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"A Review on Comparative Study of Two Water Supply Systems"

Using branch 3.0 and Loop 4.0

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Abstract: Water distribution systems are essential for providing a continuous and safe water supply to consumers. This paper explores the design and analysis of efficient water supply systems, with a focus on pipe networks. In rural areas, regional water supply schemes are often established to serve multiple villages from a shared water source. The distribution network plays a critical role in such schemes and can account for a significant portion of the project cost. Optimization techniques, including linear programming, non-linear programming, genetic algorithms, and simulated annealing, are utilized to address the hydraulic network design problem. The objective is to optimize the performance of the water supply system and ensure economic development through improved water availability. This study highlights the importance of effective water supply infrastructure and presents keywords such as water distribution system, pipe networks, optimization techniques, hydraulic network design, and economic development.

Index Terms - **Estimated population, Water distribution network design, Branch version3.0 software, LOOP version 4.0 software, Economical diameter, rural water distribution system**

1. INTRODUCTION

Water distribution systems are crucial hydraulic infrastructures that consist of various components such as pipes, tanks, reservoirs, pumps, and valves. They play a vital role in providing a continuous and safe water supply to consumers. Designing an efficient water supply system is essential when creating a new distribution network or expanding an existing one. Pipe systems are widely regarded as one of the most effective methods for ensuring the safe and uninterrupted supply of water.

In rural areas, regional water supply schemes are often established to provide adequate and continuous water to multiple villages from a shared water source through a pipe system. The distribution network is a critical component of any water supply system. In fact, the cost of designing and implementing a distribution system may account for 60% or more of the overall project cost.
Designing and analyzing pipe networks are of great importance since water availability is a significant factor in economic development. Various researchers have employed different programming techniques to gain insights into water supply networks and optimize their performance. These techniques include linear programming, non-linear programming, genetic algorithms, and simulated annealing. They formulate the hydraulic network design problem as an optimization challenge.

1.1 OBJECTIVES

- The present dissertation work has been undertaken with following major objectives:
- To carry out literature review of analysis of hydraulic networks;
- To study various constraints of a hydraulic network;
- To analyse the existing water distribution system using software and to suggest some measures if present network does not fulfil the present and future demand;
- Water Supply: The project aims to provide a consistent and adequate supply of water to meet the demands of the target areas or communities. This involves the construction of pipelines, reservoirs, pumping stations, and other infrastructure required for the transmission and distribution of water.

- Accessibility: The project seeks to enhance access to clean and safe water by extending the network to underserved or remote areas. It aims to reduce disparities in water availability and improve the quality of life for the people in those regions.

- Efficiency: The project strives to optimize water usage and minimize losses through leakage or inefficient distribution. By implementing advanced technologies and design principles, such as hydraulic modeling, pressure management, and leak detection systems, the project aims to enhance the efficiency of water transmission and reduce operational costs.

- Reliability: The network should be designed to ensure a reliable water supply, even during periods of high demand or in emergency situations. This involves redundancy measures, backup systems, and appropriate maintenance protocols to minimize downtime and disruptions.

- Sustainability: The project aims to promote sustainable water management practices by considering environmental, social, and economic factors. It may involve integrating renewable energy sources, implementing water conservation measures, and incorporating environmentally friendly materials and construction methods.

- Future Expansion: The project should also account for future growth and changing water demands. It should have the flexibility to accommodate population growth, urban development, and industrial expansion, ensuring long-term water security for the communities it serves.

2. STUDY AREA

The village of Nava Shihora is a recently developed area located approximately 15 km away from Savali Taluka. Savali Taluka, in turn, is situated around 32 km north of Vadodara, the district headquarters in Gujarat, India. The topography of the region is described as moderately undulating, indicating the presence of gentle slopes and rolling hills.

