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DESIGN OF RURAL WATER SUPPLY SYSTEM USING BRANCH 3.0 - A CASE STUDY FOR NAVA-SHIHORA REGION, INDIA

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ABSTRACT

This paper demonstrates the design of rural water distribution system for a area located in the rural region. For this study, water supply distribution network is designed for population estimated for future 30 years. The heuristic software BRANCH version 3.0 has been used for designing best economical water distribution system. Intermittent water supply planned for the study area 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 etc. The water supply distribution system is designed for the Nava-Sihora region of the state of Gujarat, India.

Key words: Estimated population, Water distribution network design, BRANCH version 3.0 software, Economical diameter, Rural water distribution system.

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1. 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, 9, 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].

2. 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 in India as shown in Figure 1. The general topography of the terrain is moderately undulating.

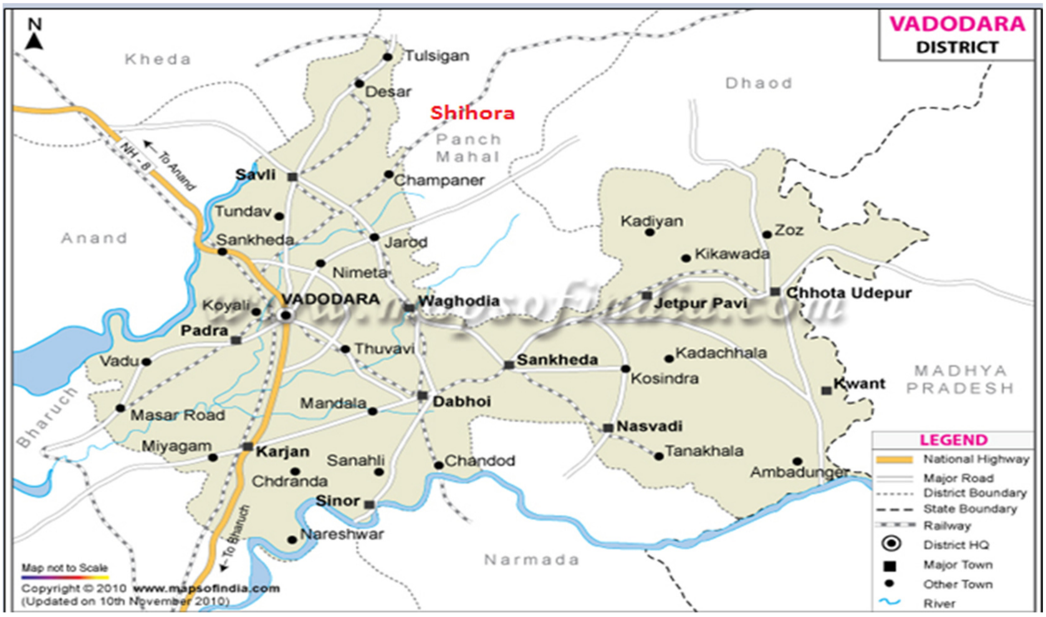

Figure 1 Index map of Vadodara district

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 lakhs 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 (ESR). 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 2 shows Shihora village in the state of Gujarat. The area of the village is about 1242 Ha. and population of the village is 6021 people as per 2011 census of india,2011.

Figure 2 Location of Shihrora village

3. BRANCH 3.0

In BRANCH 3.0 is a program that is developed by the World Bank for simulation, design & optimization of branched water distribution networks. The program is free and is in the public domain. BRANCH is used to design pressurised, branched (tree-type, non-looped) water distribution networks by choosing from among a set of commercial diameters for each pipeline so that the total cost of the network is minimised subject to meeting certain design constraints [15, 16]. Both construction costs and the design constraints can be expressed as linear, mathematical statements. The network is characterised by links (individual pipes) connected by nodes, which are points of flow input, outflow or pipe junctions [15, 16]. Version 3.0 of the software can handle up to 125 pipes. BRANCH formulates the linear programming model for the least cost design, solves the model and outputs the design as well as corresponding hydraulic information [15, 16]. Data required include description of network elements such as pipe lengths, friction coefficients, nodal demands and ground elevations, data describing the geometry of the network, the commercial pipe diameters and their unit costs, and system constraints (minimum pressures, minimum and maximum gradients). Outputs include optimal lengths and diameters of pipes in each link, total network costs and hydraulic information [15, 16].

Branch 3.0 has several additional features that increase its user friendliness and productivity significantly. These includes

Window based menus with highlight, hierarchical menus, context specific on-line help, improved and generalized file operations for copying, renaming and moving, sophisticated check data option for finding data entry and syntax errors, configuration option to allow the user to maintain data files in various subdirectories, declare name of organization, name of currency etc, command line option to set up Branch software for different run time memory models, printer paper specifications, help and output displays, facility of an on-line electronic abridged manual, Supports to color monitor and installation routine [15,16]. The branch 3.0 version configuration is as shown below.

