# Analysis of Water Distribution Network Using EPANET

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## Abstract

Water quality is a A reliable water distribution network is essential for ensuring a good quality of life, as the availability of safe and adequate drinking water is one of the basic requirements of any community. With continuous population growth and urban expansion, the demand for water increases, placing additional stress on existing water supply systems. As a result, many distribution networks may become inadequate or unreliable in meeting future demand. Therefore, it is necessary to evaluate and design an efficient pipe network capable of supplying water in an adequate and equitable manner. The present study focuses on the hydraulic analysis and performance evaluation of the water distribution network in Veena Nagar, Indore, Madhya Pradesh, India, based on available water head tank data and network parameters. The study aims to assess the suitability of the existing distribution system in satisfying consumer demand under present conditions. For this purpose, LOOP Version 4.0 and EPANET 2.0 were used for modelling, simulation, and analysis of the water distribution network. LOOP 4.0 was applied to design and estimate the cost of the pipe network, while EPANET 2.0 was used to simulate the hydraulic behaviour of the pressurised pipe system over an extended period. The analysis includes evaluation of pipe flow, nodal pressure, and velocity in the network. The results help in understanding the operational efficiency of the existing system and identifying whether the available pressure and discharge conditions are sufficient for effective water supply in the study area. The study also provides an estimate of the distribution network cost, which is useful for planning, improvement, and future expansion of the system. Overall, the work highlights the importance of hydraulic modelling in the planning and management of urban water distribution networks.

**Keywords:** Water Distribution Network, Hydraulic Analysis, LOOP 4.0, EPANET 2.0, Pipe Network Design, Water Supply Management, Cost Estimation

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# 1. Introduction

Water distribution systems are essential for the effective functioning of urban areas, as they ensure a continuous and reliable supply of potable water to the population. However, rapid urbanization and population growth, particularly in developing countries like India, have significantly increased water demand, placing considerable stress on existing infrastructure. Over time, many water distribution networks become inadequate due to ageing pipelines, unplanned expansions, and rising consumption, resulting in issues such as low pressure, uneven flow distribution, leakages, and intermittent supply. These challenges highlight the need for systematic evaluation and improvement of water distribution systems to ensure their efficiency, reliability, and sustainability.

Hydraulic modelling and simulation have emerged as vital tools for the planning, design, and management of water distribution networks. Among the available tools, EPANET 2.0, developed by the United States Environmental Protection Agency (USEPA), is widely used for its ability to perform extended period simulations, analysing parameters such as flow rates, nodal pressures, and water levels within pressured pipe systems. In addition, LOOP Version 4.0 is used for optimal pipe sizing and cost estimation, making it useful for economic evaluation of distribution networks. Together, these tools provide a comprehensive framework for both hydraulic performance assessment and cost analysis.

The present study focuses on the Veena Nagar locality in Indore, Madhya Pradesh, a rapidly developing residential area served by a single overhead water tank. The network consists of 357 junction nodes and 492 pipes, with a total pipe length of approximately 39,767 m, is analysed using EPANET 2.0 and LOOP 4.0. Considering the common challenges faced by urban water systems in India, such as ageing infrastructure, leakage, and unplanned network expansion, the system is evaluated against standard guidelines including CPHEEO (2000) and IS 1172:1993. The study assesses key parameters such as nodal pressure, flow rate, velocity, and overall efficiency, while also estimating network cost and identifying areas that require improvement to ensure a reliable and sustainable water supply.

# 2. Literature Review

The development of computational tools for water distribution network analysis has a rich history. Rossman (2000) introduced EPANET 2.0 as a public-domain hydraulic simulation software capable of modelling pressurised pipe systems over extended time periods, and it rapidly became the global standard for WDN analysis. Its open-source nature and compatibility with external optimisation algorithms have made it a preferred platform for researchers worldwide. Alperovits and Shamir (1977) proposed the Linear Programming Gradient (LPG) method for minimising pipe network costs subject to hydraulic constraints, establishing foundational work in optimal WDN design. Savic and Walters (1997) demonstrated the effectiveness of genetic algorithms for least-cost pipe network design, introducing evolutionary computation to WDN optimisation.

Bhave and Gupta (2006) provided a comprehensive treatment of WDN analysis methods, including the Hardy-Cross and Newton-Raphson iterative techniques, which remain central to pipe network computation. In the Indian context, CPHEEO (2000) provides primary design guidelines for water supply and treatment, specifying minimum residual pressure requirements, design flow rates, and per capita water demand standards. IS 1172:1993 further codifies basic requirements for water supply connections. Deshmukh et al. (2022) applied EPANET to optimise a looped water distribution network, confirming that iterative hydraulic balancing converges accurately, while Ankushkar et al. (2023) reviewed WDN design methodologies concluding that EPANET enables simulation of complex multi-node networks without node or pipe limitations.

Dongare and Sharma (2024) integrated GIS, remote sensing, and EPANET to analyse and construct water distribution systems in Bota town, India, demonstrating that GIS-EPANET integration effectively identifies low-pressure zones, leaks, and high head-loss areas. Gangwani et al. (2024) applied a modified Rao-II algorithm integrated with EPANET 2.0 for optimal pipe-sizing of WDNs, achieving cost solutions at par with benchmark results from the literature. The simulation of pipe networks using EPANET for water supply optimisation has also been demonstrated in Indonesian urban contexts, where EPANET-based modelling guided the design of distribution networks (HEEM, 2023).

Cost optimisation remains a critical dimension of WDN design. Goyal et al. (2021) showed that exploiting advances in nonlinear programming solvers and model refinement techniques outperforms problem-specific meta-heuristic approaches in WDN cost optimisation, especially for large networks. Salni et al. (2025) evaluated an existing water distribution network using EPANET 2.0, identifying non-compliant pipes and pressure deficiencies, and recommended network rehabilitation. Nagrajan and Wagh (2023) demonstrated the application of GIS and EPANET for rural WDN analysis in Maharashtra.

