# Design and Analysis of Rural Water Supply System Using Loop 4.0 and Water Gems V8i for Nava Shihora Zone 1

**Vidhi N. Mehta, Geeta S. Joshi**

***Abstract*: The study presents the hydraulic design and analysis of Rural Water Distribution System (WDS) for Nava shihora region of zone 1 of the state of Gujarat, India. Water supply distribution system is designed for this study for population estimated for future 30 years. LOOP 4.0 and Water Gems v8i software have been used and the results are compared to determine the economical size of pipes for water distribution system. The economical size of pipes of water supply distribution system is designed by considering the constraints; residual pressure at each node, velocity of flow in pipe, head loos in pipes, material of pipes, elevated service reservoir level, peak factor and available commercial pipe diameters. Further water distribution system has been analyzed for extended period simulation (EPS) for the present population scenario for intermittent water supply using Water Gems v8i. Further water supply system is analyzed the residual chlorine concentration at nodes and in the pipe links and also the total cost of water supply system of rural region is estimated.***

***Keywords* : Design of water distribution network, Loop version 4.0, WATERGEMS v8i, economical diameter, extended period simulation, Chlorine concentration analysis, Cost estimation.**

## I. INTRODUCTION

There are numerous constraints which have limited the progress in improving rural water supply. These constraints may be categorized as administrative, financial and technological. Although most countries regard financial problems as the primary constraint, it is most important to design water distribution network economically. Water distribution system comprises of components such as water sources and intake works, treatment works and storages, transmission mains and networks. The main objective for water supply system is to provide the system with a cheapest cost. The distribution network may have the cost depends upon the layout of the area. Either looped or branched configuration of pipes is provided which is depends upon the general layout of the streets in rural area.

Design of the water supply system to satisfy the functional requirement should not be the only objective but to satisfy the functional requirement at the lowest cost is most important. This paper represents the study for the design and analysis of rural water supply systems considering the aspect of economical design of the network.

As per census of India of 2011, approximately 68% to 70% population of India is staying in the rural area. Indian government has decided to provide safe, regular and adequate water to the consumer at their resident through the pipe distribution system in rural area.

A number of software's developed for design & modelling of Water Distribution Network which differs from each other in various aspects. It includes their functionality, compatibility to different computational methods; graphical user interfaces (GUIs), optimizing algorithms and program languages used in their pipe network developments [16].

Loop 4.0 software can be used advantageously for water distribution network design and cost analysis. Generally almost 50% to 70% of the total cost of the water distribution system is occupied only for piping cost [4].

References [6] provided the design for regional water supply system using Branch 3.0 software for existing distribution network for some modification and recommended the appropriate improvement.

Reference [14] presented optimization of redundancy in branched water distribution system by incorporating the loops, when added to a branch network prove most benefited to the users.

Water distribution network is analyzed using EPANET software for Intermittent and continuous water supply system by some of the researchers [1], [2], [3], [7], [11], [12], [17], [22], [23], [26].

Design and analysis of water distribution network using Water Gems v8i software found to be user friendly and it has graphical interface which facilitate analyses more effective and also, lesser time is required to reanalyze the network. In addition, Water Germs, also permit to analyze chlorine concentration at various nodes in the network [10], [20], [25].

Some of the researcher also studied using the combination of software's to design and analyze the water distribution system [9], [21], [24]. Cost for water distribution system is estimated including material of pipe, installation of pipe with replacement or repair required in supply network etc [18].

The reliability assessment of WSS is one of the important aspects in water supply network. Due to the random nature of future water demands, the water distribution system reliability for future is subjected to uncertainty [5]. Reference [13] has carried out procedure in terms of consumer utilities received from a WSS considering parameter such as available water pressure, volume, and residual chlorine concentration on which user can define acceptable

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**Vidhi N. Mehta**, Civil Engineering Department, Faculty of Technology & Engg, The Maharaja Sayajirao University of Baroda, Vadodara, India.

**Dr. Geeta S. Joshi**, Civil Engineering Department, Faculty of Technology & Engg, The Maharaja Sayajirao University of Baroda, Vadodara, India.

degree of uncertainty and in this condition MATLAB programme is suggested for the solution. An optimal discrete pipe size for new pipe network is determined using Shuffled Frog Leaping Algorithm (SFLA) in which promising results are obtained [15].In this study, the Loop 4.0 and water Gems v8i have been considered for the design of the water supply distribution network. Out of the results of the design obtained through both of these software, the design which is resulting into the minimum cost of the piping is considered as economical design and further incorporated in the Water Gems for further analysis. This paper also describes hydraulic analysis for Extended Period Simulation (EPS) of 24 hrs in WATERGEMS v8i software for this regional water supply scheme. It is verified through Water Gems v8i software that residual chlorine concentration at all nodes in the distribution system remains within the limit, when 2mg./l of chlorine is introduced at the inlet (Sump). The cost of water supply network system has been also estimated.

Objective of the Paper:

- Design and analyze the water delivery system to provide water supply appropriate quantity and pressure which may provide water to the community in accordance with their demand and requirements.
- To design the distribution network considering the increase in the future population for 30 year
- Study and use of LOOP 4.0 software to design economical diameter for water distribution network.
- Study and use of Water GEMS V8i software to design and analyzed network of the water distribution system.
- Analyze the result obtained of zone 1 from the software i.e. Pressure head, hydraulic gradient line, velocity.
- To decide the chlorine inputs
- To estimate total project cost

## II. STUDY AREA AND DATA COLLECTION

### A. Introduction about Study Area

The Nava Shihora village is selected for the study area which is located in Savali taluka of Gujarat. The area of village is about 12.42 km$^2$ having population 6021. Study is presented for zone 1 of Nava Shihora village. Fig. 1 shows Index map of Vadodara district.