Program Version: BRANCH 3.0

Language: Quick Basic 4.5

Code: Structured optimized

Memory handling: Dynamic

Operating system requirements: DOS, MS-Windows (95, 98, 2000)

Menu driven system: Hierarchical and structured, Window based with highlighted bar, Online context specific

Design: Linear programming formulation for gravity main network

Calculation method: Hazen-Williams, Darcy-Weisbach

Data Input: Tabular oriented input

Data Output: Tabular output in format of .doc files

Calculation capacity: 125 no. of pipes, 126 no. of nodes, maximum commercial diameter input up to 20 no.

Language: English

Handbook: English, electronic manual

4. INPUT DATA AND PARAMETER ESTIMATION

The following data is required for design of water distribution network using BRANCH software and it has been collected from Water and Sanitation Management Organization (WASMO), Vadodara, India. WASMO have also prepared detail map of study area by conducting level surveying and linear measurement of length of streets of this 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 parameters are Node to node connectivity of pipe, Length of pipes, Reduce levels of nodes in a study area. Hydraulic data parameters are Water supply demands at all the relevant nodes, Pipe resistance coefficient in terms of Hazen William's C. Water source data parameter is the Elevation of service reservoir. Data of cost estimation parameters are the parameters namely, Available commercial diameters with data on unit cost and allowable working pressure, Maximum and minimum pressure at nodes. Material of pipe PVC 6 kg/cm^2 has been used for distribution network in Shihora village. Historical population data of year 2011 are obtained for Shihora from census of India, 2011. The population of 2011 is 6201 and the population of zone 1 for which the study is carried out is 1325 people.

Present and future population can be predicted from equation (1) as under.

$$P_n = P_0 (1 + GR)^n \quad (1)$$

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 2017 is estimated from the population of year 2011 for zone 1, and is estimated from eq. (1) as 6662. The population of year 2047 (i.e. population after 30 years) from equation (1) have been estimated as 11046 people.

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Water supply demand (Q) for each node can be calculated as under using equation (2).

$$Q = 1.5 \times Pn \times Dpc \times Cf \quad (2)$$

where,

Q = water supply demand in lps

Pn = population catered for each node

Dpc = water demand in liter per capita per day

Cf = conversion factor (1/24 x 60 x 60)

The above mentioned data such as geometric data, hydraulic data, water sources data, cost estimates parameters data, water demand data are incorporated into BRANCH 3.0 software to distribution network design for Nava Shihora village zone 1. Input data files for BRANCH 3.0 software have been shown below. Table 1 shows the input data file for the water distribution network of the area under study.

Table 1 Water supply distribution network data

Item	Details
Title of the Project	Zone 1 shihora
Name of the User	Vidhi
Number of Pipes in the network	32
Number of Nodes in the network	33
Number of Commercial Diameters	5
Peak Design Factor	3
Minimum head loss (m/km)	0.001
Maximum head loss (m/km)	3
Minimum Residual Pressure (m)	7
Type of Formula	Hazen's

In the above Table 1, the peak design factor is taken as 3.0 i.e. as per Central Public Health and Environmental Engineering Organization (CPHEEO) manual [11]. The minimum and maximum head loss, pressure m/km) is taken 0.001 i.e. as per the rural water supply manual [10].

The Pipe input data and Node input data is shown in Table 2 and Table 3.

Table 2 Pipe input data

Pipe No.	From Node	To Node	Length (m)	Hazen Constant
		(m)		
1	1	2	205	140
2	2	3	40	140
3	3	4	40	140
4	4	5	30	140
5	4	6	144	140
6	4	7	35	140
7	4	8	130	140
8	8	9	139	140
9	8	10	118	140

Pipe No.	From Node	To Node	Length (m)	Hazen Constant
		(m)		
10	8	11	45	140
11	11	12	79	140
12	11	13	89	140
13	3	14	65	140
14	14	15	129	140
15	14	16	158	140
16	16	17	50	140
17	17	18	108	140
18	18	19	23	140
19	18	20	98	140
20	18	21	40	140
21	21	22	48	140
22	21	23	35	140
23	23	24	20	140
24	23	25	14	140
25	25	26	22	140
26	26	27	43	140
27	26	28	78	140
28	26	29	20	140
29	29	30	55	140
30	30	31	40	140
31	29	32	37	140
32	32	33	36	140