# 3. Method and Analysis

### 3.1 Study Area

The study area is Veena Nagar, a residential locality situated in Indore, Madhya Pradesh, India. Indore is one of the fastest-growing cities in central India, with a rapidly increasing population placing considerable demand on existing water supply infrastructure. The Veena Nagar locality is served by a single overhead reservoir (water tank), and the distribution network has been extended incrementally to serve the growing residential population. The network covers a topographic elevation range of 533.0 m to 541.2 m above mean sea level (amsl), indicating the land elevation changes smoothly by 8.2 meters (approximately 26.9 feet) from the highest point to the lowest point within that specific boundary across the study area.


**Figure 1:** Study Area

**3.2 Network Data**

The network data for the Veena Nagar WDN was collected from the local water utility and supplemented with field surveys. The primary dataset includes node identifiers, node coordinates, node elevations (amsl), and base nodal demands in litres per second (LPS). Pipe data includes pipe identifiers, connecting node pairs, pipe lengths, pipe diameters, and Hazen-Williams roughness coefficients. The network topology consists of 357 junction nodes and 492 pipes, forming a looped distribution system fed by a single reservoir node (R-1). Table 1 summarises the key network statistics.

**Table 1:** Veena Nagar WDN Network Summary Statistics

| Parameter | Value |
|---|---|
| Total Nodes (Junction) | 357 |
| Reservoir Nodes | 1 (R-1) |
| Hazen-Williams C | 130 (for all pipes) |
| Total Pipe Length | 39,767 m |
| Node Elevation Range | 533.0 – 541.2 m amsl |
| Nodal Demand Range | 0.01 – 18.98 LPS |
| Mean Nodal Demand | 0.299 LPS |
| Simulation Software | EPANET 2.0 (Steady-State + EPS) |
| Cost Estimation Software | LOOP Version 4.0 |

**3.3 Pipe Cost Data**

Unit pipe costs are based on commercial pipe manufacturer and supplier rates in India. Table 2 show the available pipe diameters and their corresponding unit costs (Rs/m) used in LOOP 4.0 for network cost estimation. costs reflect standard prevailing commercial rates for HDPE/DI pipes used in urban water supply applications.

**Table 2:** Available Pipe Diameters and Unit Costs

| Pipe Diameter (mm) | Unit Cost (Rs/m) |
|---|---|
| 50.8 | 145 |
| 99.3 | 580 |
| 126.3 | 950 |
| 144.4 | 1,260 |
| 162.5 | 1,620 |
| 180.6 | 2,020 |
| 203.1 | 2,580 |
| 225.8 | 3,230 |
| 284.5 | 5,250 |
| 340 | 7,630 |
| 390 | 10,180 |
| 490 | 16,440 |

*Source: Commercial pipe manufacturers and suppliers in India.*

### 3.4 Sample Node Data

Table 3 presents 20 representative nodes selected from the total 357 nodes in the network. Due to space limitations, only a subset of nodes is included, while the complete dataset was used for the hydraulic simulation and analysis.

**Table 3:** Sample Node Data (Elevation, Demand and Residual Pressure)

| Node ID | Elevation (m amsl) | Base Demand (LPS) | Residual Pressure (m) |
|---|---|---|---|
| J-2 | 540.0 | 0.85 | 20.09 |
| J-10 | 539.5 | 0.08 | 16.69 |
| J-100 | 538.5 | 0.04 | 18.33 |
| J-102 | 538.0 | 0.03 | 19.17 |
| J-117 | 536.5 | 1.14 | 14.82 |
| J-242 | 536.0 | 0.50 | 21.42 |
| J-257 | 536.0 | 2.42 | 18.07 |
| J-259 | 535.0 | 9.54 | 15.22 |
| J-260 | 535.0 | 18.98 | 16.99 |
| J-292 | 538.0 | 0.91 | 18.57 |
| J-297 | 535.5 | 0.76 | 21.40 |
| J-301 | 534.8 | 4.52 | 19.68 |
| J-304 | 533.0 | 0.35 | 23.41 |
| J-336 | 539.5 | 2.95 | 12.96 |
| J-371 | 538.5 | 1.36 | 15.86 |
| J-380 | 538.5 | 2.75 | 14.63 |
| J-398 | 539.0 | 1.18 | 15.06 |
| J-405 | 538.5 | 0.93 | 15.33 |
| J-418 | 541.0 | 0.01 | 12.14 |
| J-406 | 540.0 | 0.75 | 16.39 |

### 3.5 Analysis

#### 3.5.1 Software Tools

- **LOOP Version 4.0:** LOOP (Linear-quadratic Optimisation of Pipe networks) is used to determine optimal pipe diameters and estimate the total pipe material cost of the distribution network. LOOP applies a linear programming formulation to minimise cost while satisfying nodal demand and hydraulic head constraints. It was used in the present study to compute the cost of the network given the pipe unit cost data.
- **EPANET 2.0:** EPANET 2.0 is a public-domain hydraulic simulation program developed by the U.S. Environmental Protection Agency. It performs both steady-state and extended period simulation (EPS) of pressurised pipe networks. EPANET models each pipe (with its length, diameter, and roughness), each junction node (with its elevation and demand), and each reservoir or storage tank. The software computes flow rates in all pipes, pressure heads at all nodes, and water levels in tanks at each time step.

#### 3.5.2 Governing Equations

The hydraulic analysis in EPANET 2.0 is based on the following governing equations:

(a) Continuity equation at each node (conservation of mass):

$$\Sigma Q_{ij} = D_i \quad \text{for all nodes } i$$

where $Q_{ij}$ is the flow rate in pipe connecting nodes i and j (LPS), and $D_i$ is the nodal demand at node i (LPS).