**FIG.1. INDEX MAP OF VADODARA DISTRICT**

### B. Data Collection

To design and analysis of water supply system, following data has been collected from WASMO.

Node to node pipe connectivity, Length of pipes, Reduce levels of each node, Flow demand at each nodes, Pipe roughness coefficient in terms of Hazen William's C, Hydraulic gradient desired, Elevations of service reservoir or storage tank, The population of Shihora village of year 2011, Available commercial diameters with unit cost as shown in table I.

**Table I Cost of commercial pipes diameter**

| Diameter of pipe in mm | Unit Cost in Rs. per meter |
|---|---|
| 75 | 86.11 |
| 90 | 123.31 |
| 110 | 175.87 |
| 130 | 290.81 |
| 150 | 374.51 |
| 175 | 479.27 |
| 200 | 587.37 |

### C. Population Estimation

Present and future population can be predicted as under

$P_n = P_0 (1 + g_n)^n$ _____ (1)

where,

$P_n$ = the projected population after nth year from initial year

$P_0$ = the population in the initial year

$g_r$ =average annual growth rate considered 1.7 % for the village as per the GWSSB guide lines.

n = number of years

Present population for zone 1 is estimated 3662 people from the above equation. Also, the forecasted population of 2047 (future 30 years) is 6072 for zone 1.

The essential parameters for design network are per capita water consumption, peak flow factors, available pipe sizes and material of pipe etc.

Another important parameter for the design of the water distribution system is the design period.

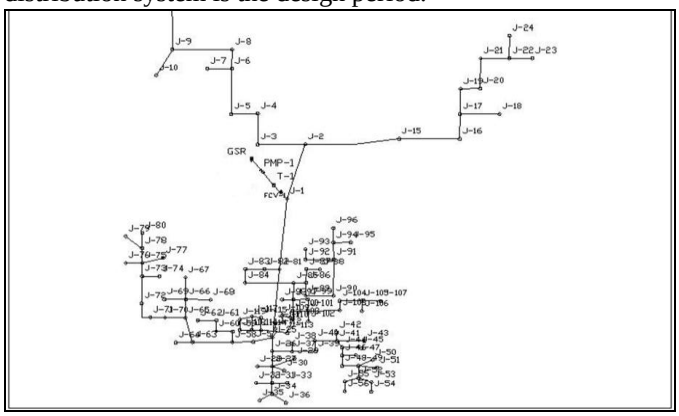



**Fig. 2. Layout map of proposed pipe distribution network of zone 1**

Fig. 2 shows Layout map of proposed pipe distribution network of water supply system of zone 1 which is prepared in Auto-cad by conducting level surveying, reduced level has been taken and by using rodometer, linear measurement of length of streets has been taken of the study area. The route of the pipeline is proposed along the road. Material of pipe is PVC 6 kg/cm$^2$ has been used for distribution network in Shihora village.

## III. ETHODOLOGY

Computation of Storage Capacity and diameter of Sump and ESR:

The storage capacity of sump for zone I and zone 2 of this Nava shihora village is computed by the storage mass curve calculations for 16 hours incoming inflow and 8 hours supply with forecasted population of 11046 people in future for 30 years.

Similarly, the storage capacity of elevated service reservoir (ESR) of zones 1 is computed by the storage mass calculations for 8 hours incoming flow and 4 hours supply to the consumer with forecasted population of 6072 people in future for 30 years. It is found that storage capacity required is 0.5 Million Litter for sump and 0.218 Million Litre for ESR which is to feed water to the consumer of zone 1.

Diameter of the ESR and sump is computed as under for input in the software Water Gems V8i.

$V = \frac{1}{4} \times \pi \times D^2 \times H$

Where,

V = ESR/Sump capacity in m3

D = diameter of ESR/Sump container (m)

H = Height of the ESR/Sump (m)

H is considered as 3 m for ESR and 5 m for Sump.

Pumping machinery calculation:

Horse power (HP) required to run the pump for supplying water in ESR from sump is calculated by using the excel with the help of formula mentioned below

H.P. of the pump required = Q x H x 1.1/75 x E ------- (2)

where,

Q = discharge in Litres per second (LPS)

H = Total lift in m

= static lift + residential head + Head loss

E = Pump efficiency = 60% = 0.6

The input data for the head (total lift) is considered as 23 m and design discharge is considered as 17 LPS, considering the life of the pump as 15 years and water requirement (liters) of the population forecasted. Using equation (2), the required pump capacity is obtained as 7 K.W. to lift the water in sufficient quantity from sump to ESR for zone 1.

Computation of Flow requirement at each node:

Flow demand (LPS) for each node = 1.5 x Pn x Dpc x Cf _____ (3)

where,

Pn = population catered for each node,

Dpc = water demand in litre per capita per day

Cf = conversion factor (1/86400)

Using equation (3), the inflow requirement at each node of the water supply distribution (WSD) network of the study area have been computed.

Fig. 3 shows the flow chart of methodology followed in this study. The water supply distribution network design and analysis have been carried out in this study using CPHEEO Manual [8], and Rural Water Supply Manual [19].

