without adequate potable water at adequate pressure. This paper reports the design of gravity-fed water distribution networks for Hiremanakatti and Basavanakoppa, two villages in Shiggaon taluka, Haveri district, Karnataka, under the Jal Jeevan Mission. The 2011 populations of 1,945 and 211 were projected to 2050 by the geometric increase method, giving 2,969 and 334 persons. At 55 lpcd and 20% losses the demand is 195,962 and 22,035 L/day. Networks of 3,865 m and 1,160 m of 63–90 mm pipe were analysed in LOOP 4.0 with a peak factor of 4 and a Hazen–Williams coefficient of 145. All nodes have positive residual pressure. For Basavanakoppa it ranges from 8.96 to 17.50 m. For Hiremanakatti it ranges from 0.76 to 13.55 m, and 34 of the 61 nodes are below 7 m. The estimated costs are Rs 75.17 lakh and Rs 23.70 lakh. The Hiremanakatti design needs a further iteration to raise the low residual heads.

Index Terms—water distribution network, LOOP software, Jal Jeevan Mission, rural water supply, hydraulic analysis, residual pressure.

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I. Introduction

Water is essential to life, yet India has only about 4% of the world's freshwater for 18% of its population. Government estimates put per-capita annual availability at 5,177 m³ in 1951 and 1,545 m³ in 2011, falling to about 1,368 m³ in 2019. Demand is rising while sources are finite, groundwater is being over-extracted, and many rural supply systems are poorly operated and maintained.

Rural water supply in India began with the National Water Supply Programme in 1954 and was extended through the Accelerated Rural Water Supply Programme (1972–73), the National Rural Drinking Water Programme (2009–10) and, from 2019, the Jal Jeevan Mission (JJM). JJM aims to give every rural household a functional household tap connection (FHTC) by 2024. On 31 March 2019 only about 18% of rural households (3.28 of 17.87 crore) had a tap connection. Under JJM the Gram Panchayat and the local community plan, run and maintain the in-village system.

A distribution network must deliver the required flow at adequate residual pressure to every consumer. Computer programs that carry out the hydraulic analysis save the long manual calculations and allow several pipe-size options to be compared quickly. Such programs have been applied to many village schemes [1]–[9]. Here, the design of the in-village networks for Hiremanakatti and Basavanakoppa is carried out with LOOP.

A. LOOP software

LOOP is a World Bank/UNDP program for the simulation, design and optimisation of looped water distribution networks. It solves the network by the Newton–Raphson technique using the Hazen–Williams or Darcy–Weisbach equation. Version 4.0 handles up to 1,000 pipes and 750 nodes, with multiple sources, booster pumps, check valves and pressure-reducing valves. It reports flows, velocities, head losses, hydraulic grade lines, nodal pressures and costs. The usual design process is trial and error: the engineer assumes a set of pipe sizes, checks the hydraulic conditions and revises the sizes until the constraints are met.

II. Objectives of the Project

The objectives of the project are: (i) to design the gravity-fed distribution networks of Hiremanakatti and Basavanakoppa villages using LOOP; (ii) to forecast the population and water demand for a 30-year design period; (iii) to check the flows, velocities and residual pressures in the networks; and (iv) to estimate the cost of providing FHTCs to the households under JJM.

III. Literature Review

Mehta and Joshi [1] designed a rural water supply system in LOOP 4.0 for a population projected 30 years ahead, with intermittent supply at 100 lpcd, and found that the software gives an economical design. Shetkar *et al.* [2] used LOOP 4 for the hydraulic design of a village network. They noted that it is used for water supply projects in 11 districts of Karnataka and gives accurate results quickly, without lengthy manual calculation. Other studies applied LOOP or BRANCH to the Kuchhadi village network [3], the Dhrafad regional scheme [4], an optimal loop system [5] and the Pindkepar village network [6], where the population forecast over three decades and the village survey were used in the design.