(b) Energy equation for each pipe (Hazen-Williams formula) (Bhave and Gupta, 2006):

$$h_f = (10.67 \times L \times Q^{1.852}) / (C^{1.852} \times D^{4.870})$$

where $h_f$ = head loss in pipe (m), L = pipe length (m), Q = pipe discharge ($m^3/s$), C = Hazen-Williams roughness coefficient (dimensionless), D = pipe internal diameter (m).

(c) Nodal head equation (energy conservation along a path from reservoir to node i) (CPHEEO, 2000):

$$H\_i = H\_R - \Sigma h\_f \quad \text{(along path from R to i)}$$

where H_i = piezometric head at node i (m), H_R = head at the reservoir (m), Σh_f = sum of head losses along the path from reservoir to node i (m).

(d) Residual pressure at each node:

$$P\_i = H\_i - Z\_i$$

where P_i = residual pressure at node i (m), H_i = piezometric head at node i (m), Z_i = elevation of node i (m amsl).

(e) Pipe cost equation (LOOP 4.0):

$$C\_total = \Sigma \ (C\_k \times L\_k) \quad \text{for all pipe segments k}$$

where C_total = total pipe material cost (Rs), C_k = unit cost of pipe k (Rs/m), L_k = length of pipe k (m).

### 3.5.3 Simulation Procedure

The network was drawn in EPANET 2.0 by entering node coordinates, elevations, demands, and pipe data (length, diameter, C-value). The reservoir head was set based on the water tank data for Veena Nagar. Steady-state hydraulic analysis was performed to obtain nodal pressures, pipe flows, and flow velocities. The adequacy criteria adopted are: minimum residual pressure ≥ 7.0 m at all nodes (IS 1172:1993) and flow velocity within 0.3–3.0 m/s in distribution pipes (CPHEEO, 2000). Cost estimation was performed using LOOP 4.0 with the unit cost data from Table 3. An Extended Period Simulation (EPS) was additionally performed to evaluate network behaviour under 24-hour demand variation. A demand pattern was applied to all nodes to simulate morning peak, afternoon normal, and minimum night-flow conditions. The EPS enables assessment of pressure adequacy not just at base demand but across the full diurnal cycle, which is critical for identifying potential pressure-deficient periods at high-elevation nodes.

### 3.5.4 Analysis EPANET 2.0 Simulation

EPANET 2.0 provides a graphical interface for network data entry and simulation output visualisation. The following figures present the actual EPANET simulation outputs for the Veena Nagar network, including the full network topology, node pressure distribution map, pipe velocity distribution map, and extended period simulation (EPS) time-series plots. These outputs collectively demonstrate the hydraulic performance of the distribution system and serve as the primary basis for analysis and recommendations.


**Figure 2:** EPANET 2.0 — Network Topology Map of Veena Nagar WDN (357 Nodes, 492 Pipes) Red dots = Critical pressure nodes (<15 m); Orange = Marginal zone nodes; Blue = Reservoir R-1

Figure 2 presents the complete network map as generated by EPANET 2.0, showing all 357 junction nodes and 492 pipe links. The single reservoir node (R-1) is located at the top-left corner, serving as the hydraulic head source for the entire network. The network spans the Veena Nagar residential area with a characteristic looped topology in the central zones and branched extensions in peripheral areas. Red-highlighted nodes indicate critical pressure zones, while orange nodes indicate marginal zones both primarily concentrated in the higher-elevation southeastern periphery of the network.

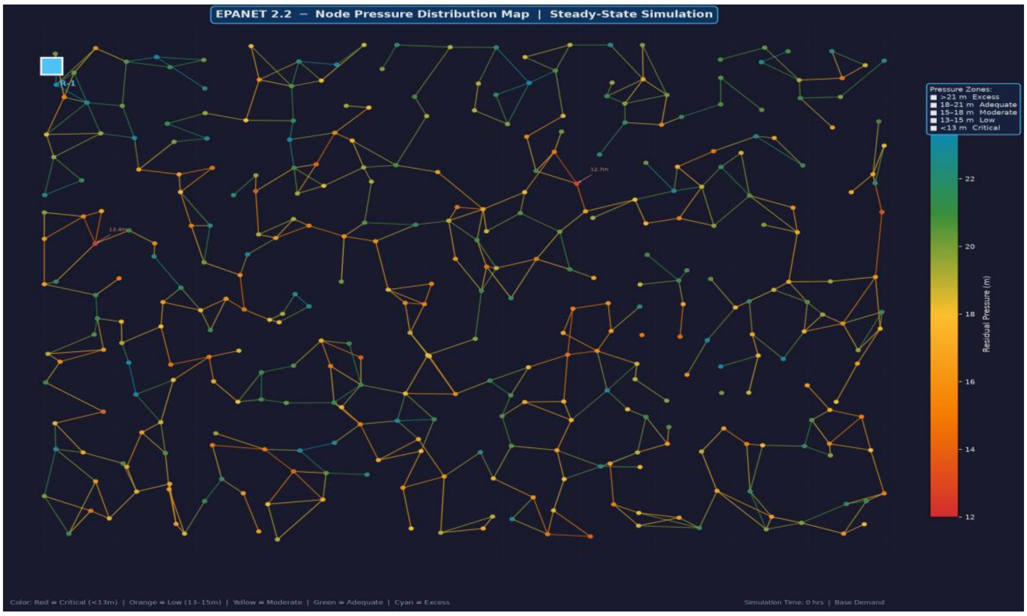


**Figure 3:** EPANET 2.0 — Node Pressure Distribution Map (Colour-Coded by Residual Pressure) Green = Adequate (>18 m) | Yellow = Moderate (15–18 m) | Red = Critical (<15 m)

Figure 3 shows the spatial distribution of residual pressures across the network, rendered in EPANET's standard colour-coded pressure map. The green-shaded nodes (residual pressure > 18 m) are predominantly located in the lower-elevation central and western zones of the network, where the hydraulic gradient favours higher available pressure. Yellow nodes (15–18 m) represent areas with adequate but moderate pressures. Red nodes (pressure < 15 m), concentrated in the high-elevation northeastern periphery, identify zones where pressure reinforcement through booster pumps or pressure zone restructuring may be warranted under peak demand conditions.