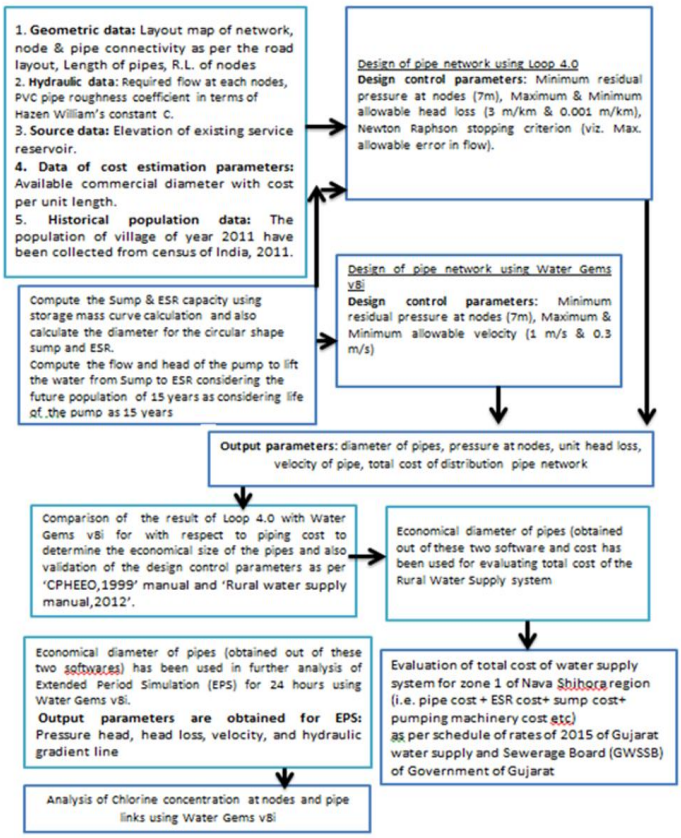



**Fig. 3. Flow chart of Methodology**

### A. About Loop Software

LOOP 4.0 software is freely available and it has been used to compare the results with Water Gems v8i software. Study area is presented for zone 1 for distribution of water supply network in which total 120 nodes are there for distribution network of water supply system. Branch 3.0 could not solve the network for 120 nodes. Hence, to solve the network of zone 1, two Loop (i.e. 2 closed circuit connections) are formed in network. So, design has been done for zone 1 with help of Loop 4.0 instead of branch software 3.0. Table II shows the input data file for LOOP 4.0.

**Table II Encoding of Input Data**

| | |
|---|---|
| Title of the Project | Nava shihora zone 1 |
| Name of the User | Vidhi |
| Number of Pipes in a network | 121 |
| Number of Nodes in a network | 120 |
| 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 |
| Simulate or Design? (S/D) | D |
| Type of Formula | Hazen's |

Pipe input data: from node - To node, Length of pipe (m) and Hazen constant. Hazen constant is considered as 140 recommended in CPHEEO Manual, for PVC pipe.

Node input data: peak factor, flow (m/s) (i.e. required demand), reduce level of nodes, minimum residual pressure and maximum pressure.

Water source data of Elevation of service reservoir have been incorporated as an input. - 114.1 m

**B. About Watergems v8i Software**

Water Gems v8i is a tool to provide simulation of hydraulic modelling for water distribution systems with advanced interoperability, geospatial model building, optimization of network'. 'Water Gems V8i provides an easy-to-use environment for engineers to design and analyze water distribution systems' [10].

Water Gems v8i is computer software that performs EPS (extended period simulation) of hydraulic and water quality behavior within pressurized pipe networks. A network consists of pipes, nodes (i.e. pipe junctions), pumps, valves and storage tanks or reservoirs. 'Water Gems shows the flow and velocity of water in each pipe, the pressure at each node and the height of water in each tank'. 'It is possible to analyzed calculated residual chlorine at all nodes' [10].

'Water Gems v8i software is time saving for reanalysis network with modify in input data, running hydraulic and water quality simulations, and viewing the results in a variety of formats'. 'These include color-coded network maps, data tables, and graphs of time series and contour plots' [2].

Hydraulic Modelling Capabilities:

Water Gems V8i is an art of hydraulic analysis engine that includes the following capabilities:

- It can be designed distribution network using Darwin designer tool.
- The places where no limit on the size of the network that can be analyzed for EPS in cracked version of software but in student server it is limited up to 250 nodes of network.
- Computes pipe friction head loss using the Hazen-Williams, Darcy-Welsbach, or Manning formulas includes minor head losses for bends, fittings, etc.
- Models can run on constant or variable speed pumps.
- Models having various types of valves including shutoff, check, pressure regulating and flow control valves.
- Model can allows storage tanks to have any different shape.
- Considers multiple demand categories at nodes.
- Model can run based on operation on both simple tank level or timer controls.
- Models can track residual chlorine at each nodes and pipes with time.

Fig. 4 shows the layout map of water distribution system of zone 1 of Nava shihora village developed in Water Gems v8i using different elements. (i.e. pipe, node, tank, sump, pump and valve).

