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Network analysis of water distribution system in rural areas using EPANET

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Abstract

In order to ensure the availability of sufficient quantity of good quality of water to the various section of community in accordance with the demand. Many computer tools were developed, out of all the tools available EPANET become most popular and convenient for the effective design of complex pipe networks. This paper highlights only the effective design and distribution of network of pipes using EPANET tool.The residual head at each and every node was found out by having the elevation as input and thereby the corresponding flow quantities were derived like residual head, velocity and nodal demand etc.

*Keywords:*Distribution network; EPANET; Nodal demand; Effective design;Mathematical models

1. Introduction

Water distribution system is a hydraulic infrastructure consisting of elements such as pipes, tanks reservoirs pumps and valves etc. It is crucial to provide drinking or potable water to the end users; hence, effective water supply is of paramount importance in designing a new water distribution network or in expanding the existing one [1]. Computation of flows and pressures in a complex network has been of great challenge and interest for those involved with designs, construction and maintenance of public water distribution systems. Analysis and design of pipe networks create a relatively complex problem, particularly if the network consists of range of pipes as

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frequently occurs in water distribution systems of large metropolitan areas. In the absence of significant fluid acceleration, the behaviour of a network can be determined by a sequence of steady state conditions, which form a small but vital component for assessing the adequacy of a network [2]. Such an analysis is needed each time changing pattern of consumption or delivery are significant or, added features such as supplying of water, addition of booster pumps, pressure regulating valves or storage tanks, change the system. Many methods have been used in the past to compute flows in network of pipes such methods range from graphical methods to the use of physical analogies and finally to the use of mathematical models [2 & 3]. These methods of network analysis have been developed and implemented on the computer over the last fifty years. Of all the available methods, the first and probably the most widely used method of analysis is the Hardy Cross Technique. This method makes corrections to initial assumed value by using a first order expansion of the energy equation in terms of selection factor for the flow rate in each loop. In certain cases it has been found that the Hardy Cross method converges very slowly or not at all. This leads to suggest special measures to improve convergence and a constrained model for the minimum cost design of water distribution networks. This methodology attempted to account for the uncertainties in required demands, required pressure heads, and pipe roughness coefficients. It was formulated an optimization problem as a non-linear programming model which is solved using a generalized reduced gradient method. It shows that uncertainties in future demands, pressure head requirements, and pipe roughness can have significant effects on the optimal design and cost.

Further the reliability of water distribution system can be computed by treating the demand, pressure head, and pipe roughness as random variables. It can also be assumed that water demand and pipe roughness coefficient follow a probability distribution, and then used a random number generator to generate the values of random variables for each node and pipe. It leads to hydraulic simulation and computed the pressure heads at the demand nodes, provided the demands are satisfied. Finally, nodal and system hydraulic reliabilities can be computed using EPANET.

1.1 Background of water distribution network analysis

One of the earliest theories into finding solution to water flow and pressure in water distribution network includes the popular Hardy Cross method which is an iterative method for determining the flow in pipe network systems where the inputs and outputs are known, but the flow inside the network is unknown. The Hardy Cross method is an adaptation of the Moment distribution method, which was also developed by Hardy Cross as a way to determine the moments in indeterminate structures. The method was later made obsolete by computer solving algorithms employing Newton-Raphson method or other solution methods that removed the need to solve nonlinear systems of equations by hand.

1.2 Justification for the use of EPANET

The EPANET software developed by the USA Environmental Protection Agency is adopted because it is for general public and educational use and it is available free on-line. It has the capacity to analyze unlimited number of pipes and tanks. EPANET has become a popular tool in analyzing complex and simple water distribution networks in both the developed and developing countries of the world. EPANET is a computer program that performs extended period simulation of hydraulic and water quality behaviour within pressurized pipe networks [4]. A network consists of pipes, nodes (pipe junctions), pumps, valves and storage tanks or reservoirs. EPANET tracks the flow of water in each pipe, the pressure at each node, the height of water in each tank, and the concentration of a chemical species throughout the network. EPANET is designed to be a research tool for improving our understanding of the movement and fate of drinking water constituents within distribution systems. It can be used for many different kinds of applications in distribution systems analysis. In this paper it was used to carry out the hydraulic analysis of the distribution network of the study area. The results obtained are verified and observed that the pressures at all junctions and the flows with their velocities at all pipes are feasible enough to provide adequate water to the network of the study area.

