SIMULATION AND FUTURISTIC PLANNING OF WATER PIPE NETWORK SYSTEM OF A SEMI-URBAN HILLY AREA USING EPANET

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ABSTRACT

Water distribution system is crucial to provide water to the consumers. In this paper an assessment of the water supply situation have been done using EPANET for the semi-urban hilly area of NERIST campus, Nirjuli, Arunachal Pradesh in existing and different hypothetical futuristic conditions to help decision maker for campus planning. In this water distribution network simulation, variations in different parameters have been observed; discussed and further some modification has been suggested. Due to increased demand capacity of Pump-1, 2 and 3 to be increased significantly and for that an empirical relationship has been prescribed.

INTRODUCTION

Water distribution system, a hydraulic infrastructure consisting of elements such as pipes, tanks, reservoirs, pumps, and valves 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 in expanding the existing one. It is essential to investigate and establish a reliable network ensuring adequate head. However, the optimal network design is quite complicated due to nonlinear relationship between flow and head loss and the presence of discrete variables, such as market pipe sizes. In addition, the objective function, which represents the cost of the network, is also nonlinear and causes great difficulty in the design optimization of the network. Researchers in recent years have focused on probabilistic approach to overcome these difficulties [1].

Assessment of the water supply situation may have been done before in various places and conditions, but it has been seen that there are certain obstacles that arrives due to higher altitude or lower altitude variations, pump distribution variation, losses due to pressure head. Another significant parameter is Non-revenue water (NRW), which is the water that has been produced and is “lost” before it reaches the customer. Losses can be real losses (through leaks, sometimes also referred to as physical losses) or apparent losses (for example through theft or metering inaccuracies). High levels of NRW are detrimental to the financial viability of water utilities to the quality of water itself. NRW is typically measured as the volume of water "lost" as a share of net water produced. However, it is sometimes also expressed as the volume of water “lost” per km of water distribution network per day [2]. In view of the above discussions following exercises have been taken under consideration as the project work.

OBJECTIVES

Following are the components of the analysis to be done in this project work:

(i) Detailed Survey and Modeling of the Water Distribution Network for NERIST campus in EPANET software.
(ii) Survey and prepare the demand curve for the main nodes (like Hostel wise, residence TYPE wise, Administrative

block wise)

(iii) Inserting valves in some important junction of the network with proper values (according to the IE office of the NERIST or taking suitable assumptions)

(iv) Calculation of Pressure Variations for Main Nodes for Varied Demand

(v) Calculation of Velocity variation for some main Links for Varied Demand

(vi) Calculation of Pressure and Head Loss for some main Links

(vii) Estimation of pump capacity for particular demand for the proposed network.

For completion of above objectives following methodologies have been adopted.

METHODOLOGY

In this project we will be working on a rural area subject to our site availability. Regarding this we will be working on Software named EPANET Version-2. EPANET is a computer program that performs extended period simulation of hydraulic and water quality behavior within pressurized pipe networks. 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 during a simulation period comprised of multiple time steps [3, 4]. Moreover, a GPS data is to be used to measure the accurate position and proximity of the project network where it has to be performed.

Topography of water distribution networks

Like electric power lines, roads, and microwave radio networks, water systems may have a loop or branch network topology, or a combination of both. The piping networks are circular or rectangular. If any one section of water distribution main fails or needs repair, that section can be isolated without disrupting all users on the network. Most systems are divided into zones. Factors determining the extent or size of a zone can include hydraulics, telemetry systems, history, and population density. Sometimes systems are designed for a specific area then are modified to accommodate development. Terrain affects hydraulics system very much. While each zone may operate as a stand-alone system, there is usually some arrangement to interconnect zones in order to manage equipment failures or system failures [5].

Analysis Algorithms

Analysis algorithms are elaborately discussed in EPANET manual [6]. To solve the flow continuity and headloss equations that characterize the hydraulic state of the pipe network at a given point in time can be termed a hybrid node-loop approach. In 1987, Todini and Pilati [7] and later in 1988 Salgado et al. [8] chose to call it the "Gradient Method". Similar approaches have been described by Hamam and Brameller [9] (the "Hybrid Method) and by Osiadacz [10] (the "Newton Loop-Node Method"). The only difference between these methods is the way in which link flows are updated after a new trial solution for nodal heads has been found. Because Todini's approach is simpler, it was chosen for use in EPANET.