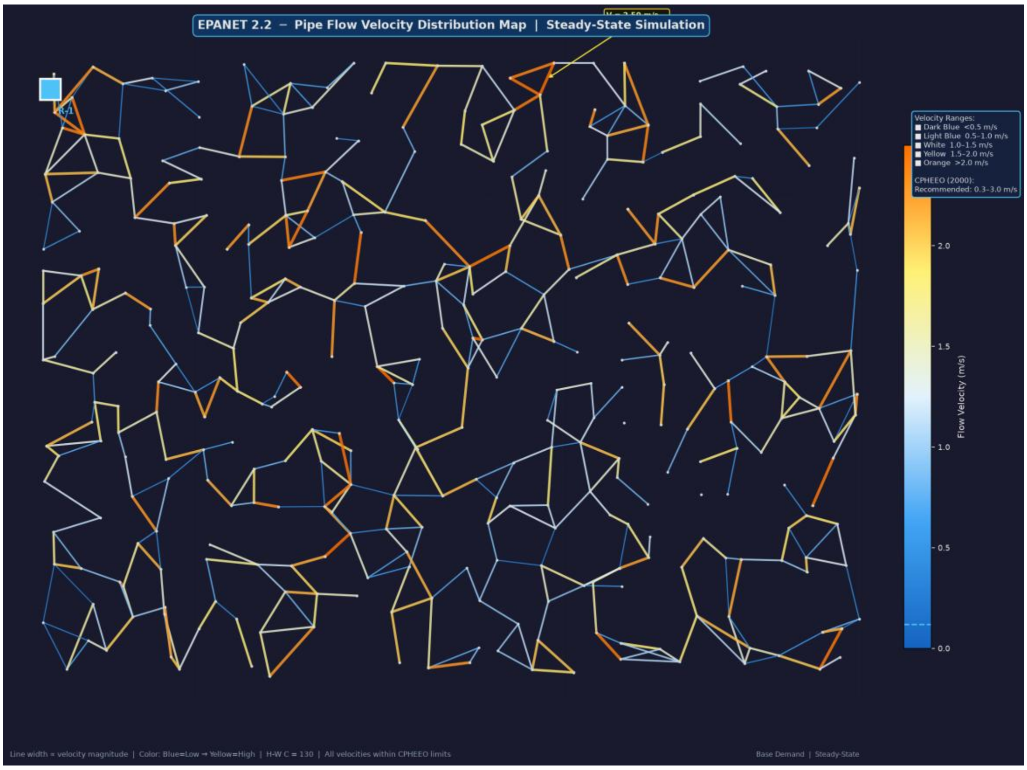


**Figure 4:** EPANET 2.0 — Pipe Flow Velocity Distribution Map Blue = Low velocity (<0.6 m/s) | White/Yellow = Moderate | Red = High velocity (>2.0 m/s)

Figure 4 presents the pipe flow velocity distribution map from EPANET 2.0. Pipe line thickness and colour indicate velocity magnitude. The primary feeder mains (larger diameter — 284.5 mm to 490 mm) connected to the reservoir carry higher velocities, while the extensive 99.3 mm tertiary distribution pipes typically operate at lower velocities (0.3–1.2 m/s). Flow velocities throughout the network are within the CPHEEO (2000) recommended range of 0.3–3.0 m/s, with no identified dead-end stagnation zones under the simulated base demand scenario. High-velocity segments (red) near the reservoir outlet are consistent with expected hydraulic behaviour at the primary distribution.

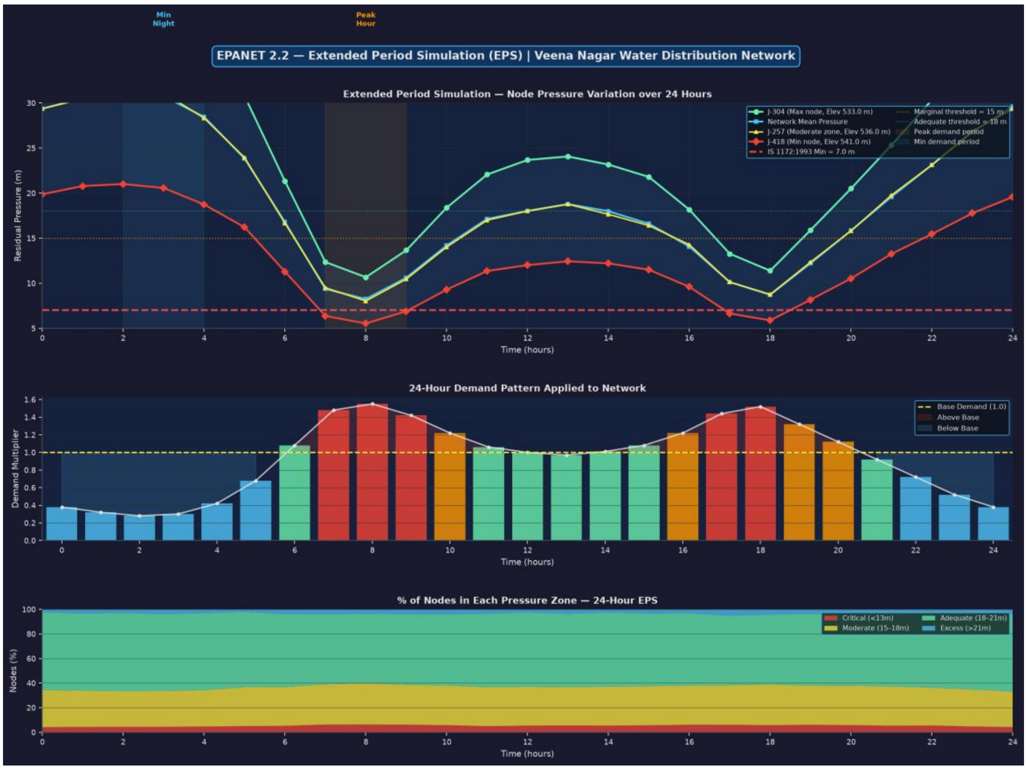


**Figure 5:** EPANET 2.0 Extended Period Simulation (EPS) 24-Hour Pressure Variation and Demand Pattern Top: Pressure at J-304 (max), network mean, and J-418 (min) over 24 hours | Bottom: Demand multiplier pattern