1.3 Advantages of EPANET

Following are some basic advantages of EPANET for using in network and distribution analysis.

- Flow rates in the network is obtained by using linear method.[6 & 7]
- Headlosses due to friction are computed using Darcy-Weisbach or Mannings formulae.
- It has the capability in considering minor losses from bends, fittings, etc.
- It also can duplicate demands which vary over time.
- It can also handle for different demand patterns for each node.

2. Study area

In this paper, to design the effective network of water distribution, Chowduru of Proddaturumandal in YSR Kadapa District of Andhra Pradesh, India, is considered. The study area lies in 57/J/5/SE toposheet as per the records available from Survey Of India (SOI). The geographical extents of the study area varying from 78° 27’ 30” N, 14° 45’ E to 78° 30’ N, 14° 47’ 30” E. As, the optimized design of distribution network for supplying of drinking water is not done earlier for the present study area using EPANET tool, hence, this area is considered for the present analysis in this paper. In addition to the above, basic topographical data such as base map, layout for distribution network to be designed; the population of the study area was collected from the concern authorities at the mandal level.

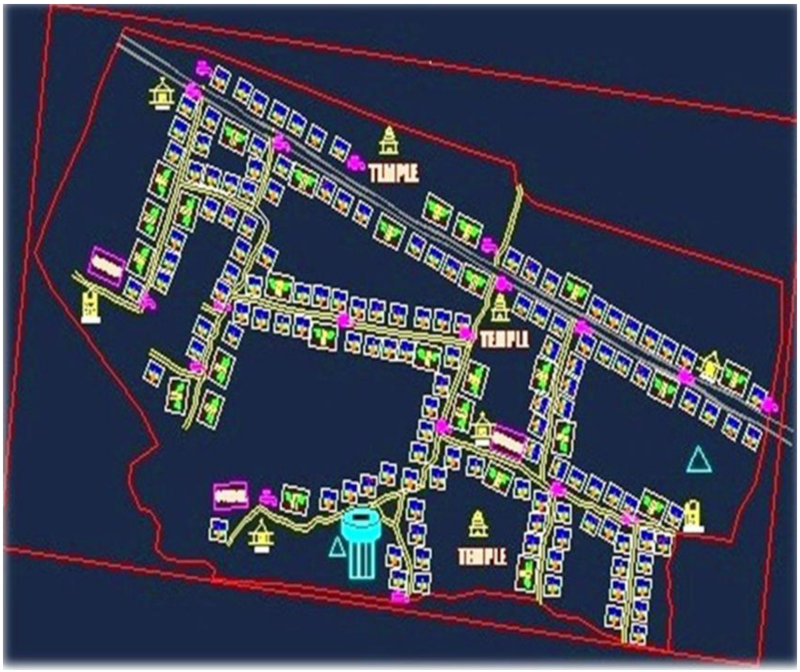

Fig. 1. Base map of study area

The population data available from the statistical department at the mandal level of the study area according to 2011 census is taken as 3308 No’s. Then the same population was forecasted for ultimate year (2031) by assuming 1% growth of population. The population for the ultimate year (2031) is estimated to be 4037 No’s. Hence, for the above said population, by taking the corresponding rate of demand assuming the per capita supply as 55 lpcd (Litres Per Capita per Day) including losses as per CPHEEO manual [5].

3. Methodology

The latest imagery of the study area is collected using Google satellite imagery as per the known latitudes, longitudes which can be extracted from the toposheet numbered 57/J/5/SE. Base map is generated by the method of digitizing using Auto CAD tool. Different layers are generated to distinguish well-known places such as temples, churches and mosques etc, representation of sources for the distribution of water to study area if any existing, which was shown in Fig. 1.As the EPANET tool is very user friendly, one can adopt the following procedure as mentioned here under with the base map generated.