Yengale and Wadhai [7] wrote a program in Visual Basic for discharge and cost analysis of the Karanja village network, to reduce the time and effort of manual analysis. Yadav *et al.* [8] used LOOP 4 to design an economical rural network and found that the network accounts for about 50–70% of the total cost of a water supply system, with residual pressure, velocity, pipe material, reservoir level, peak factor and available diameters as the main constraints. Sumithra *et al.* [9] analysed the

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Tirunelveli system for 30 years with LOOP and WaterGEMS at 135 lpcd and a minimum head of 7.0 m, and found both programs efficient, with WaterGEMS the more user-friendly.

These studies show that LOOP suits village-scale design. The present work applies it to two Shiggaon-taluka villages and also reports the cost estimate under JJM.

IV. Study Area and Data

A. Study areas

Hiremanakatti lies in Shiggaon taluka of Haveri district, about 6 km from Shiggaon and 40 km from Haveri, with an area of 681.11 ha. Its 2011 population was 1,945 in 376 households. Basavanakoppa lies in the same taluka, about 12 km from Shiggaon and 40 km from Haveri, with an area of 574.54 ha, and had 211 persons in 41 households in 2011. Both villages are covered by the NRDWP multi-village scheme with a surface source, and treated water is to be supplied by gravity from an elevated service reservoir (ELSR). The works are included in JJM for 2020–21. The existing networks are old and leaking, supply is insufficient and at low pressure, and some areas have no pipeline.

B. Population and demand

The population was forecast for 30 years by the geometric increase method,

$$P_n = P_0 \, (1 + r / 100)^n \qquad (1)$$

where P_0 is the base population, r the decadal growth rate (%) and n the number of decades. The census figures of 2011 and 2020 were used. The decadal growth is 10.48% for Hiremanakatti and 11.79% for Basavanakoppa. Water demand is the population times 55 lpcd, with 20% added for losses. The required storage is compared with the existing storage, and a new reservoir is proposed when the balance is positive (Table I).

C. Network layout

The layout was prepared in AutoCAD (Fig. 1) from level surveying and linear measurement of street lengths. The ELSR is located first. A node is placed where two or more roads meet and where a road ends, and a pipe is placed between nodes. Houses, schools, temples, mosques and other buildings were plotted by overlaying the Google Earth image on the drawing, and a pipe connection was drawn to each. Node elevations were found by level surveying.

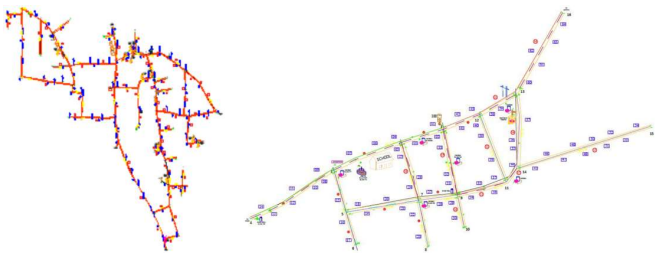


Fig. 1. AutoCAD layout of the networks: (a) Hiremanakatti, (b) Basavanakoppa.

V. Network Design in LOOP

The work was carried out in four parts (Fig. 2): drawing, Excel sheet, LOOP design and estimation. The Excel sheet lists, for every pipe, the pipe number, from-node, to-node, length, diameter, number of houses, population, daily demand and flow. The number of persons per house is the 2050 population divided by the number of houses plotted (2,969 / 400 = 7.4, taken as 8, for Hiremanakatti; 334 / 64 = 5.2, taken as 6, for Basavanakoppa). The demand of a pipe is then

$$Q = N \times p \times q \, / \, 86\,400 \qquad (2)$$

where Q is the flow (L/s), N the number of houses on the pipe, p the persons per house and q = 55 L per person per day. For example, 6 houses × 8 persons × 55 L = 2,640 L/day, or 0.03 L/s, in Hiremanakatti, and 3 × 6 × 55 = 990 L/day, or 0.01 L/s, in Basavanakoppa.