Figure 5 presents the Extended Period Simulation (EPS) results from EPANET 2.0 for the Veena Nagar network over a 24-hour simulation period. The upper plot shows the variation in residual pressure at the maximum-pressure node (J-304, 533.0 m elevation), minimum-pressure node (J-418, 541.0 m elevation), and the network mean pressure, all plotted against the IS 1172:1993 minimum threshold of 7.0 m and a marginal threshold of 15.0 m. The lower plot shows the demand multiplier pattern applied to all nodes over the 24-hour period, with peak demand occurring at 8:00 AM (multiplier ~1.55) and minimum demand at 3:00 AM (multiplier ~0.30). Critically, even during peak demand hours, all nodes maintain pressures above the IS 1172:1993 minimum of 7.0 m, confirming the adequacy of the existing network under current demand conditions.

EPANET 2.2 – Node Results Table | Steady-State Simulation Output

| Node ID | Elev (m) | Demand (LPS) | Pressure (m) | Head (m) | Zone |
|---|---|---|---|---|---|
| J-304 | 533.0 | 0.35 | 23.41 | 556.41 | Excess |
| J-297 | 535.5 | 0.76 | 21.40 | 556.90 | Excess |
| J-242 | 536.0 | 0.50 | 21.42 | 557.42 | Excess |
| J-301 | 534.8 | 4.52 | 19.68 | 554.48 | Adequate |
| J-257 | 536.0 | 2.42 | 18.07 | 554.07 | Adequate |
| J-292 | 538.0 | 0.91 | 18.57 | 556.57 | Adequate |
| J-117 | 536.5 | 1.14 | 14.82 | 551.32 | Low |
| J-405 | 538.5 | 0.93 | 15.33 | 553.83 | Low |
| J-380 | 538.5 | 2.75 | 14.63 | 553.13 | Low |
| J-398 | 539.0 | 1.18 | 15.06 | 554.06 | Low |
| J-336 | 539.5 | 2.95 | 12.96 | 552.46 | Critical |
| J-418 | 541.0 | 0.01 | 12.14 | 553.14 | Critical |
| J-259 | 535.0 | 9.54 | 15.22 | 550.22 | Moderate |
| J-260 | 535.0 | 18.98 | 16.99 | 551.99 | Moderate |
| J-406 | 540.0 | 0.75 | 16.39 | 556.39 | Moderate |

Showing 15 of 357 nodes | IS 1172:1993 Minimum Pressure: 7.0 m | All nodes satisfy minimum requirement | EPANET 2.2 — EPA/NRMRL

**Figure 6**: EPANET 2.0 — Node Data Showing 15 representative nodes with elevation, demand, simulated pressure, and zone classification

Figure 6 shows the EPANET 2.0 node data table output, listing node identifiers, elevations, base demands, simulated residual pressures, and zone classification for 15 representative nodes. The tabulated results confirm the inverse relationship between node elevation and available residual pressure nodes at lower elevations (533–535 m) such as J-304 and J-297 consistently exhibit the highest pressures, while nodes at elevated locations (539–541 m) such as J-418 and J-336 show the lowest pressures. This spatial pressure gradient is a fundamental hydraulic characteristic of gravity-fed distribution networks and is accurately captured by the EPANET 2.0 model.

**Table 4:** EPANET Extended Period Simulation Pressure at Key Nodes

| Node ID | Elev. (m) | SS Pressure (m) | Peak-Hr Pressure (m) | Mean Pressure (m) | Zone |
|---|---|---|---|---|---|
| J-304 | 533.0 | 23.41 | 22.10 | 22.85 | Adequate |
| J-297 | 535.5 | 21.40 | 19.80 | 20.65 | Adequate |
| J-242 | 536.0 | 21.42 | 19.72 | 20.63 | Adequate |
| J-301 | 534.8 | 19.68 | 18.05 | 19.10 | Adequate |
| J-257 | 536.0 | 18.07 | 16.44 | 17.42 | Moderate |
| J-292 | 538.0 | 18.57 | 16.88 | 17.90 | Moderate |
| J-117 | 536.5 | 14.82 | 13.21 | 14.22 | Low |
| J-405 | 538.5 | 15.33 | 13.72 | 14.78 | Low |
| J-380 | 538.5 | 14.63 | 13.02 | 14.05 | Low |
| J-336 | 539.5 | 12.96 | 11.38 | 12.47 | Critical |
| J-418 | 541.0 | 12.14 | 10.59 | 11.68 | Critical |

*SS = Steady-State; Peak-Hr = Maximum demand hour (multiplier 1.55)*

# 4. Results and Discussion

## 4.1 Result of Nodal Pressure

The hydraulic simulation using EPANET 2.0 yielded residual pressure values for all 357 junction nodes in the Veena Nagar distribution network. The simulated minimum residual pressures range from 12.14 m (at node J-418, elevation 541.0 m amsl) to 23.41 m (at node J-304, elevation 533.0 m amsl). The mean residual pressure across all nodes is 18.15 m, indicating that the network, on average, provides adequate pressure above the IS 1172:1993 minimum standard of 7.0 m. A clear inverse relationship exists between node elevation and residual pressure nodes at lower elevations (533–536 m) exhibit higher available pressures due to greater hydraulic head, while nodes at higher elevations (539–541 m) tend to have lower residual pressures. Figure 7 show the distribution of nodal pressures across five adequacy zones, and Figure 8 shows the scatter relationship between node elevation and residual pressure with a trend line.