Assume we have a pipe network with N junction nodes and NF fixed grade nodes (tanks and reservoirs). Let the flow-headloss relation in a pipe between nodes i and j be given as:

$$H_i - H_j = H_{ij} = rQ_{ij}^n + mQ_{ij}^2 \qquad ....(1)$$

Where H is nodal head, h is headloss, r is resistance coefficient, Q is flow rate, n is flow exponent, and m is minor loss coefficient. The value of the resistance coefficient will depend on which friction headloss formula is being used (see below). For pump s, the headloss (negative of the head gain) can be represented by a power law of the form

$$h_{ij} = -\omega^2 (h_0 - r(Q/\omega)^n \qquad ....(2)$$

Where h_0 the shutoff head for the pump, ω is a relative speed setting, and r and n are the pump curve coefficients. The second set of equations that must be satisfied is flow continuity around all nodes:

$$\sum_j Q_{ij} - D_i = 0 \ for \ i = 1, ...N \qquad ....(3)$$

Where Di is the flow demand at node i and by convection, flow into a node is positive. For a set of known heads at the fixed grade nodes, we seek a solution for all heads Hi and flow Q_{ij} that satisfy Eqs. (1) and (3).

The Gradient solution method can be obtained in details in EPANET manual [6].

Water Treatment

Virtually all large systems must treat the water; a fact that is tightly regulated by global, state and federal agencies, such as the World Health Organization (WHO) or the United States Environmental Protection Agency (EPA). Water treatment must occur before the product reaches the consumer and afterwards (when it is discharged again). Water purification usually occurs close to the final delivery points to reduce pumping costs and the chances of the water becoming contaminated after treatment [4].

STUDY AREA AND DATA REQUIRED FOR THIS ANALYSIS

The study has been done for the NERIST Campus. NERIST has an existing water distribution network, which was developed at the beginning of the construction of this educational institute. Later, this network has been modified and increased its proximity several times due to the increased demand and growth of the population in NERIST campus. Lack of proper maintenance and natural hazard surrounding the source of water always created problem for the NERIST residential. Most of the times, this network is unable to fulfill the minimum demand of the NERIST. Quality of the water is getting vulnerable in due course of time. These problems lead us to examine and analyze the existing water distribution network and propose a couple of good suggestions.

For the present Analysis different types of data viz. Ground Elevation, Discharge points locations, Map of existing pipeline / contributing area, Pipe diameter, length and material, Loss coefficients, Actual Water demand, Proposed/Projected Water demand, No. of House connection are obtained from NERIST Institute Engineers office or SRTM data, Google Maps or pipe handbook or survey. According to the availability of data, water distribution network has been modeled in EPANET software which is discussed in the following section.

WATER DISTRIBUTION NETWORK MODELLING

Water Distribution Network of NERIST has been performed in two stages. Firstly, modeling has been done taking default values of the software and finally it is updated with the exact values obtained by survey, or according to the data of NERIST IE office and standard values where no data are available.

Preliminary network model

Water Distribution Network of NERIST has main two types of source: (i) a water reservoir (source), which is situated approximately 2 km areal distance from the campus by the side of a nala/river. A two stage (gravel bed) water filtration technique has been applied to store the water in a 15m×8m×2m reservoir, which is supplying water to a tank inside NERIST campus having a height of 20 m (Tank-1) by gravity. This distribution has a diversion towards boys' hostel also (ii) 3 pumps, having capacity of 5 hp. One pump (Pump-1) is installed very near to the Tank-1, having capacity of 5 hp and lifting water from 42 m below ground level. Pump-1 is supplying water to the residence (nearby Type-II, III, IV, V), Girls' hostel and also the Academic/ administrative buildings. Sometimes Pump-1 also supplies water directly to Boys' hostel. For Boys' Hostel, there is also a separate pump (Pump-2) having capacity of 5 hp, which is lifting water to an overhead tank (Tank-2) of 24 m height. There are two more pumps (having capacity of 5-10 hp) for PG hostel and Type –I quarters. But, as these are not connected directly and separated by the nala/river so excluded from this Network. There is another pump (Pump-3) having a capacity of 5 hp lift water and connected to the network of Pump-1. This existing network is modeled in EPANET to run the analysis..