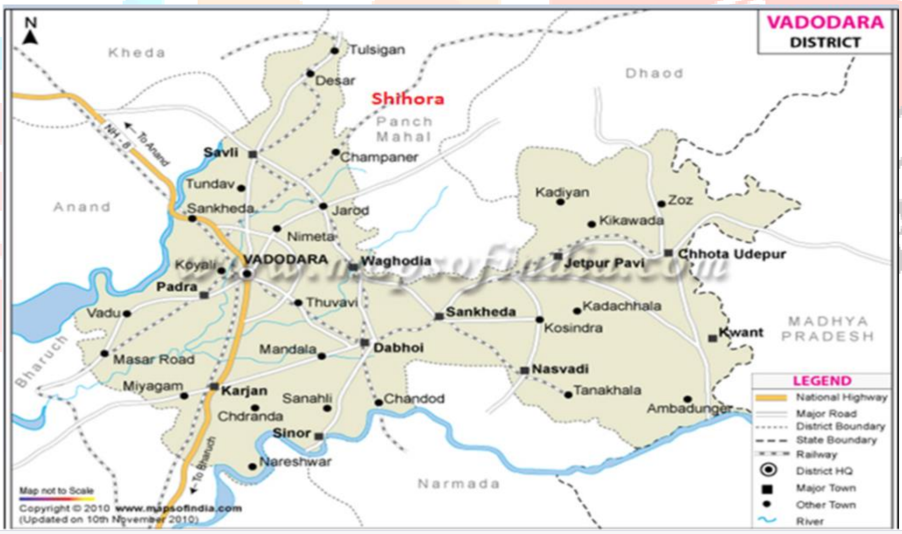

Image 1: Index map of Vadodara District

The primary water source for the study area is the Mahi River, which provides surface water. There are a total of 136 villages in Savli taluka, but the regional water supply scheme only includes 90 villages, including Shihora village.In the regional water supply scheme, water is pumped from the Mahi River to the water treatment plant (WTP). After treatment, the water is conveyed to the master sump, which has a capacity of 41 lakhs liters. From the master sump, the water is pumped to the elevated service reservoir, which has a capacity of 21 lakhs liters. This forms the primary network.

In the secondary network, water is conveyed through pipes from the elevated service reservoir to the Shihora village sump. From the sump, the water is further conveyed to the Shihora village elevated service tank (ESR). Finally, in the tertiary network, water is distributed from the elevated service tank to the consumers through a pipe system.To ensure proper distribution of water, the village of Shihora is divided into various zones. In the present study, an economical water distribution system has been designed for Zone 1 of Shihora village. The total area of the village is approximately 1242 hectares, and the population was recorded as 6021 people according to the 2011 census of India.

Image 2 : Location of Shihrora Village

2.1 BRANCH 3.0

BRANCH 3.0 is a software program developed by the World Bank for simulating, designing, and optimizing branched water distribution networks. This program is freely available to the public and falls under the public domain. It is specifically designed to create pressurized, branched water distribution networks that do not have loops, resembling a tree-like structure.

The primary objective of BRANCH is to minimize the total cost of the network while satisfying certain design constraints. These constraints and construction costs can be expressed as linear mathematical statements. The network consists of links, which represent individual pipes, and nodes, which indicate points of flow input, outflow, or pipe junctions.Version 3.0 of the software has the capacity to handle up to 125 pipes. BRANCH formulates a linear programming model based on the least-cost design principles. It then solves the model and provides outputs that include the design itself and corresponding hydraulic information.
To use BRANCH effectively, various data inputs are required. This includes descriptions of network elements such as pipe lengths, friction coefficients, nodal demands, and ground elevations. Additionally, data specifying the network's geometry, available commercial pipe diameters, their associated unit costs, and system constraints (such as minimum pressures and minimum/maximum gradients) need to be provided. Outputs include optimal lengths and diameters of pipes in each link, total network costs and hydraulic information.

The features of the Branch 3.0 version configuration include:

- Window-based menus with highlight
- Hierarchical menus
- Context-specific online help
- Improved and generalized file operations (copying, renaming, and moving)
- Sophisticated check data option for identifying data entry and syntax errors
- Configuration option for maintaining data files in various subdirectories
- Ability to declare the name of the organization and currency
- Command line option for setting up Branch software for different run-time memory models
- Printer paper specifications
- Help and output displays
- On-line electronic abridged manual
- Support for color monitors
- Installation routine

2.2 LOOP 4.0

Loop 4.0 is a program developed by the World Bank for simulating, designing, and optimizing looped water distribution networks. This program is freely available to the public and is in the public domain. Its primary purpose is to determine the most economical pipe sizes for the network.

The algorithm used in Loop is heuristic and is based on the work reported by Dixit and Rao (1987). This method has been found to be effective compared to other more theoretically rigorous methods, providing a quick and good starting solution for further improvement by the user.Loop simulates the hydraulic characteristics of a pressurized, looped water distribution network, which consists of pipes and nodes. The necessary input data includes descriptions of the network elements such as pipe lengths, diameters, friction coefficients, nodal demands, ground elevation, and network geometry. The program calculates and outputs flows, velocities, and pressures in the network's links and nodes.