- Preparing a scheme of design with the available data
- Importing layout of distribution network into EPANET tool from Auto – CAD.
- Fixing the total demand from reservoir or tank based on the hydraulic scheme design.
- Assigning the units of flow as LPM, fix the head loss formula to Hazard – Williams (H – W) method.
- The hydraulic properties to the network of pipes like length, diameter, roughness etc. are to be assigned based on the method of importing into EPANET platform.
- Thoroughly check the pipes and nodes are properly connected at intersections and reservoir nodes.
- Run the hydraulic analysis.

The layout of pipe network is extracted from the base map of the study area as stated earlier and shown in Fig. 2. It was assumed that the pipes used for supplying of water to the end users will be laid along the side of roadway. In this network diagram nodesat different points were identified and marked in pink colour.

Fig. 2. Layout of road network for the study area

4. Results and discussions

In this paper the distribution network of Chowduru network was obtained and analyzed. The entire distribution network consists of 53 pipes of same materials, 49 junctions, 1 tank and 1 source reservoir from which water is pumped to the elevated service reservoir which is shown in Fig. 3.

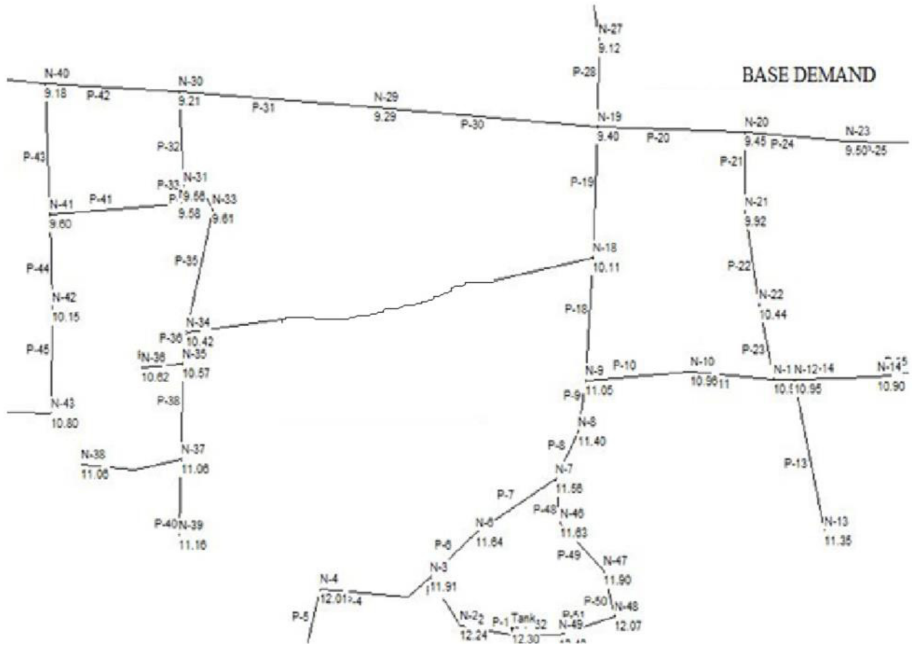

Fig. 3. Pipe network in EPANET

As mentioned earlier, the population of the study area is considered to be 3308 No's as per 2011 census, and assuming 1% rate of growth in increase in population for the ultimate year 2031 the population is estimated as 4037 No's. Also, by considering the rate of supply per capita as 55 lpcd as per CPHEEO manual, the corresponding rate of demand in LPM is shown in Table – 1.

Table 1.Details of population and rate of demand for base year and ultimate year

Population	Rate of demand
Population as per 2011 census (Base year)	3308 No's
Projected population for ultimate year (2031) @ 1% growth	4037 No's
Rate of demand for base year (2011)	252.70 lpm
Rate of demand for ultimate year (2031)	308.37 lpm

Table 1 represents population for both base year and ultimate year with corresponding to the 55 lpcd. For the base year 2011 the rate of demand in lpm is obtained to be 252.70 lpm and for the ultimate year 2031 the rate of demand is obtained around 308.37 lpm. After obtaining the required rate of demand, the network has to be designed for the obtained lpm. Hence, for the effective design of distribution system, following inputs to lateral distribution network with the basic parameters like length between nodes, roughness of pipe based on material, Initial diameter of pipe in distribution network system are to be assigned. Therefore, table – 2 shows the input parameters assigned to the network system.