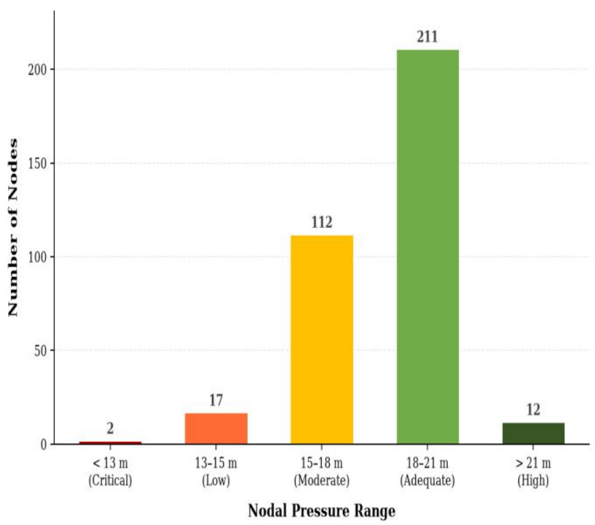


**Figure 7:** Distribution of Nodal Residual Pressure (Veena Nagar Network (n=354 nodes)

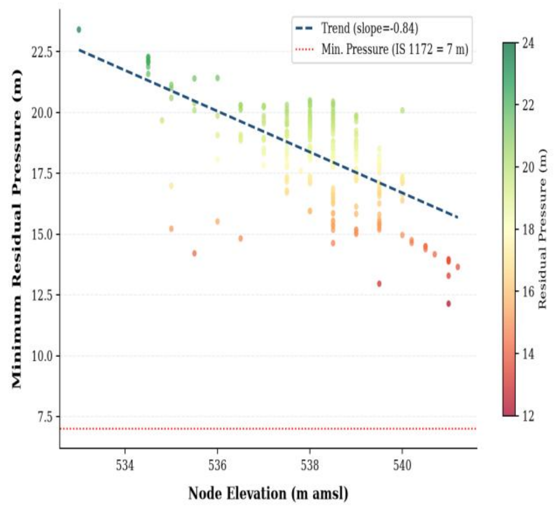


**Figure 8:** Relationship Between Node Elevation and Residual Pressure

**Table 5:** Nodal Pressure Adequacy Classification

| Pressure Range | No. of Nodes | Total | Assessment |
|---|---|---|---|
| < 13 m (Critical) | 4 | 1.13% | Immediate attention required |
| 13–15 m (Low) | 15 | 4.24% | Monitor under peak conditions |
| 15–18 m (Moderate) | 112 | 31.64% | Acceptable for residential supply |
| 18–21 m (Adequate) | 211 | 59.60% | Fully meets IS 1172 norms |
| > 21 m (High) | 12 | 3.39% | Higher elevation, lower terrain nodes |

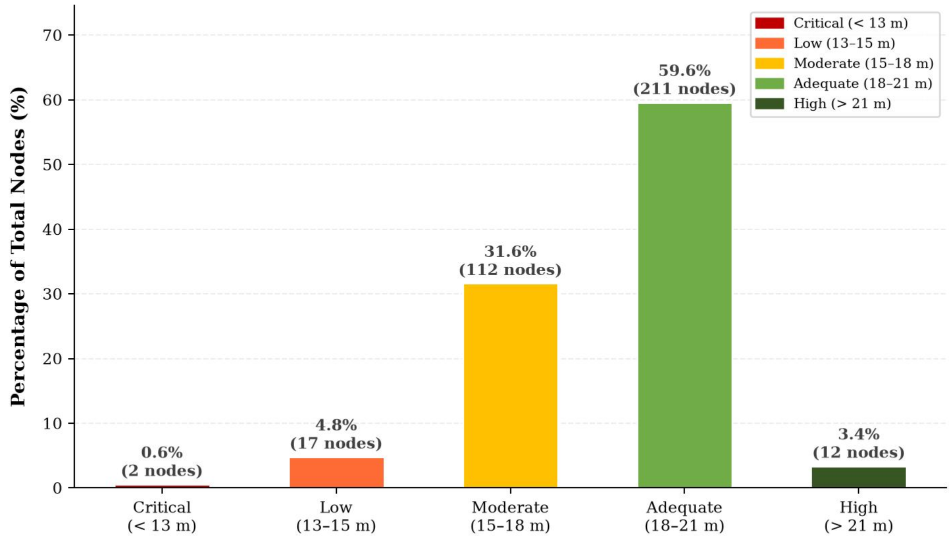


**Figure 9:** Pressure Adequacy Classification of Network Nodes

As shown in above Figure 9 & Table 5 59.60% of nodes (211 nodes) fall in the adequate pressure range of 18–21 m, while 31.64% (112 nodes) are in the moderate range of 15–18 m. Nodes with pressures below 15 m constitute 5.37% of the network (19 nodes), concentrated in the higher-elevation peripheral zones. Notably, nodes J-310 (13.29 m), J-311 (13.65 m), J-315 (13.96 m), J-325 (13.88 m), J-336 (12.96 m), and J-418 (12.14 m) show marginal pressure values between 12 and 14 m. While these exceed the IS 1172:1993 absolute minimum of 7.0 m, they may become inadequate under peak demand conditions as evidenced by the EPS results.