It's important to note that Loop 4.0 does not support in-line booster pumps or pressure reducing valves. It can handle networks with up to 1000 pipes and simulate and design up to 10 nodes with known hydraulic grade lines, such as storage reservoirs. The program's typical use is to simulate and design the hydraulic response of a network to single or multiple inputs, with at least one known hydraulic gradient line elevation. Once the final design is completed, Loop also provides a sub-program for generating a cost summary.

In most cases, the loop network designed by Loop 4.0 will have a minimum-size connection between the extremities of the tree network.

3. COLLECTION OF DATA

The following data is required for design of water distribution network using BRANCH and 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.

Estimation of the population
Present and future population can be predicted as under

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

where,
Pn = the projected population after nth year from initial year
P0 = 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

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

Total water demand Q (lps) for each node = 1.5 x Pn x Dpc x Cf

where,
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 and Loop software for distribution network design for zone- 1 of Shihora village

3.1 INPUT DATA

Title of the Project shihora : zone 1
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

Pipe Data					Node Data				
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 (Bench mark)	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	14	15	129	140	14	3	-0.095	99.112	7
15	14	16	158	140	15	3	-0.078	99.465	7
16	16	17	50	140	16	3	-0.165	99.404	7
17	17	18	108	140	17	3	-0.069	99.987	7
18	18	19	23	140	18	3	-0.139	100.587	7
19	18	20	98	140	19	3	-0.043	100.857	7
20	18	21	40	140	20	3	-0.113	101.588	7
21	21	22	48	140	21	3	-0.078	101.565	7
22	21	23	35	140	22	3	-0.061	101.854	7
23	23	24	20	140	23	3	-0.043	101.909	7
24	23	25	14	140	24	3	-0.026	102.012	7
25	25	26	22	140	25	3	-0.043	102.574	7
26	24	26	20	140	26	3	-0.043	102.742	7
27	26	27	43	140	27	3	-0.043	102.985	7
28	26	28	78	140	28	3	-0.113	103.554	7
29	26	29	20	140	29	3	-0.026	103.849	7
30	29	30	55	140	30	3	-0.043	104.578	7
31	30	31	40	140	31	3	-0.026	104.786	7
32	29	32	37	140	32	3	-0.017	104.556	7
33	32	33	36	140	33	3	-0.026	104.585	7

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: 1and 2 Input data for pipes

4. OUTPUT

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

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

Table 3 and 4: Cumulative cost of pipes using Branch and Loop Software\

5. RESULTS AND DISCUSSION

For the 75 mm diameter pipe:

Cumulative cost for BRANCH 3.0: 116.89 thousand Rs.
Cumulative cost for Loop 4.0: 118.63 thousand Rs.

For the 90 mm diameter pipe:

Cumulative cost for BRANCH 3.0: 142.46 thousand Rs.
Cumulative cost for Loop 4.0: 127.98 thousand Rs.

For the 110 mm diameter pipe:

Cumulative cost for BRANCH 3.0: 217.35 thousand Rs.
Cumulative cost for Loop 4.0: 186.33 thousand Rs.

For the 140 mm diameter pipe:

Cumulative cost for BRANCH 3.0: 289.41 thousand Rs.
Cumulative cost for Loop 4.0: 251.92 thousand Rs.

For the 160 mm diameter pipe:

Cumulative cost for BRANCH 3.0: 289.41 thousand Rs.
Cumulative cost for Loop 4.0: 344.72 thousand Rs.

Based on the given data, it can be concluded that the 90 mm diameter pipe is more economical when using BRANCH 3.0 software, as it has a lower cumulative cost (142.46 thousand Rs.) compared to Loop 4.0 (127.98 thousand Rs.).
However, for the other pipe diameters (75 mm, 110 mm, 140 mm, and 160 mm), Loop 4.0 software results in lower cumulative costs compared to BRANCH 3.0. Therefore, if one were to prioritize overall cost efficiency, Loop 4.0 would be the more economical option for these pipe diameters.

Both software solutions, BRANCH 3.0 and Loop 4.0, contribute to the hydraulic design process by simulating the behavior of the water supply distribution system. They aid in determining the appropriate pipe sizes, pressure requirements, and overall system performance, ultimately facilitating the development of an economical and efficient water supply scheme for the Nava Sihora village in Gujarat, India.

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