Smart Self-Balancing Water Distribution Network
with Integrated Leak Detection System

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What is a Self-Balancing Network?

A system that can self-balance the flows at all its outlets irrespective of the inlet flow. The system is integrated with a flow controlling valve that can be controlled to manage the changing outlet demand. It also includes an advanced leak detection system which can detect and estimate the region and severity of leak.

Why do we need Network that can self-balance the flows?

In real networks, inlet flow and pressure constantly vary, which causes an unequal distribution. A self-balancing system will ensure that every outlet receives equal distribution improving reliability, reducing manual adjustments and maintain proper supply.

How does the Network work?

All paths to each outlet are designed to have equal total head loss. With identical hydraulic resistance on every route, the water will naturally divide equally throughout the network.

Network Flow Direction
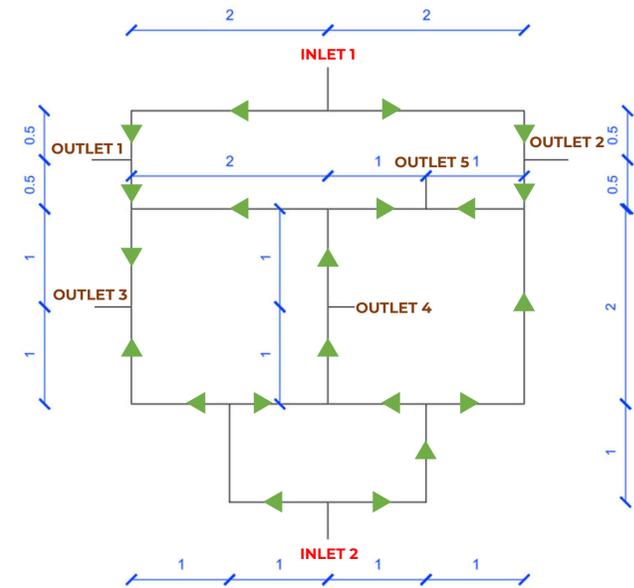
All Dimensions are in Metres
Fig: Line diagram of the network showing the flow directions in all pipes.

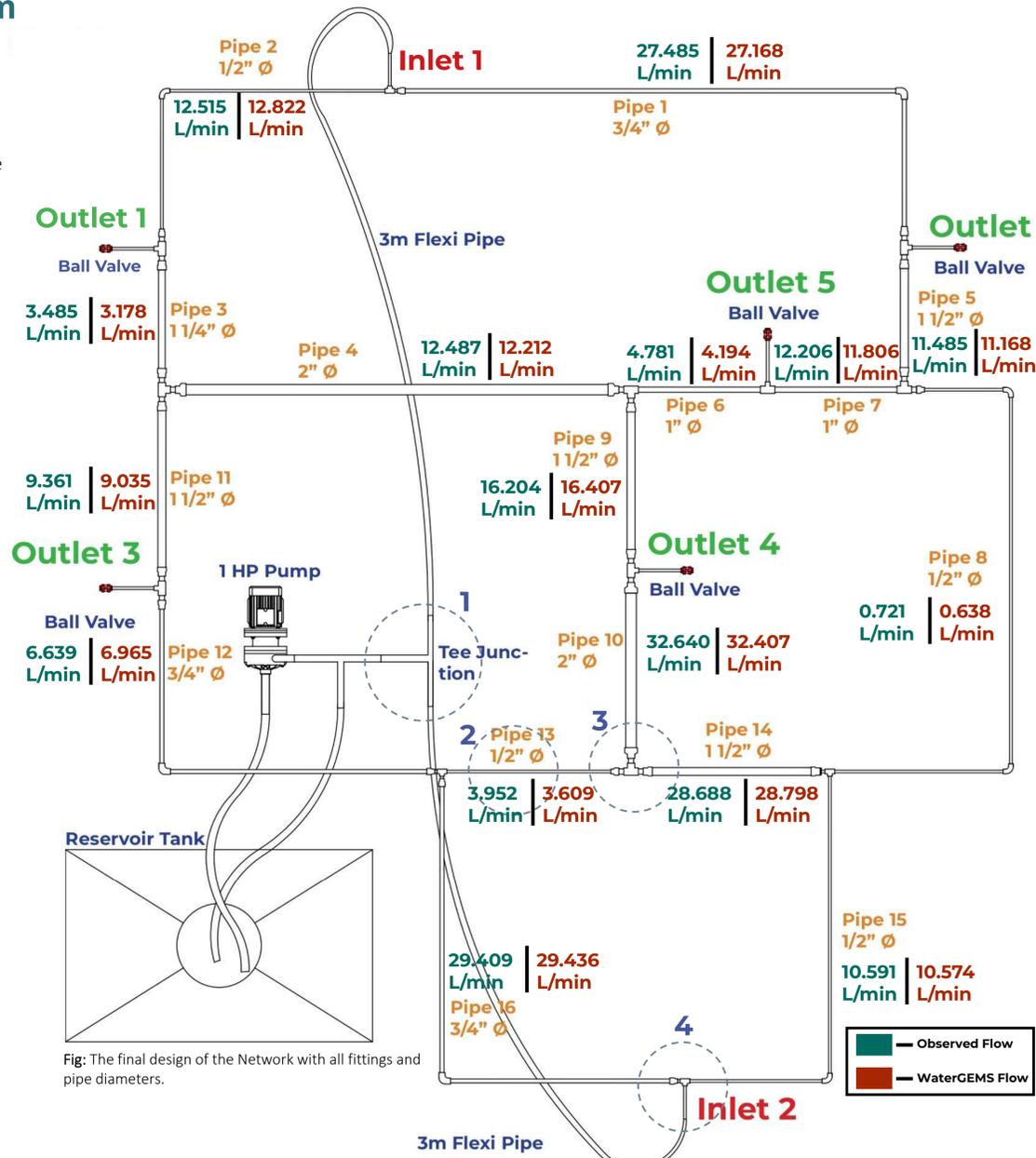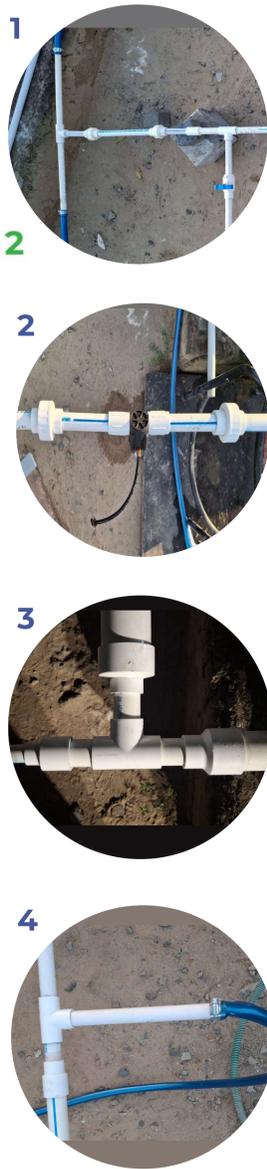Fig: UPVC Pipes were used in the network with all available diameters and lengths.