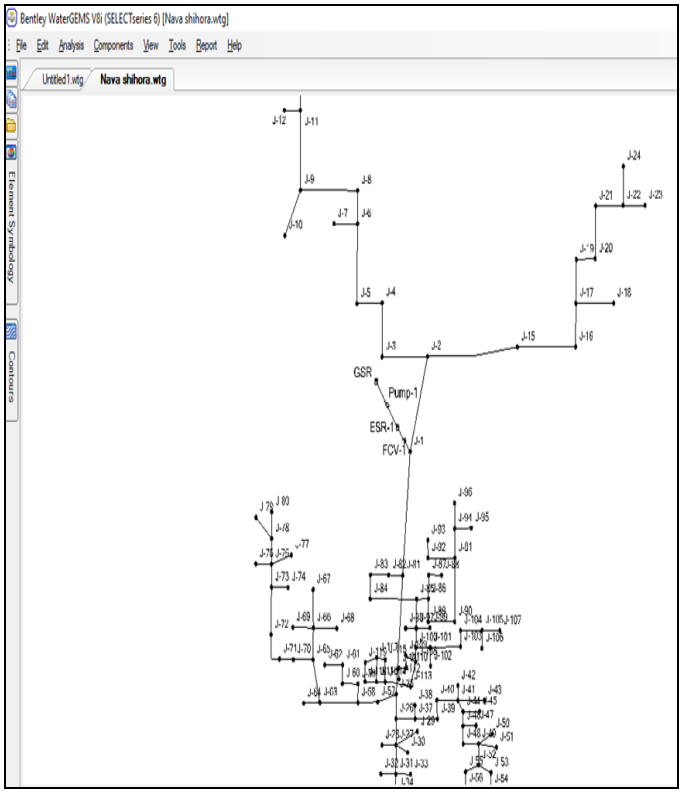



**Fig. 4. Layout map of distribution system of Nava shihora village of zone 1**

Input data required in Water Gems V8i:

The required data has been incorporated in Water Gems V8i as under.

Node input data: Elevation of node and demand at nodes

Pipe input data: length of pipe, pipe material, Hazen constant

Table III shows the ESR, sump (GSR) input parameters required in terms of their capacity container (i.e. Minimum, initial and maximum level of container).

**Table III Source Input parameter in WG**

| Label | Elevation (Base) (m) | Elevation (Minimum) (m) | Elevation (Initial) (m) | Elevation (Maximum) (m) | Diameter (m) |
|---|---|---|---|---|---|
| SUMP | 96 | 96 | 100.5 | 101 | 11.28 |
| ESR | 114 | 114 | 114.1 | 117 | 9.62 |

Minimum level of ESR / Sump given as an input indicates lowest allowable water surface level. If the ESR/Sump drains below this point, it will be automatically shut down the system.Initial level is indicates starting water surface level in simulation and the water level ESR/Sump. Maximum level is indicates highest allowable water surface level of ESR/Sump. In Water Gems V8i software diameter of the pipe has been designed using Darwin designer tool.Input parameter of Darwin designer tool: maximum pressure (60 m), minimum pressure (7 m) and pressure constrain elements (i.e. nodes of distribution network), minimum velocity (0.3 m/s), maximum velocity (1 m/s) and flow constrain elements (i.e. pipes of distribution network) of zone 1.

Output parameter: Economical diameter of the pipe.

The procedure is followed to compare total costing of the pipes, and the diameter at various nodes have been obtained as a result of the design of the network, for the software which has given the lower costing of the pipes. The economical design of the network (with respect to the pipe cost) has been used for further extended period simulation (EPS) through water Germs v8i.

## IV. RESULTS

Results of the economical design of the water supply network with respect to the piping cost

Fig. 5 shows the cost of the pipes in network of the respective diameter in Loop 4.0 and water Germs v8i software. The total cost of the various sized (diameter of pipe designed by the respective software) pipe have been represented in Fig. 6.

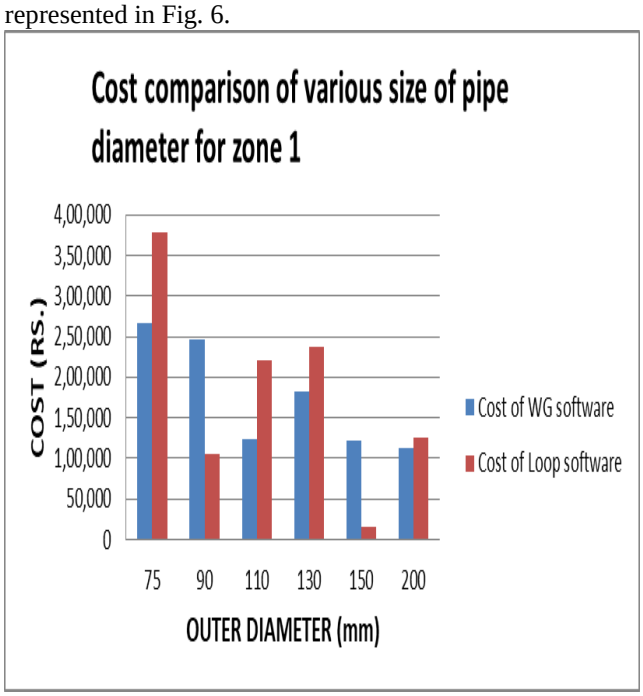



**Fig. 5. Cost comparison of pipe diameter for zone 1**

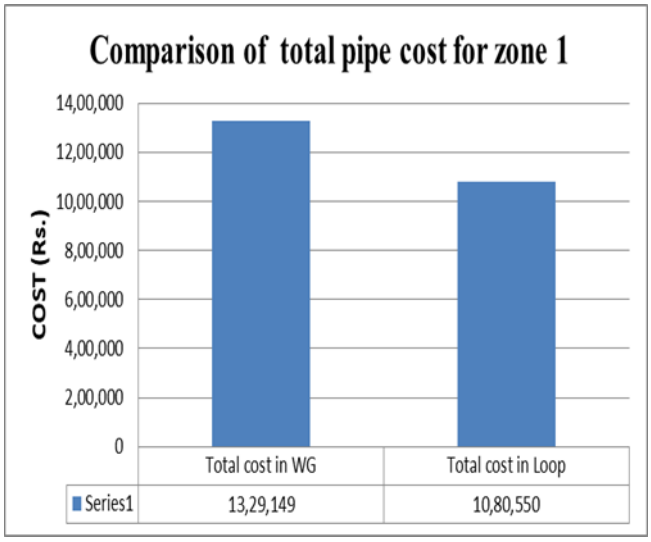



**Fig. 6. Comparison of total pipe cost for zone 1**

It is found from Fig. 6 that LOOP 4.0 software yield the most economical design of the water supply network with respect to the total cost of the pipes.