Table – 2 represents the length between two nodes, the corresponding diameter required for the free flow and co-efficient of roughness of pipe used to transfer the flow of water in the system.

The analysis of any typical water distribution network includesdetermining quantities of flow, head losses in the entire network of pipe lines and resulting residual pressure at various nodes in the network junctions. In the same lines, the demands at nodes (nodal demands) were also calculated by taking the rate of demand as 55 lpcd and the results were tabulated and shown in Table 3.

Table 2.Details of network from EPANET tool

ID	Node1	Node2	Length (m)	Diameter (mm)	Roughness
P-47	N-45	N-40	11.00	63.5	135
P-29	N-27	N-28	4.00	63.5	135
P-24	N-20	N-23	7.00	63.5	135
P-25	N-23	N-24	6.00	63.5	135
P-26	N-24	N-25	6.00	63.5	135
P-27	N-25	N-26	7.00	63.5	135
P-43	N-40	N-41	8.00	63.5	135
P-44	N-41	N-42	6.00	63.5	135
P-45	N-42	N-43	7.00	63.5	135
P-41	N-41	N-32	9.00	63.5	135
P-33	N-32	N-31	0.60	63.5	135
P-36	N-35	N-34	2.00	63.5	135
P-37	N-36	N-35	3.00	63.5	135
P-18	N-18	N-9	9.00	63.5	135
P-21	N-20	N-21	5.00	63.5	135
P-22	N-21	N-22	6.00	63.5	135
P-23	N-22	N-11	5.00	63.5	135
P-11	N-10	N-11	6.00	63.5	135
P-9	N-9	N-8	3.00	63.5	135
P-8	N-8	N-7	3.00	63.5	135
P-48	N-7	N-46	3.00	63.5	135
P-49	N-46	N-47	4.00	63.5	135
P-50	N-47	N-48	3.00	63.5	135
P-51	N-48	N-49	4.00	63.5	135
P-52	N-49	N-1	3.00	63.5	135
P-2	N-1	N-2	3.00	63.5	135
P-3	N-2	N-3	4.00	63.5	135
P-7	N-6	N-7	6.00	63.5	135
P-12	N-11	N-12	1.00	63.5	135
P-15	N-14	N-15	4.00	63.5	135
P-16	N-15	N-16	4.00	63.5	135
P-42	N-40	N-30	9.00	63.5	135
P-32	N-30	N-31	6.00	63.5	135
P-35	N-33	N-34	8.00	63.5	135
P-38	N-35	N-37	6.00	63.5	135
P-14	N-12	N-14	6.00	63.5	135
P-5	N-4	N-5	6.00	63.5	135
P-13	N-12	N-13	9.00	63.5	135
P-17	N-15	N-17	10.00	63.5	135
P-34	N-31	N-33	2.00	63.5	135
P-31	N-30	N-29	14.00	63.5	135
P-30	N-29	N-19	15.00	63.5	135
P-46	N-44	N-43	9.00	63.5	135
P-39	N-38	N-37	7.00	63.5	135
p15	N-18	N-34	24.00	63.5	135
P-4	N-4	N-3	6.00	63.5	135
P-19	N-18	N-19	6.00	63.5	135
P-20	N-19	N-20	7.00	63.5	135
P-28	N-19	N-27	4.00	63.5	135
P-6	N-3	N-6	3.00	63.5	135
P-40	N-39	N-37	5.00	63.5	135
P-10	N-9	N-10	4.00	63.5	135

Table 3.Nodal demands at nodes of the network

Node number	Demand at nodes (lpm)
N-1	6.47
N-10	7.19
N-11	8.62
N-12	11.5
N-13	6.47
N-14	7.19
N-15	12.93
N-16	2.87
N-17	7.19
N-18	28.02
N-19	22.99
N-2	5.03
N-20	13.65
N-21	7.9
N-22	7.9
N-23	9.34
N-24	8.62
N-25	9.34
N-26	5.03
N-27	5.75
N-28	2.87
N-29	20.84
N-3	9.34
N-30	20.84
N-31	6.18
N-32	6.9
N-33	7.19
N-34	24.43
N-35	7.9
N-36	2.16
N-37	12.93
N-38	5.03
N-39	3.59
N-4	8.62
N-40	20.12
N-41	16.53
N-42	9.34
N-43	11.5
N-44	6.47
N-45	7.9
N-46	5.03
N-47	5.03
N-48	5.03
N-49	5.03
N-5	4.31
N-6	6.47
N-7	8.62
N-8	4.31
N-9	11.5

Table 3 represents the nodal demands for the given network after analyzing for the required outputs the results obtained for the study area are presented here from Fig. 4 to Fig. 6.