Network Diagram

Inlet 1

Pipe 2 1/2" Ø
12.515 L/min | 12.822 L/min

Pipe 1 3/4" Ø
27.485 L/min | 27.168 L/min

3m Flexi Pipe

Outlet 1 — Ball Valve
3.485 L/min | 3.178 L/min

Pipe 3 1 1/4" Ø

Pipe 4 2" Ø
12.487 L/min | 12.212 L/min

Outlet 5 — Ball Valve
4.781 L/min | 4.194 L/min

Pipe 6 1" Ø

Pipe 7 1" Ø

12.206 L/min | 11.806 L/min

Outlet 2 — Ball Valve
Pipe 5 1 1/2" Ø
11.485 L/min | 11.168 L/min

Pipe 9 1 1/2" Ø
16.204 L/min | 16.407 L/min

Pipe 11 1 1/2" Ø
9.361 L/min | 9.035 L/min

Outlet 3 — Ball Valve
6.639 L/min | 6.965 L/min

1 HP Pump

Pipe 12 3/4" Ø

Tee Junction (1)

Outlet 4 — Ball Valve

Pipe 10 2" Ø
32.640 L/min | 32.407 L/min

Pipe 8 1/2" Ø
0.721 L/min | 0.638 L/min

Pipe 13 1/2" Ø (2)
3,952 L/min | 3.609 L/min

Pipe 14 1 1/2" Ø (3)
28.688 L/min | 28.798 L/min

Reservoir Tank

Fig: The final design of the Network with all fittings and pipe diameters.

Pipe 16 3/4" Ø
29.409 L/min | 29.436 L/min

Pipe 15 1/2" Ø
10.591 L/min | 10.574 L/min

(4)

3m Flexi Pipe

Inlet 2

■ Observed Flow
■ WaterGEMS Flow

Network Setup

Fig: The final network was laid onto concrete blocks and levelled at the same elevation using spirit level

Results

The network achieved a similarity of **97.3%** in flows at all outlets which was just **2.2%** short of our calculated ideal performance. This strong RESULT confirmed that the system was able to consistently balance flows even when the inlet flows were changed frequently.

Future Applications

This type of self-balancing network can be implemented in urban and rural water supply systems to ensure equal distribution. It improves reliability under fluctuating pressure and demand conditions, reduces the need for manual adjustments and enhances the systems efficiency by maintaining consistent outlet flow under varying operating conditions.