It may be summarized that the designed diameters differ in both the software may be found due to change in the design control parameters of the respective software. In Loop software, design control parameters are Minimum residual pressure (m) and Maximum and Minimum Head loss (m) constraint. Whereas in Water Gems software, design control parameters are considered as Minimum residual pressure (m) and Maximum and Minimum velocity constraints (m/s).

Fig. 7 shows the economical size of inner diameter of pipe for water supply network with the help of colour coding.

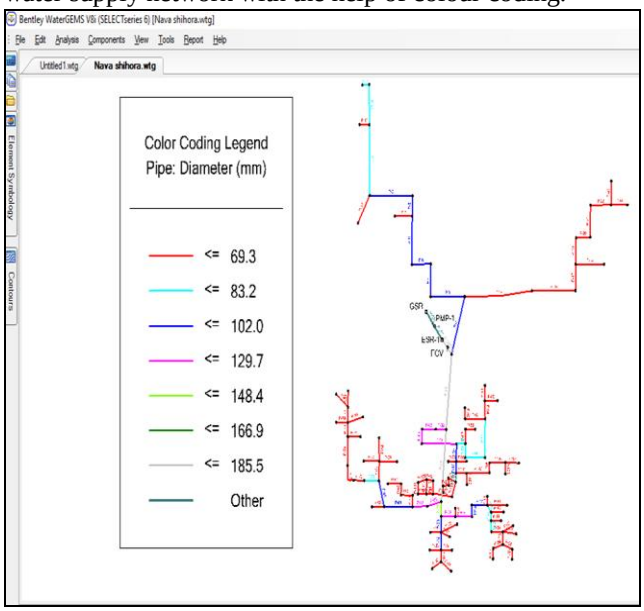



**Fig.7. Economical size of pipe diameter of water supply network**

This network design of the pipe diameter obtained in Loop 4.0 is further used for extended period simulation for 24 hrs. for distribution network of water supply system.

## V. EXTENDED PERIOD OF SIMULATION USING WATER GEMS V8I

These economical design of the water distribution system network as shown in figure 8, obtained through the Loop 4.0 software is considered and incorporated as an input to the Water Gems v8i for extended period simulation (EPS).

The analysis of the extended period simulation (EPS) of the water supply distribution system for each of hours during a water supply has been carried out in Water Germs v8i. As, in India, in the area around the study area, the intermittent water supply system is followed, In this study also, the intermittent water supply system for 4 hours (i.e. 2 hrs in morning and 2 hrs in evening), have been considered from ESR in a one day.

Input data required for EPS in Water Gems V8i:

Node input data: Elevation of node and demand at nodes

Pipe input data: length of pipe, pipe material, Hazen constant and inner diameter (mm).

Inner diameter is taken from output of Loop 4.0 software which is given economical diameter for zone 1.

The ESR is receiving water supply from common sump in duration of 8 hours incoming but for 4 hours outgoing i.e. for supply of water (i.e. 7.00 a.m. to 9.00 a.m. & 5.00 p.m. to 7.00 p.m.). The above mentioned data are incorporated into WATERGEMS v8i software to analysis of EPS for distribution network of zone- 1 of Nava Shihora village. Fig. 8

shows the demand pattern input parameter.

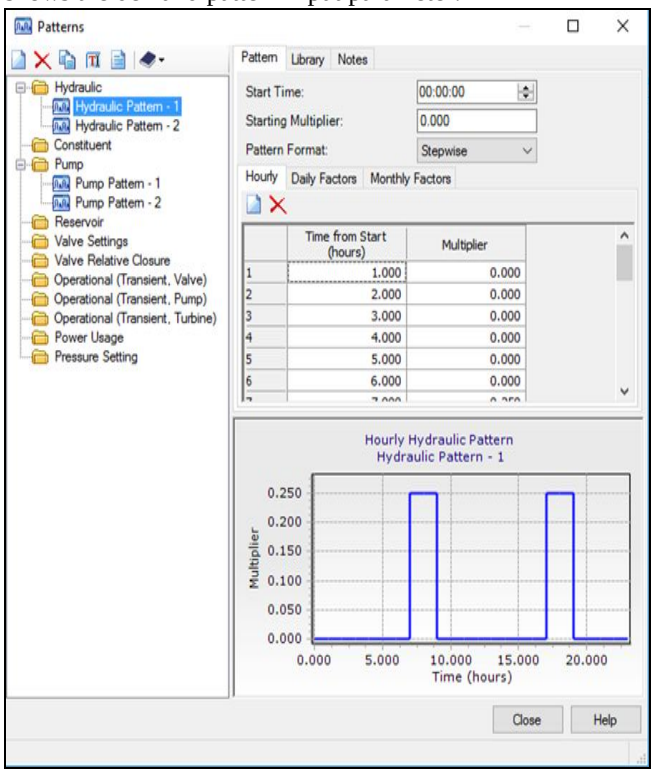



**Fig. 8. Demand Pattern Input Parameter**

Fig. 9 shows the validation procedure from the software Water Gems v8i for inputting parameters to run successful extended period simulation. After this validation procedure, it is possible to run extended period of simulation.