This above mentioned existing Network Model has been developed for the NERIST Campus with the help of EPANETz software. This freely available software has a capability of integrating EPANET v2.0 and Google Earth software (both are freeware). It can automatically calculate the length of the pipe developed in the network and the altitudes of different nodes. Physical scenario of the existing Network has been understood by the discussion/survey with IE Engineers, NERIST and has been modeled in EPANETz software (Fig 1).

Later, this Network has been transferred to EPANET v2.0 for the check. Analysis showed that the Model works successfully with some default values used for pipe, reservoir and valves; which will be changed after procuring the exact values from IE office. If necessary, some extra valve, capacity of the pump or modification of the Network will also be proposed for the betterment of this network.

Finalization of network model and its assumptions

After the successful run of the network model actual data have been fed to it which was collected by survey or from IE office, NERIST. Following assumptions have been adopted for this analysis.

Assumptions while taking Input Parameters

1) Pump Curve: These have been considered according to IE office data, (K.S.B., Fourteen Stage, 5HP) (Fig 2). Additionally, instead of using the pump curve the Network is tested with the three pumps having constant energy as 5HP and found successful.

2) Demand patterns: For different nodes, demand patterns have been adopted according to the actual situation and consulting with the IE office workers. Demand multipliers have been taken in such a way that average demand multiplier could not exceed 1.0. Demand pattern multiplier 0.1 has been considered instead of zero for zero-demand to avoid the errors (zero/zero or squire root of zero etc.) in EPANET.

3) Practical demand for Hostels: Flow rate has been measured from different hostels (Table 1). Data has been taken from a single water tap around 10 a.m. in the morning and it is considered equivalent to demand multiplier 1.0. These demands of the hostels have been averaged and used to project the average actual demand for different Hostels. Afterwards, it is being multiplied by the number of water taps (functional) in different hostel to get the actual total demand of a hostel. Then specifically a demand pattern is used to

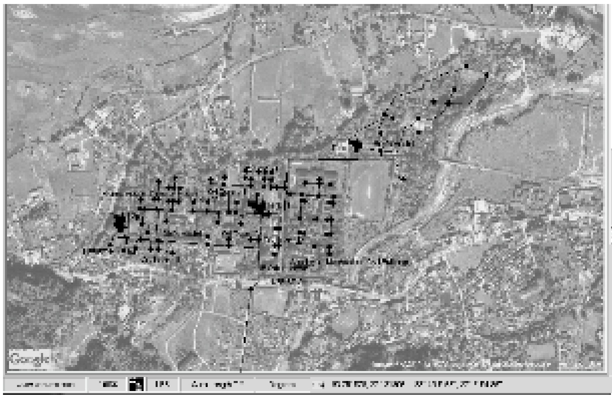
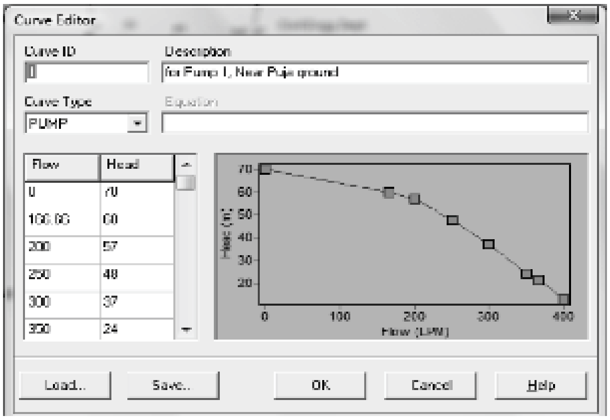


Fig Pipe Network of NERIST (Background Image Source: Google earth, Pipe Network made by EPANETz software)