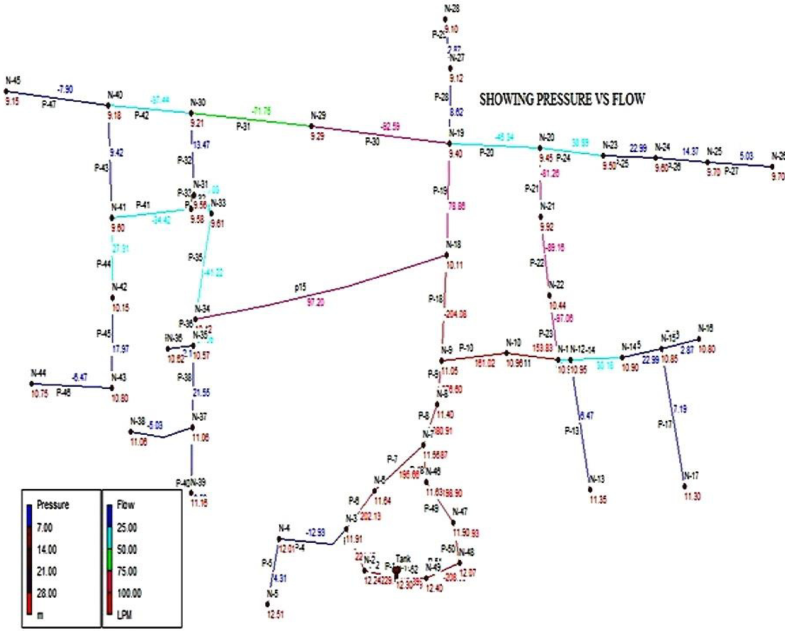

Fig. 4.Pressure VS flow

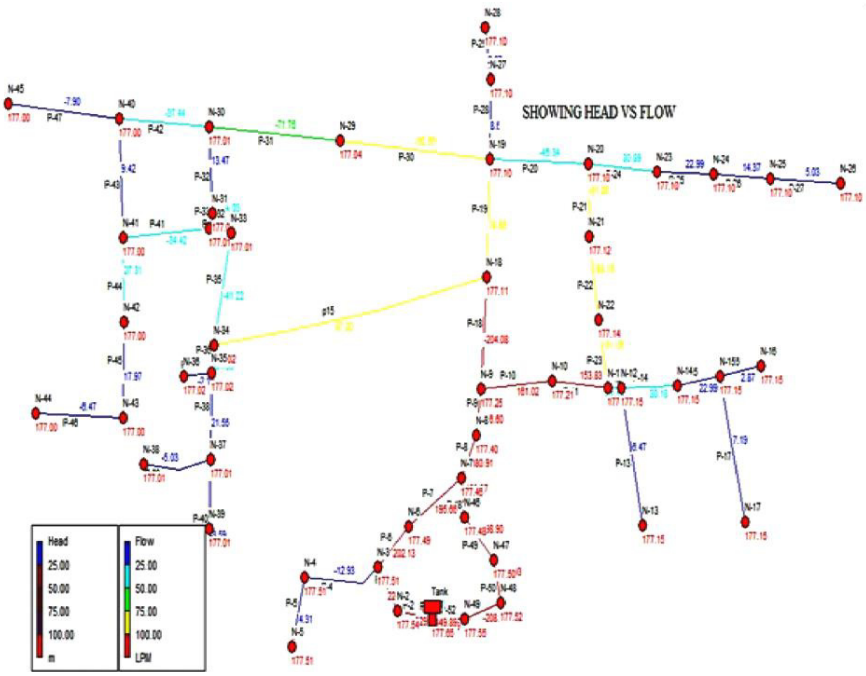

Fig. 5.Head VS flow

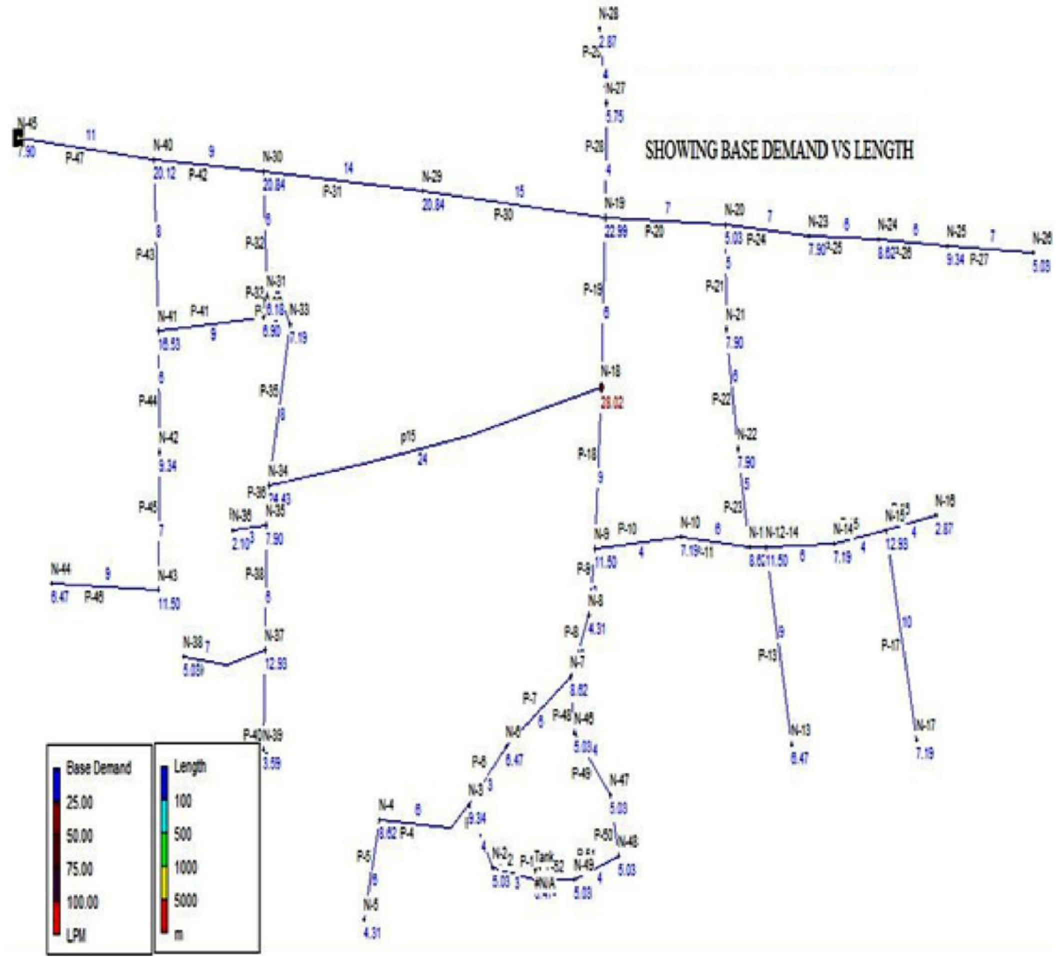

Fig. 6.Base demand VS flow

Fig. 4 shows the representation of distribution network between residual pressures at all node and corresponding flow in pipes. By knowing these two basic parameters the diameter of the pipes can be fixed by trail and error procedure. Further, to study the network in detail various other parameters can be verified like head Vs. flow and base demand Vs. length of pipes which can be seen from Fig. 5 and Fig. 6 respectively.

5. Conclusions

The following conclusions can be drawn from the study:

- The residual pressure at all nodes is found to be greater than 7.00 m. Hence, the flow can take easily.
- The assumed internal diameter of 63.50 mm is sufficient to withstand for the pressure for the entire network.
- By using tools like EPANET, the analysis can be done with in a period of time even for complex type of networks.
- The designed network can also withstand for 5 % increase in population instead of 1 % as we consider in the scheme design.

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