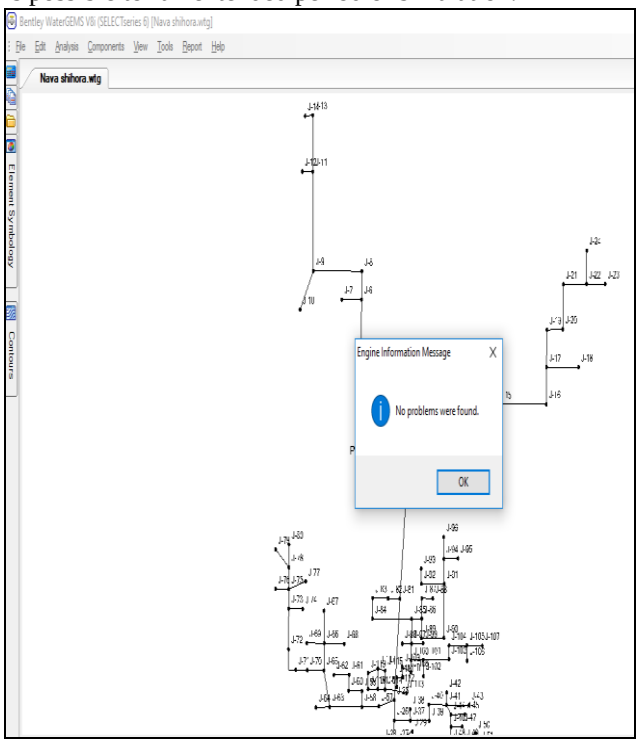



**Fig. 9. Validation of Model**

### Chlorine Concentration Analysis

In Water Supply System, concentration of chlorine mg/ l is added in order to make water drinkable by consumer. Fig. 10 shows the Initial chlorine concentrations in Sump and ESR.

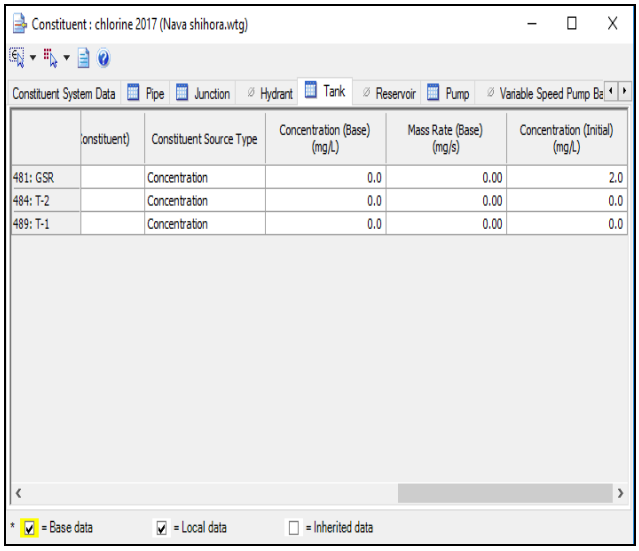



**Fig. 10. Initial chlorine concentration in GSR and Tank**

So, initially on trial bases, 2 mg/L chlorine concentration is decided to add with water in Sump/GSR, to check that the residual chlorine at all nodes that is higher than the minimum requirement i.e. 0.1 mg/l, as per IS specification 1992. The trial is taken considering the 2mg/l in Sump because the limit over 2 mg /l may be toxic for consumer.

## VI. RESULTS OF EXTENDED PERIOD SIMULATION AND DISCUSSION

EPS analysis is done for present scenario of zone 1 (i.e. node analysis and link analysis). After simulation of Distribution Network of water supply system, obtained results have been shown as below in terms of graph at an evening hour (i.e. for 1 hr. (6 to 7p.m.)) which is the last hour of water supply system in a day. Other than that has not been shown here but it is observed that it is yielding under the limit.

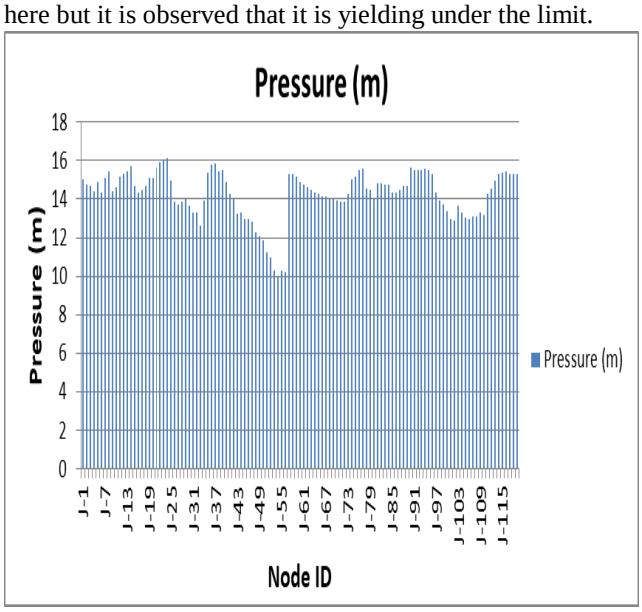



**Fig. 11. Pressure Variation in Nodes of zone 1**

Fig. 11 shows the results represented graphically for zone 1 to visualize the maximum and minimum pressure at particular time instant at each node. After running the model, it has been observed that the pressure in all the nodes during supply hours at 6 p.m. is ranging from 10.00 to 16.00 m for zone 1, which above the criteria of the minimum pressure given as

an input criteria in Water Germs v8i.