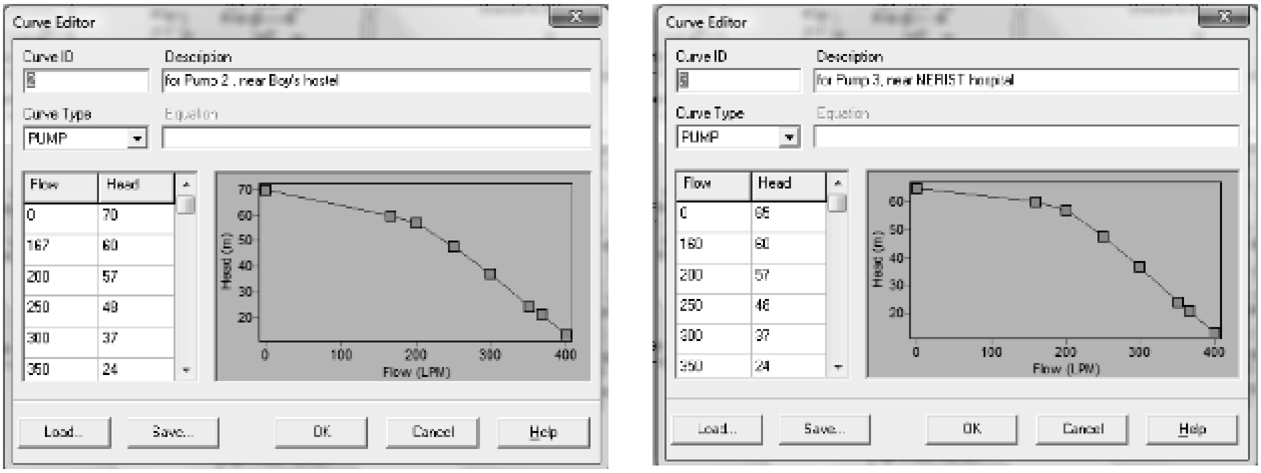


Fig 2 Different Pump Curves (for Pump-1, Pump-2 and Pump-3) obtained from IE office

Table 1 Measurement and calculation of actual demand

Hostel block	Time required to fill one liter bottle (Sec) *	Average demand per water tap (LPM)	Average demand per Hostel (LPM), considered as single node
(i)	(ii)	(iii)	(iv)
A **	31.23	2	28
B **	27.08	2	28
C **	43.09	2	28
D **	17.82	2	28
E ***	45.32	2	52
F ***	19.10	2	52
G ‡	--	2	44
Average	**30.03**		

* As all the values are fluctuating. So we have chosen approximately 2 LPM for the entire water tap.
** Here, we have considered 6 bathrooms with 1 water tap (functional), 1 water tap in kitchen and 7 washbasins.
*** For large block, we have considered 12 bathrooms with 1 water tap (functional), 2 water taps in kitchen and 12 washbasins.
‡ Considered as medium/large hostel, we have considered 10 bathrooms with 1 water tap (functional), 2 water taps in kitchen and 10 washbasins.

4) Demand for the academic block: different pattern has been selected for this section. Average flow rate from a tap is found more or less same as hostel. So, 2 LPM per water tap is taken as standard value for the rest of the Network also.

5) Demand for the staff quarters: different pattern have been chosen for these sections. Type II and III having same pattern and Type IV and V having another. Patterns have been made according to the utilization and lifestyle of the members residing these areas. Demand values have been set considering 2 tap in each quarter and 1 hand basin. However it is assumed that a single node of the network is contributing water to four quarters.

6) Valves: Nine PRV (Pressure reducing valve) valves have been inserted in the network to simulate the operating procedure of NETWORK by the IE office. Diameters of these valves are taken corresponding to the connecting pipe diameter and setting coefficient is taken as 60 for all the valves.

7) Water Quality: Due to lack of data water quality modeling has been excluded from this analysis.

Assumptions during the Analysis of Network

During the analysis of the network, following errors have been encountered when individual measured actual demand for Block E, F and G have been entered into the EPANET and during the analysis (Fig 3).

1) P3 closed at 7.62 hrs (adjusted by tuning the demand pattern multiplier, by decreasing the multiplier values from 2 (initially taken) to 1.5).
2) Negative pressure (adjusted by resetting the base demand, re-surveying and minimizing the number of functional water tap).
3) P1 open but could not obtain sufficient pressure to deliver water at 1.42 hrs (adjusted by tuning the supply pattern multiplier of pump, by increasing it).
4) System unbalanced (One of the PCV valves, which connecting the Administrative block to the main pump 1 was in reverse direction, adjusted by reversing the direction).
5) Pump 3 could not deliver with sufficient head (adjusted by tuning the supply pattern multiplier of pump, by increasing it).

RESULT AND DISCUSSIONS

Objective of this analysis was to simulate and study the existing water distribution network of NERIST. It has been done successfully. Considering the newly constructed hostel for girls, some modification of network for the future has been adopted also. A successful run of the network at 19.00 hrs is shown in the Fig 3. In this figure elevation of the nodes and flow rate through the links (pipes) are shown. It is clear that flow rate at the Academic section is very low (Blue lines) as all academic activities are finished at 7.00 p.m. and flow rate at residential areas and hostel are very high as water consumptions at that time is very high (Red line).