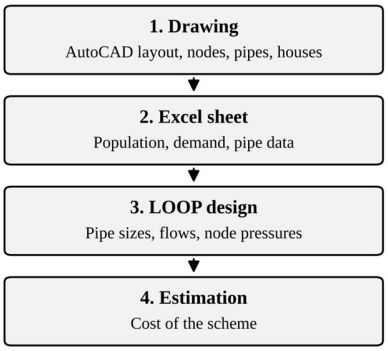


Fig. 2. Steps of the design process.

The LOOP input file holds the pipe data, the node flows and the node elevations, with a peak factor of 4, a maximum head loss of 30 m/km and a Hazen–Williams coefficient of 145. Candidate diameters were 63, 75, 90, 110, 140 and 160 mm. Head loss in each pipe follows the Hazen–Williams equation,

$$h_f = 10.67 \, L \, Q^{1.852} / (C^{1.852} \, d^{4.87}) \qquad (3)$$

with L the length (m), Q the flow (m³/s), C the coefficient and d the diameter (m). LOOP balances the flows at the nodes by the Newton–Raphson technique and reports the pressure at every node.

VI. Results and Discussion

A. Population and demand

Table I gives the forecast. The Hiremanakatti population grows from 1,945 to 2,969 by 2050, and the demand with losses is 195,962 L/day. The existing storage is 100,000 L, so a balance of 95,962 L is required and a new 100,000 L ELSR is provided. For Basavanakoppa the population grows from 211 to 334 and the demand with losses is 22,035 L/day. There is no existing storage, so a new 25,000 L ELSR is provided.

TABLE I
POPULATION FORECAST AND WATER DEMAND

Item	Hiremanakatti	Basavanakoppa
Population, 2011	1,945	211
Population, 2020	2,202	239
Population, 2030	2,433	267
Population, 2040	2,688	299
Population, 2050	2,969	334
Decadal growth (%)	10.48	11.79
Demand, 2050 (L/day)	163,301	18,362
With 20% losses (L/day)	195,962	22,035

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Item	Hiremanakatti	Basavanakoppa
Existing storage (L)	100,000	0
Balance storage required (L)	95,962	22,035
New ELSR provided (L)	100,000	25,000

B. Pipe network

Table II gives the pipe lengths. Most of both networks is 63 mm pipe. The Hiremanakatti network has 69 pipes with a total length of 3,865.35 m serving 400 houses. The Basavanakoppa network has 20 pipes with a total length of 1,159.70 m serving 64 houses. These lengths are from the design tables of the project.

TABLE II
PIPE LENGTH BY DIAMETER (M)

Diameter	Hiremanakatti	Basavanakoppa
63 mm	3,270.24	1,153.00
75 mm	569.11	6.70
90 mm	26.00	—
Total length	3,865.35	1,159.70
Number of pipes	69	20
Houses served	400	64

C. Residual pressures

Table III summarises the LOOP output and Fig. 3 plots the node pressures. Every node has a positive residual pressure, so the flows can be delivered. In Basavanakoppa the pressure is 8.96–17.50 m at the 15 nodes listed in the output. The pipe velocities are only 0.01–0.25 m/s and the head loss is at most 1.12 m/km against the 30 m/km limit, so the 63 mm pipes have ample spare capacity.