Table 3 Node input data

Node No.	Peak Factor	Flow (lps)	Reduce level	Minimum. Pressure
		(lps)	(m)	(m0
1	3	0.000	100 (Bench mark)	7
2	3	0.000	99.987	7
3	3	-0.061	101.112	7
4	3	-0.035	101.210	7
5	3	-0.035	101.074	7
6	3	-0.139	100.920	7
7	3	-0.043	101.270	7
8	3	-0.148	101.588	7
9	3	-0.148	101.596	7
10	3	-0.148	102.321	7
11	3	-0.078	101.001	7
12	3	-0.087	99.543	7
13	3	-0.087	99.109	7
14	3	-0.095	99.112	7
15	3	-0.078	99.465	7
16	3	-0.165	99.404	7
17	3	-0.069	99.987	7
18	3	-0.139	100.587	7
19	3	-0.043	100.857	7
20	3	-0.113	101.588	7
21	3	-0.078	101.565	7
22	3	-0.061	101.854	7
23	3	-0.043	101.909	7
24	3	-0.026	102.012	7
25	3	-0.043	102.574	7
26	3	-0.043	102.742	7
27	3	-0.043	102.985	7
28	3	-0.113	103.554	7
29	3	-0.026	103.849	7
30	3	-0.043	104.578	7
31	3	-0.026	104.786	7
32	3	-0.017	104.556	7
33	3	-0.026	104.585	7

Table 4 Commercial pipe diameter data

Pipe internal diameter (mm)	Hazen's constant	Unit cost/length	Allowable Pressure	Pipe material
(mm)		(Rs./m)	(m)	
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 5 Data for fixed head

Source Node	Head	Ref Reservoir
	(m)	
1	114.00	R

In the above Table 5, head 114m has been obtained from the summation of base elevation plus staging height of tank. In this study, the possibility is also explored for the staging height of the tank 13.0 m. In that case. head (m) is shown in Table 5 is given as a data as 113.0 m. The results are also obtained for head 113.0 m at source node.

5. RESULTS AND DISCUSSION

Results are obtained from BRANCH software 3.0 and is as shown below.

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). 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 Output for pipe details

Pipe No.	Flow (lps)	Diameter	head Loss	head loss per 1000 m (m)	Length
	(lps)	(mm)	(m)	(m)	(m)
1	6.897	129.7	0.49	2.39	205
2	6.897	129.7	0.10	2.50	40
3	2.844	102	0.06	1.50	40
4	0.105	63.9	0.0	0.0	30
5	0.417	63.9	0.06	0.42	144
6	0.129	63.9	0.0	0.0	35
7	2.088	83.2	0.30	2.31	130
8	0.444	63.9	0.07	0.50	139
9	0.444	63.9	0.06	0.51	118

Pipe No.	**Flow (lps)**	**Diameter**	**head Loss**	**head loss per 1000 m (m)**	**Length**
	(lps)	(mm)	(m)	(m)	(m)
10	0.756	63.9	0.06	1.33	45
11	0.261	63.9	0.01	0.13	79
12	0.261	63.9	0.02	0.22	89
13	3.87	102	0.17	2.62	65
14	0.234	63.9	0.02	0.16	129
15	3.351	102	0.32	2.03	158
16	2.856	102	0.08	1.60	50
17	2.649	102	0.14	1.3	108
18	0.129	63.9	0.0	0.0	23
19	0.339	63.9	0.03	0.31	98
20	1.764	83.2	0.07	1.75	40
21	0.183	63.9	0.0	0.0	48
22	1.347	83.2	0.04	1.14	35
23	0.078	63.9	0.0	0.0	20
24	1.140	63.9	0.4	2.86	14
25	1.011	63.9	0.05	2.27	22
26	0.129	63.9	0.0	0.0	43
27	0.339	63.9	0.02	0.26	78
28	0.414	63.9	0.01	0.50	20
29	0.207	63.9	0.01	0.18	55
30	0.078	63.9	0.0	0.0	40
31	0.129	63.9	0.0	0.0	37
32	0.078	63.9	0.0	0.0	36