Apart from this, an analysis has been performed for the futuristic demand of this existing network. For this, pump capacity have been calculated for 125, 150 and 175 % of existing demand which are discussed as follows.

Pump capacity for futuristic demands

It is found that all three pumps are capable of delivering up to 125% of the existing demand. But, if demand increased up to 150%, then P1 needs to be changed up to 15 hp to fulfill the network demand. Apart from this, some pipes [viz. pipe ID 44,45,73,77 (main supply line to Admin block), 112 (main supply line to Type II quarter)] are needed to be replaced with 80 cm diameter pipe to carry the increased flow rate. When demand increased up to 175 % of the existing demand P1,P2,P3 needs to be change to 40,10,15 hp respectively. After getting these results, three trend lines have been plotted for these three pumps, by which one can observe the nature of performances of the pumps, interpolate pump capacity values and modification needed for this water distribution network within 175 % of existing demand. R2 values of these trend lines show that prediction is quite good, as the R2 values are very close to 1.0. Also, one can extrapolate capacity of the pumps (beyond 175 % of existing demand) in this network using the following equations obtained from these trend line (Table 2).

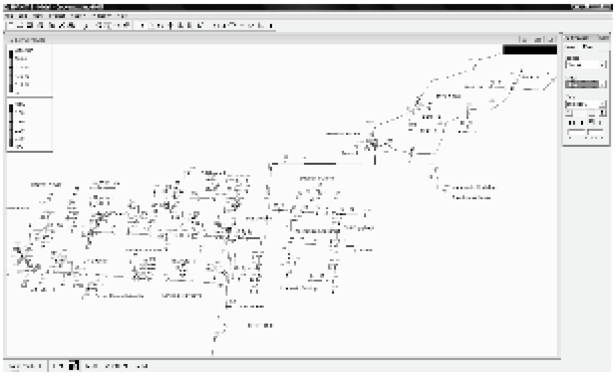


Fig 3 Successful run of the modified network at 19.00 Hrs., showing elevation of the nodes and flow rate through the links (pipes)

Furthermore, different parameter variations viz. unit head loss and flow variation with time for pipes having ID 44,45,73,77,112 were shown in the following section which were replaced during the analysis of increment of the network demand up to 175 % of existing demand. It is observed from the Fig 4 that at higher demand, to keep the flow rate are at higher magnitude through the selected pipes, the unit head losses became less than the actual case.

Table 2 Demand and Capacity relationships of the pumps of these networks

Pump No	Capacity (hp) P of pumps corresponding to the futuristic demand (in % of existing demand) D				Equation $P = f(D)$	R^2 Value
	100	**125**	**150**	**175**		
P1	5	5	10	40	$P = 0.01D^2 - 2.29D + 134.25$	0.9985
P2	5	5	5	10	$P = 0.004D^2 - 0.98D + 63.5$	0.9333
P3	5	5	5	15	$P = 0.002D^2 - 0.49D + 34.25$	0.9333