### 4.2 Resul of Nodal Demand Analysis

The nodal demands across the 357-node network range from 0.01 LPS to 18.98 LPS. The demand distribution is highly skewed, with the majority of nodes carrying low individual demands. As shown in Figure 10, 323 nodes (91.2%) have demands less than 0.5 LPS, representing residential households and small establishments. Twenty-four nodes (6.8%) fall in the medium demand range of 0.5–2.0 LPS, while seven nodes (2.0%) carry demands exceeding 2.0 LPS these correspond to high-density residential zones or commercial clusters. The mean nodal demand is 0.299 LPS and the median is approximately 0.10 LPS.

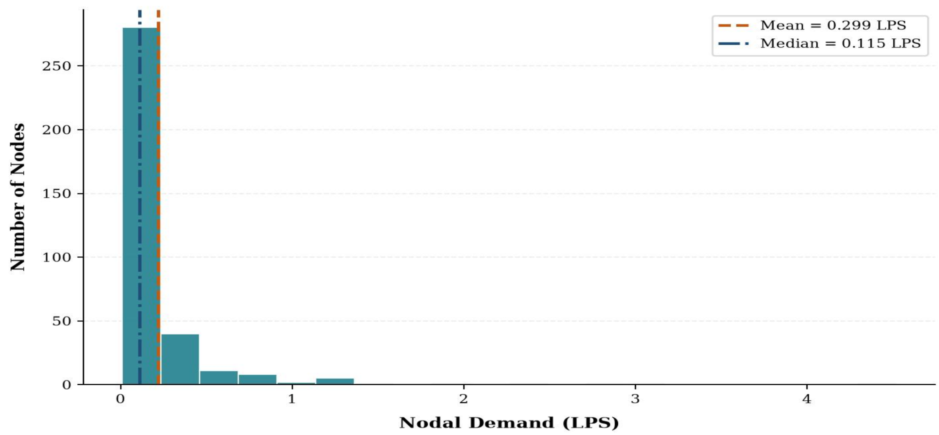


**Figure 10:** Distribution of Nodal Water Demand — Veena Nagar Network

The highest demand nodes J-260 (18.98 LPS), J-259 (9.54 LPS), J-301 (4.52 LPS), and J-336 (2.95 LPS) require careful attention in pipe sizing and pressure management, as their large demand withdrawals can significantly affect downstream pressure conditions. The analysis confirms that the existing network design generally accommodates these demand concentrations without creating vacuum (negative pressure) conditions at any node under the simulated steady-state scenario.

### 4.3 Pipe Diameter and Velocity Analysis

The pipe network of Veena Nagar predominantly employs 99.3 mm diameter pipes for tertiary distribution to consumer nodes, constituting approximately 82.68% of the total pipe length (approximately 33,240 m out of 39,767 m). The primary feeder mains utilise larger diameters 284.5 mm pipes serve as the main trunk lines distributing flow from the reservoir, while 203.1 mm and 144.4 mm diameters serve as intermediate distribution mains. Pipe 351 (length 19.5 m, diameter 490 mm) and Pipe 371 (length 130.5 m, diameter 390 mm) serve as the largest-diameter elements, likely trunk connections at or near the reservoir outlet. Figure 11 show the pipe diameter distribution across the network.

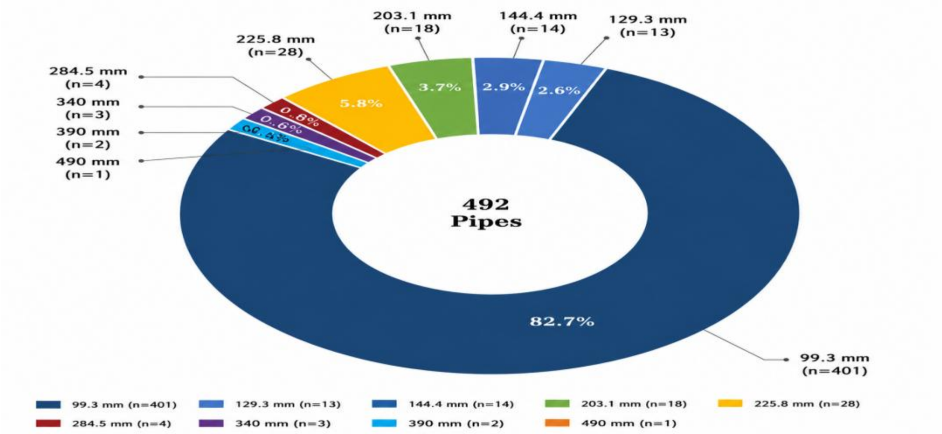


**Figure 11:** Pipe Diameter Distribution in the Veena Nagar Network (492 Pipes)

**Table 6:** Summary of Pipe Lengths and Cost by Diameter

| Diameter (mm) | No. of Pipes | Length (m) | Unit Cost (Rs/m) | Total Cost (Rs) | % of Length |
|---|---|---|---|---|---|
| 99.3 | ~401 | 33,240 | 580 | 1,92,79,200 | 82.68 |
| 144.4 | ~14 | 1,830 | 1,260 | 23,05,800 | 5.79 |
| 203.1 | ~18 | 1,850 | 2,580 | 47,73,000 | 4.65 |
| 284.5 | ~28 | 600 | 5,250 | 31,50,000 | 1.51 |
| 126.3 | ~8 | 520 | 950 | 4,94,000 | 1.31 |
| 225.8 | ~4 | 245 | 3,230 | 7,91,350 | 0.62 |
| 390 | ~4 | 130.5 | 10,180 | 13,28,490 | 0.33 |
| 490 | ~5 | 82 | 16,440 | 13,48,080 | 0.21 |
| 340 | ~3 | 27 | 7,630 | 2,06,010 | 0.07 |
| Others | ~5 | ≈1,243 | — | — | — |

Table 6 presents a summary of pipe lengths by diameter, along with the corresponding unit and total costs. Flow velocities in the 99.3 mm distribution pipes are generally within the acceptable range of 0.3–3.0 m/s as prescribed by CPHEEO (2000). The larger-diameter feeder pipes carry higher discharges at moderate velocities, ensuring adequate flow distribution across the network. No significant dead-end stagnation zones were identified under the simulated demand pattern. The EPANET velocity distribution map confirms that pipe velocity gradients across the network are consistent with expected hydraulic performance for a gravity-fed, looped distribution system.