Scan to view the Full Report

Flow Controlling Valve

When one or more valves were closed, the hydraulic balance of the network changed and the older configuration for equal flow was not applicable. Upon adjusting one valve, the system was able to balance the flows.

The Flow Controlling Valve was able to regulate and equalize the flow at all outlets by just working at only one outlet, providing greater control over the network and allowing it to adapt smoothly to the changing demand conditions. The valve was made as a cost-effective alternative to industry grade proportional solenoid valve.

By operating the valve through a switch, the system was effectively balanced, resulting in equal flow at all outlets.
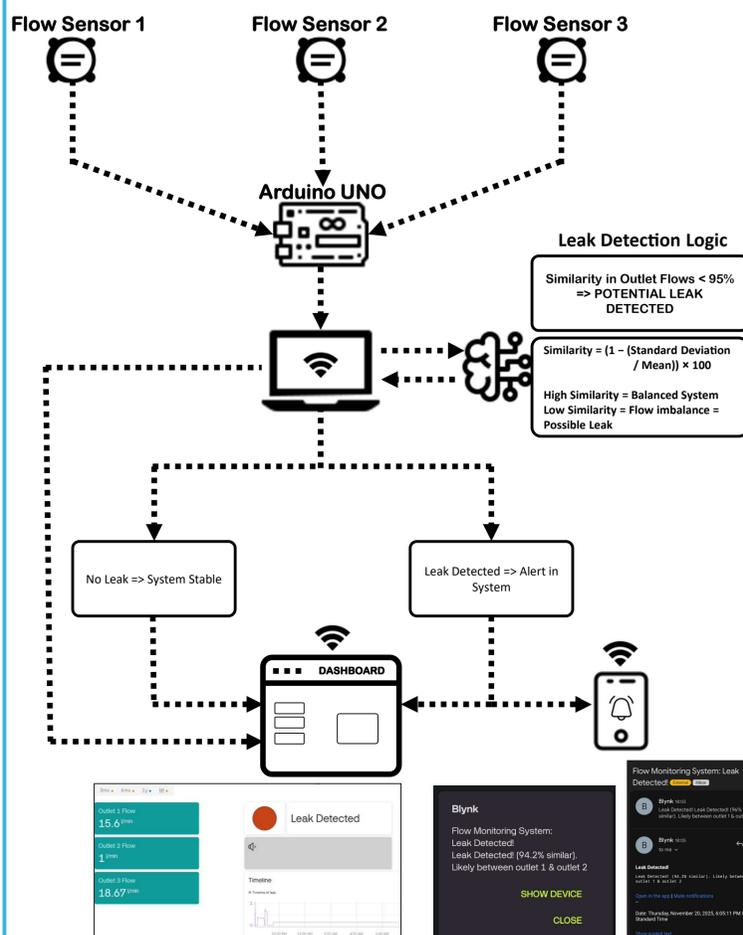
Scan to view the valve's working demo

Leak Detection System
By monitoring only Outlet Flows

The network is integrated with a Similarity-based leak detection system that monitors only the outlet flows to identify anomalies and notify the user through push notifications or an email.

Flow Sensor 1   Flow Sensor 2   Flow Sensor 3

Arduino UNO

Leak Detection Logic

Similarity in Outlet Flows < 95% => POTENTIAL LEAK DETECTED

Similarity = (1 – (Standard Deviation / Mean)) × 100
High Similarity = Balanced System
Low Similarity = Flow imbalance = Possible Leak

No Leak => System Stable

Leak Detected => Alert in System

DASHBOARD

Purpose of the System
- Monitor flow rates only from outlets.
- Identify imbalances in the system instead of absolute limits.
- Adaptive learning of normal behavior over time.
- Leak location detection.
- Sending alerts and logging data.

Properties
- **Minimum Flow Protection** to prevent false detection and activate only on minimum required flow.
- **Sudden Drop Detection (Time-Based Analysis)** to look for rapid changes in similarity. The system stores and calculates the average of last 10 similarity readings. This method helps in detecting instant pipe burst and works even before thresholds are crossed.
- **Adaptive Threshold Learning** to learn normal behavior of network and adjust to the external factors such as pipe aging, sensor defects or pressure changes.
  Adaptive Threshold = Learned Average × 0.97

- **Leak Severity Classification** based on similarity percentage helping in prioritizing alerts and actions.
  <70% -> Critical, <90% -> Moderate. <95% -> Minor

- **Leak Location Detection** helps in comparing differences between outlets. The largest difference indicates where the leak is likely located.
- **Alert on Dashboard** with Push notification of severity and location displayed.
- **Data Logging** to enable historical analysis and performance validation for further integration.

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