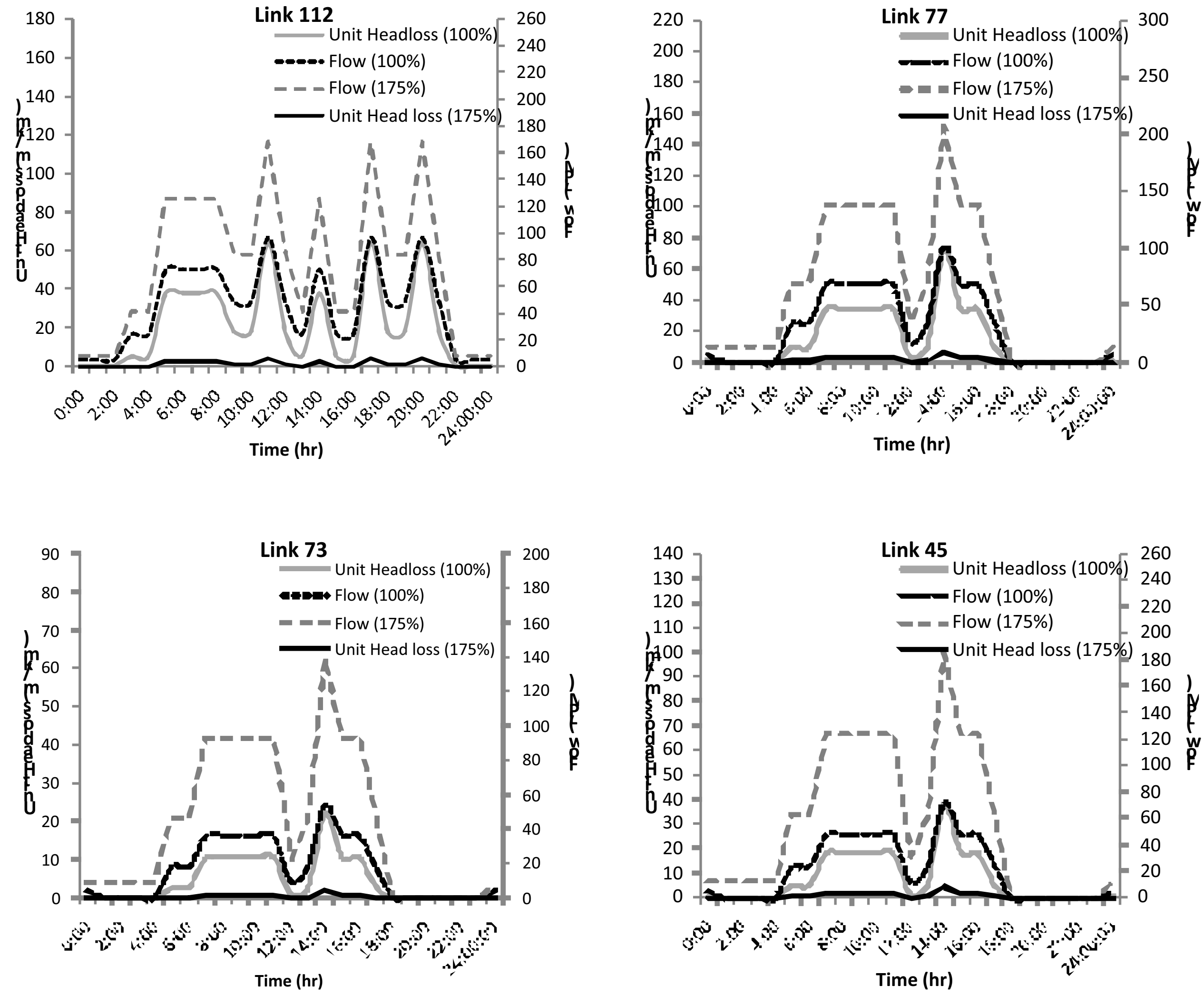


Fig 4 Unit head loss and Flow variation in time for some main links (ID 45, 73, 77 and112) of the network

CONCLUSIONS

8) Objective of the study, i.e. simulation of the water distribution network of NERIST was done successfully. Modeling Analysis is done in the two parts. Firstly, network has been drawn in EPANET software with the help of EPANETz software spatially (considering the location only, using satellite data) and taking the values of the some other parameters of the network as the default value of EPANET. Later, a survey is performed and available exact values of the assumed parameters have been fed to the model and run till the model works correctly. Meanwhile, some modifications of the existing network also have been done keeping in view the new construction going on in the campus. During the analysis some difficulties regarding data collection and selection has been encountered, which were solved assuming some suitable assumptions which are discussed in the 'Finalization of network model and its assumptions' Section. Calculations based on some futuristic demand also have been performed keeping in view the increasing population in NERIST campus, specially increasing student strength. For the futuristic demand, an analysis is performed for 100, 125, 150 and 175 % of existing demand. During this analysis, the inter-relationships of the pumps inside the network have been found. A set of equations has been prescribed for the calculation if extrapolation of water demand (beyond 175%) is required. During the analysis following drawbacks have been found which could be rectified for the betterment of the model (i) calibration could not be performed for the lack of measured data as proper equipments were not available (ii) Lots of assumptions were present in analysis during calculation of the exact demand (iii) in some places of the network authors were dependent very much upon the verbal information of IE office personnel, which could not be crosschecked properly (iv) due to lack of data water quality modeling has been excluded from this analysis.

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