Fig. 12 shows the results for the head loss (m/km) in each pipe links

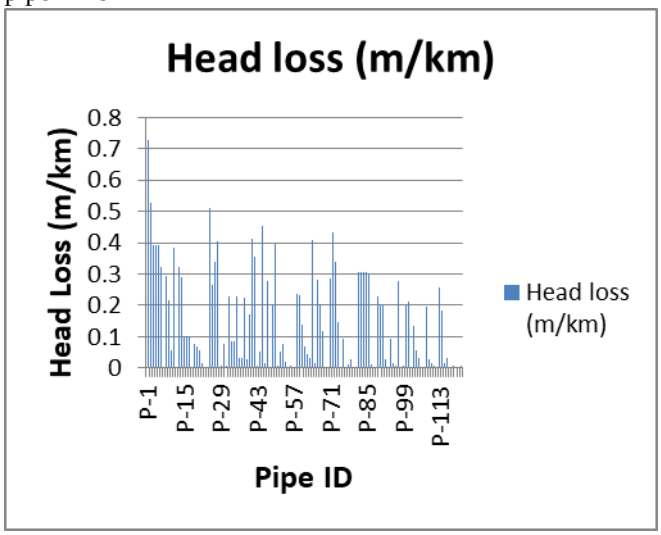
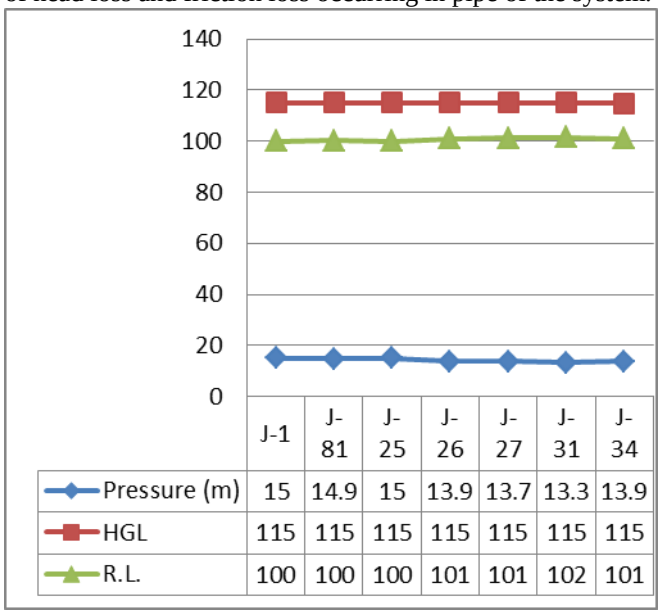



**Fig. 12. Head Loss Representation of zone 1**

After running the model, it has been observed that the unit head loss in all the links during supply hour at 6 p.m. is ranging from 0 to 0.8 m/km which is less than maximum limit i.e. 10 m/km (specified by rural water supply manual).

Fig. 13 shows hydraulic gradient line (HGL) (m), R.L. (m) and pressure (m) for selective nodes which is coming in one link of the pipe in distribution network of water supply system. It is seen from figure 14 that HGL is declined because of head loss and friction loss occurring in pipe of the system.




| | J-1 | J-81 | J-25 | J-26 | J-27 | J-31 | J-34 |
|---|---|---|---|---|---|---|---|
| Pressure (m) | 15 | 14.9 | 15 | 13.9 | 13.7 | 13.3 | 13.9 |
| HGL | 115 | 115 | 115 | 115 | 115 | 115 | 115 |
| R.L. | 100 | 100 | 100 | 101 | 101 | 102 | 101 |

**Fig. 13.Pressure (m), HGL (m) and R.L. (m) at selected nodes of zone 1**

Fig. 14 shows Time series plot pressure value versus time for selected nodes on pipe link over the time period of 24 hours.

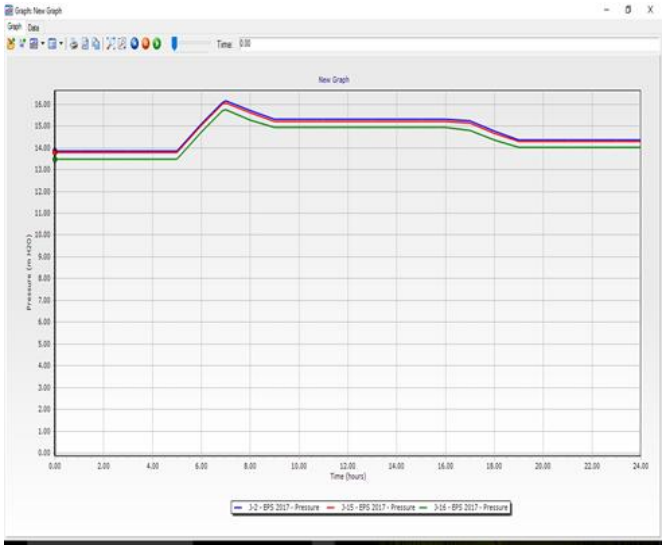


**Fig. 14. Time series Graph of Water-Gems V8i for the system**

It is seen from the figure 15 that pressure increases between 5 a.m. to 7 a.m. which indicates pumping hours to lift the water from sump to ESR. Pressure at nodes reduces between 7 a.m. to 9 a.m. and 5 p.m. to 7 p.m. which indicates the water supply hours from ESR to the consumer in the water distribution system.

## VII. RESULTS AND DISCUSSION OF CHLORINE CONCENTRATION IN THE WATER DISTRIBUTION SYSTEM

Fig. 15 shows chlorine concentration in water distribution network obtained Water Germs v8i.