TABLE III
NODE PRESSURES FROM LOOP (M)

Item	Hiremanakatti	Basavanakoppa
Nodes in output	61	15
Minimum (node)	0.76 (45)	8.96 (1)
Maximum (node)	13.55 (3)	17.50 (6)
Mean	6.57	13.14
Nodes below 7 m	34	0
Nodes below 3 m	13	0

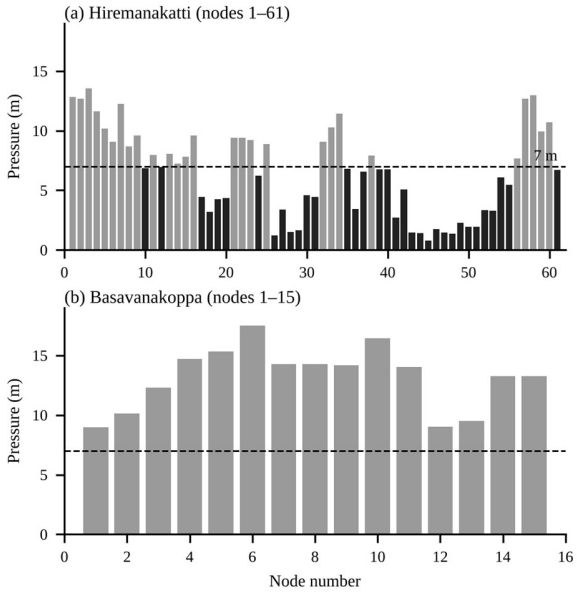


Fig. 3. Residual pressure at the nodes. Dark bars are below 7 m; the dashed line marks 7 m, the minimum head used in [9].

In Hiremanakatti the pressure ranges from 0.76 to 13.55 m, with a mean of 6.57 m. Taking the 7.0 m minimum head used in [9] as a reference, 27 of the 61 nodes meet it and 34 do not, and 13 nodes are below 3 m. The 13 nodes below 3 m (nodes 26, 28, 29, 41 and 43–51) lie at ground levels of 637.7–639.7 m under a hydraulic grade line of 640.4–640.8 m. The highest pressures, 8.7–13.6 m, are at nodes 1–9 and 57–60. The network therefore delivers the demand, but the residual head at the tail is marginal. The design should be revised, for example by raising the ELSR level or enlarging the pipes on the main feeders, and re-run in LOOP.

D. Cost estimate

Table IV gives the estimates, prepared from the RDW&S schedule of rates 2019–20 (Belagavi circle) and the PWD schedule of rates 2018–19, with 12% GST. The total is Rs 75.17 lakh for Hiremanakatti (270 household connections) and Rs 23.70 lakh for Basavanakoppa (64 connections). This is about Rs 27,800 and Rs 37,000 per household connection respectively, as calculated from the grand totals.

TABLE IV
COST ESTIMATE (RS)

Item	Hiremanakatti	Basavanakoppa
New ELSR	1,947,680	856,100
Rising main	915,390	227,810
Repair of existing ELSR	466,450	—
Distribution pipeline	1,190,160	500,340
Household connections	1,488,110	358,910
Retrofitting existing FHTC	306,360	47,370
Total of works	6,314,150	1,990,530
Inspection, DPR, misc., tender premium	397,791	125,403
12% GST	805,433	253,912
Grand total	7,517,374	2,369,845

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E. Limitations

The Hiremanakatti LOOP output gives node results only, and the Basavanakoppa output lists 15 of its nodes, so pipe velocities are discussed for Basavanakoppa alone. The minimum residual pressure used in the design is not stated, and 7 m is taken here from [9] as a reference. Only one design iteration is reported for each village, and the cost estimates were not re-worked for a revised design.

VII. Conclusion

Gravity-fed distribution networks were designed in LOOP 4.0 for Hiremanakatti and Basavanakoppa. The 2050 populations are 2,969 and 334, the demands with losses are 195,962 and 22,035 L/day, and the networks are 3,865 m and 1,160 m long. In Basavanakoppa the residual pressure is 8.96–17.50 m, and the pipe velocities and head losses are low. In Hiremanakatti every node has positive pressure, but the range is 0.76–13.55 m and 34 of 61 nodes are below 7 m, so the design must be revised before it is adopted. The estimated costs are Rs 75.17 lakh and Rs 23.70 lakh. Future work should include a revised Hiremanakatti design with higher residual heads, velocity checks for all pipes, a second demand scenario, and a cost comparison of the pipe-size options.

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