Table 6 Output for each node

Node No.	Flow	Reduce level	HGL	Pressure for 13m height of ESR	Pressure for 14m height of ESR
	(lps)	(m)	(m)	(m)	(m)
1	6.897	100.0	114.0	13.0	14.0
2	0.00	99.99	113.51	12.53	13.52
3	-0.183	101.11	113.41	11.31	12.30
4	-0.105	101.21	113.35	11.15	12.14
5	-0.105	101.07	113.35	11.29	12.28
6	-0.417	100.92	113.29	11.39	12.37
7	-0.129	101.27	113.35	11.09	12.08
8	-0.444	101.59	113.06	10.48	11.47
9	-0.444	101.60	112.99	10.41	11.39
10	-0.444	102.32	113.0	9.70	10.68
11	-0.234	101.00	113.0	11.02	12.0
12	-0.261	99.54	112.99	12.46	13.45
13	-0.261	99.11	112.99	12.89	13.88
14	-0.285	99.11	113.24	13.14	14.13
15	-0.234	99.46	113.22	12.78	13.76
16	-0.495	99.40	112.92	12.54	13.52
17	-0.207	99.99	112.85	11.87	12.86
18	-0.417	100.59	112.71	11.14	12.12
19	-0.129	100.86	112.70	10.86	11.84
20	-0.339	101.59	112.68	10.11	11.09
21	-0.234	101.57	112.64	10.09	11.07
22	-0.183	101.85	112.63	9.81	10.78
23	-0.129	101.91	112.60	9.72	10.69
24	-0.078	102.01	112.60	9.60	10.59
25	-0.129	102.57	112.57	9.04	10.0
26	-0.129	102.74	112.52	8.86	9.78
27	-0.129	102.99	112.52	8.61	9.53
28	-0.339	103.55	112.50	8.03	8.95
29	-0.078	103.85	112.51	7.74	8.66
30	-0.129	104.58	112.50	7.0	7.92
31	-0.078	104.79	112.50	6.7	7.71
32	-0.051	104.56	112.51	7.0	7.95
33	-0.078	104.58	112.51	7.0	7.93

In above table, -ve sign indicate that node getting supply from source.

Table 7 Output for pipe cost

Outer diameter (mm)	Pipe material	Length	Cost	Cumulative cost
(mm)		(m)	(1000 Rs.)	(1000 Rs.)
75	PVC	1342	116.89	116.89
90	PVC	205	25.57	142.46
110	PVC	421	74.89	217.35
140	PVC	245	72.06	289.41
160	PVC	0	0	289.41

Figure 3 shows hydraulic gradient line (HGL) (m) and R.L. (m) of nodes. It is seen from Figure 3 that HGL is declined because of head loss and friction loss occurring in pipe of the system. Figure 4 shows pressure head (m) at nodes. It is seen from Table 7 that for staging height of ESR as 13m the pressure head achieved at terminal node 31 is 6.7m which is less than the pressure requirement (7 m) shown in Table 1. Also, it is observed from Table 7 that for staging height of ESR as 14m the pressure head achieved at terminal node is 7.71m. So it is found from the analysis of the above results that the staging height of ESR should be designed as 14m so as to achieve a pressure 7m at terminal node of the system.

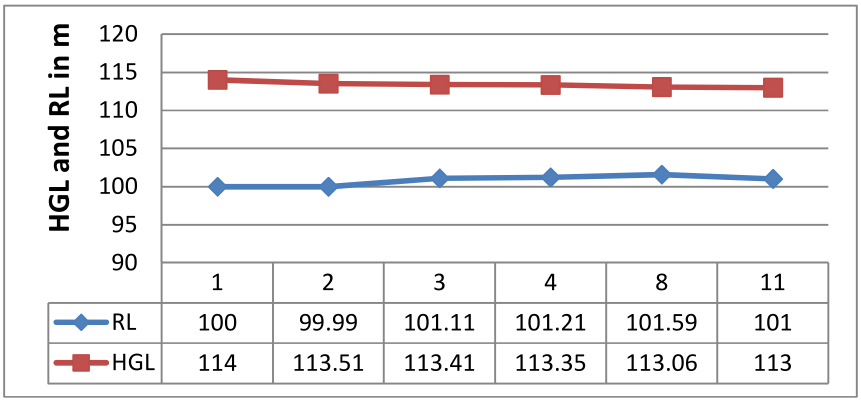

Figure 3 Hydraulic gradient line and Reduced level (m)

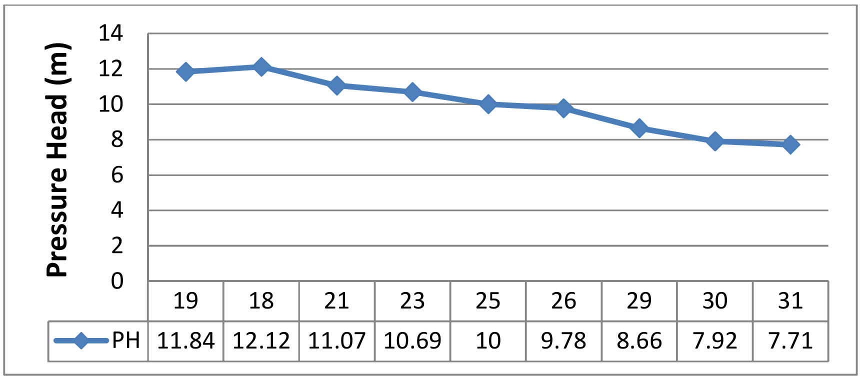

Figure 4 Pressure head at nodes

6. CONCLUSION

The BRANCH 3.0 software provides successful solutions for economical water supply distribution system design. This paper describes the simulations through BRANCH 3.0 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, India The program results include flows in the links and pressures at the nodes in water supply system.

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