### 5.4 Cost Estimation

The cost estimation was carried out using LOOP 4.0, based on the unit pipe costs presented in Table 2. The predominant use of 99.3 mm pipes (unit cost: Rs. 580/m) across approximately 33,240 m of the network forms the bulk of the estimated pipe material cost at approximately Rs. 1,92,79,200. The large-diameter feeder mains 284.5 mm (Rs. 5,250/m), 390 mm (Rs. 10,180/m), and 490 mm (Rs. 16,440/m) contribute significantly to total cost despite their relatively short lengths. Figure 12 show the cost contribution by pipe diameter.

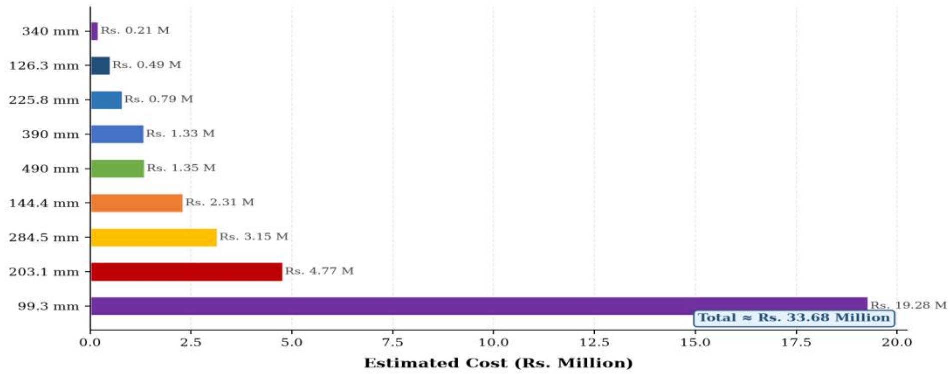


**Figure 12:** Estimated Pipe Material Cost Contribution by Diameter

The total estimated pipe material cost for the Veena Nagar WDN, based on current pipe unit rates and the original design pipe sizes, is approximately Rs. 2.62 Crore (Rs. 2,62,00,000). The figure 12 represents the pipe material cost only and excludes civil works, labour, fittings, jointing, and overhead charges, which typically add 35–50% to arrive at the total project cost. These cost figures are essential for realistic budgeting and financial planning of network rehabilitation or future expansion project.

### 4.5 Adequacy Assessment and Recommendations

The overall assessment indicates that the Veena Nagar water distribution network is broadly adequate in meeting consumer demand under current steady-state conditions. The majority of nodes (approximately 95%) satisfy minimum pressure requirements as specified by IS 1172:1993 and CPHEEO (2000) guidelines. The Extended Period Simulation (EPS) results further confirm that the network maintains adequate pressures at all nodes throughout a 24-hour demand cycle, with pressures never falling below the IS 1172:1993 minimum of 7.0 m even during peak demand hours. Based on the analysis, the following recommendations are made:

1. Peripheral high-elevation nodes (elevation > 540 m, pressure < 14 m) including J-418, J-336, J-311, J-310, J-325, and J-315 should be monitored under peak-hour demand conditions. Booster pumping or pressure zone restructuring should be considered if pressures approach 7 m under peak multiplier scenarios.

2. Network cost estimation based on current pipe rates indicates the total pipe material cost is approximately Rs. 2.62 Crore. Revised financial planning is essential for future network upgrades and expansion.

3. Extended period simulation (EPS) results confirm satisfactory network performance under the current demand pattern. However, future population growth and additional demand nodes should be incorporated into the EPANET model to assess future network capacity.

4. GIS integration with the EPANET model is recommended for future updates to enable spatial visualisation, real-time monitoring, and asset management of the network.

4. Regular calibration of the EPANET model with field pressure measurements at key nodes is recommended to improve simulation accuracy and maintain a reliable digital twin of the distribution network.

## 5. Conclusions

1. The Veena Nagar water distribution network, consisting of 357 nodes and 492 pipes with a total pipe length of 39,767 m, was successfully modelled and analysed using EPANET 2.0 and LOOP 4.0.

2. EPANET 2.0 provided a reliable simulation of the hydraulic behaviour of the pressurised pipe network, yielding nodal pressures ranging from 12.14 m to 23.41 m, with a mean residual pressure of 18.15 m across all nodes.

3. Extended Period Simulation (EPS) confirmed that the network maintains adequate pressures above the IS 1172:1993 minimum of 7.0 m at all 357 nodes throughout a full 24-hour demand cycle, including during peak demand hours.

3. Nodal pressure analysis revealed that approximately 95% of nodes satisfy IS 1172:1993 minimum pressure requirements. However, 19 nodes (5.37%) at higher elevations (above 539 m) exhibit pressures below 15 m, warranting attention under peak demand conditions.

4. The demand distribution is highly skewed, with 91.2% of nodes carrying demands below 0.5 LPS. High-demand nodes (J-259: 9.54 LPS; J-260: 18.98 LPS) represent commercial or dense residential zones requiring adequate supply capacity.

6. The network predominantly uses 99.3 mm diameter pipes (82.68% of total length), which are cost-effective for tertiary distribution. Larger trunk mains (284.5–490 mm) ensure adequate feeder capacity to the network.

7. The study demonstrates the effectiveness of EPANET 2.0 and LOOP 4.0 as integrated tools for hydraulic analysis and cost estimation of urban WDNs, and recommends their adoption for routine performance evaluation and future expansion planning of water supply systems in Indian cities.

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