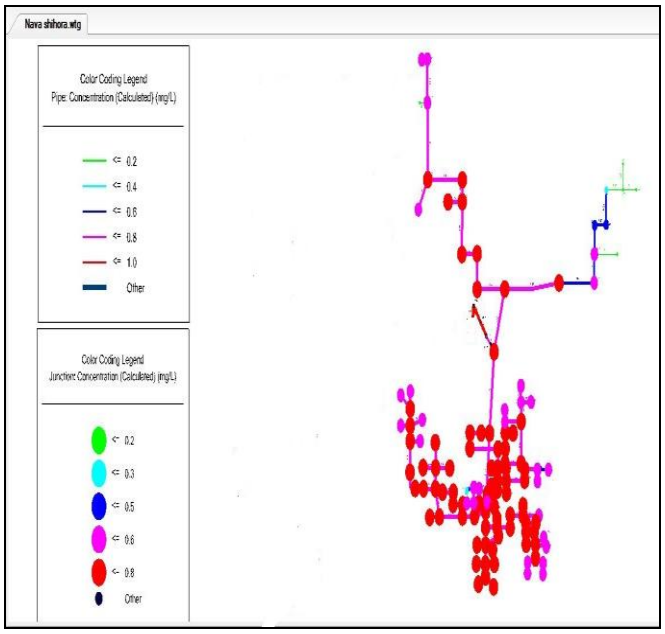



**Fig. 15. Chlorine concentration in distribution network obtained through Water Gems v8i**

Fig. 15 shows that the chlorine concentrations with respect to the given initial concentration at inlet in water supply network as 2 mg /l. It is found from the from figure 16 that chlorine concentration is obtained within the range of 0.2 to 0.8 mg/l at Nodes and range within 0.2 to 1 mg/l in pipes, which is found to be greater than the minimum residual chlorine 0.1 mg/l (Drinking Water specification IS: 1992).

## VIII. RESULTS AND DISCUSSION ON THE COST ESTIMATION OF WATER DISTRIBUTION SYSTEM

Costing is one step in the economic assessment of water supply projects and an economic assessment is one part of the full set of information likely to be used by decision makers in selecting specifications of the system to implement. The cost for water supply distribution network of zone 1 of Nava shihora village is estimated as per GWSSB. SOR, 2015.

The specifications, for which, the estimates are made are as follows.

• Providing a distribution network of standard length ISI mark rigid plasticized PVC 6 kg/cm2 pipes suitable for potable water as per IS specification no. 4985 to 1988 including all taxes, transportation, freight charges, inspection charges, loading, unloading conveyance to departmental stores, including cost of jointing material etc.

• The structural design of GSR and ESR shall be in accordance with provisions relevant I.S. 3370-1965 or revised.

• Submersible Pumping machinery has been used for the distribution of water supply network. (Cat: SM 3.3 and SM 4.4).

Table IV shows the cost of each component of the water supply distribution network.

**Table IV Total Project Cost**

| Sr. No. | Name of work | Cost (Rs.) |
|---|---|---|
| 1 | Distribution network | 10,80,550 |
| 2 | Underground sump | 14,10,000 |
| 3 | Elevated service reservoir | 26,15,635 |
| 4 | Pumping machinery | 37028 |
| Total cost of zone 1 for water supply network of Nava shihora village in Rs. | | 51,43,213 |

Note:

The cost for providing and supplying ISI mark CI D/F Sluice Valves, Butterfly Valves & Reflux Valves is not considered. Costs for excavation for pipe line trenches, for providing bedding, for construction of valve chambers are not included here. Cost for lowering, laying, jointing of ISI standard pipes is not estimated in this cost analysis.

The cost for construction of chlorination plant and underground pump house are not included here in analysis.

## IX. CONCLUSION

For this study area of i.e. zone 1 of Nava Shihora village of Savli taluka of Vadodara district, Gujarat, the software Loop 4.0 and Water Gems v8i has been used for the design and analysis of water distribution system. They are first of all applied to determine the diameter for pipes in a distribution network in water supply system. Results obtained for the size/diameter of pipes through both software are varying.

It may be summarized that the designed diameters through both the software are varying, it may be due to change in the design control parameters of the respective software. In Loop 4.0 software, design control parameters are Minimum residual pressure (m) and Maximum and Minimum Head loss (m) constraint; whereas in Water Gems software, design control parameters are as Minimum residual pressure (m) and Maximum and Minimum velocity constraints (m/s).

On comparison of the piping cost obtained through the design of both software, it is found that LOOP 4.0 software provides successful solutions for economical water supply distribution system design with respect to the piping cost.

This economical design of the water distribution system network obtained through the Loop 4.0 software is considered and incorporated as an input to the Water Gems v8i for extended period simulation (EPS). This paper also describes hydraulic analysis for Extended Period Simulation (EPS) of 24 hrs in Water Gems v8i software for this regional water supply scheme. It is resulting into representation and verification for velocity and head loss in the pipes, pressures at the nodes etc.

It is verified through Water Gems v8i software that residual chlorine concentration at all nodes in the distribution system remains within the limit, when 2mg/l of chlorine is introduced at the inlet (Sump). The cost of water supply network system has been also estimated. It is found that 50 to 70 % of the total cost of the water supply system is occupied by pipe network. In the course of the research and the simulation process, the following assumptions were made: The contribution of leaks and bursts to pressure loss is negligible, since it is not possible to estimate leakage losses in software. Local losses resulting from added turbulence that occurs at bends and fittings are neglected.

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## AUTHORS PROFILE

**Ms. Vidhi N. Mehta,** B. E. (Civil), M. E. (Civil) M.S.U., Vadodara. Assistant Professor in Civil Engineering Department of Faculty of Technology & Engineering.

**Dr. Geeta S. Joshi,** B. E. (Civil), M. E. (Civil), Ph.D. IIT Bombay. Associate Professor in Civil Engineering Department of Faculty of Technology & Engineering