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Transient Leakage Estimation in Pressure-Reducing Valves: A Comparative Assessment Using RWCM and EPS Models

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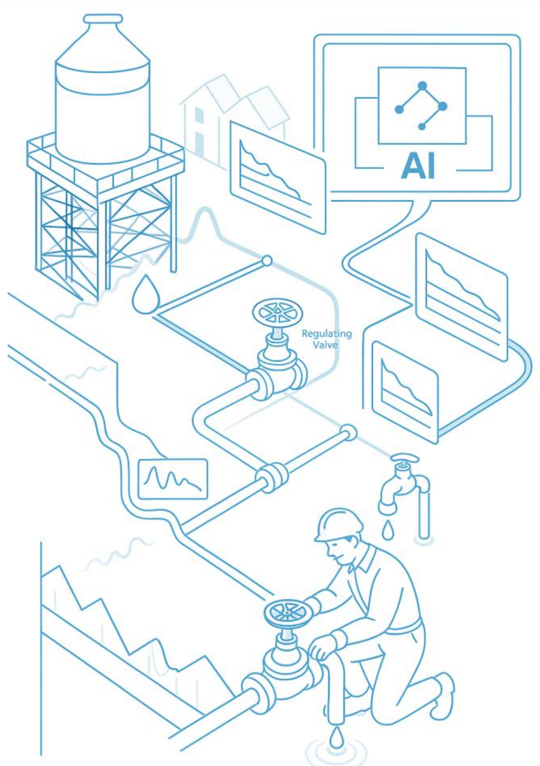
INTRODUCTION & AIM

Water distribution networks are increasingly instrumented and controlled, yet leakage remains one of the main sources of **Non-Revenue Water (NRW),** accounting for over **126 billion m³** of losses annually.Traditional **Extended Period Simulations (EPS)** assume steady-state conditions and cannot reproduce the **transient effects** that occur during valve manoeuvres, where both pressure and leakage vary dynamically.This study introduces the **Rigid Water Column Model (RWCM)** as an enhanced approach to capture those short-term dynamics and quantify their impact on operational losses.



Key objectives:

- Compare the leakage estimation capabilities of EPS and RWCM under realistic PRV operations.
- Quantify the transient variation of pressure, flow, and leakage during valve manoeuvres.
- Evaluate how these differences translate into instantaneous NRW fluctuations and operational inefficiencies.

METHOD

The study integrates hydraulic and physical leakage models within a comparative framework between the Extended Period Simulation (EPS) and the Rigid Water Column Model (RWCM).

The methodology was divided into four interconnected stages, as shown below.

1. Leak Modelling: Real water losses were represented using the **Power Leakage Equation** and the **Fixed and Variable Area Discharge (FAVAD)** method, both describing the nonlinear pressure–leakage relationship:

$$Q_l = K_f\ h^{\alpha} \text{ and } Q_l = C_d\sqrt{2g}(A_0 h^{0.5} + m h^{1.5})$$

These formulations capture the sensitivity of leak flow to pressure, pipe material, and crack geometry.

The **IWA Water Balance** was integrated to relate measured inflow (Q_i), consumption (Q_m), and leakage (Q_l) within a consistent NRW framework.

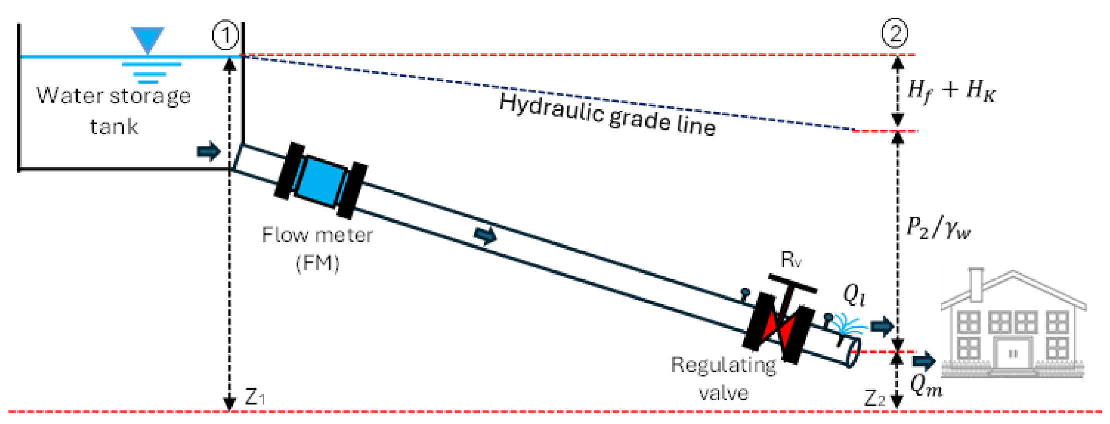


Fig. 1 – Schematic representation of a single-pipe leakage system showing pressure, head loss, and local leakage terms in the RWCM.

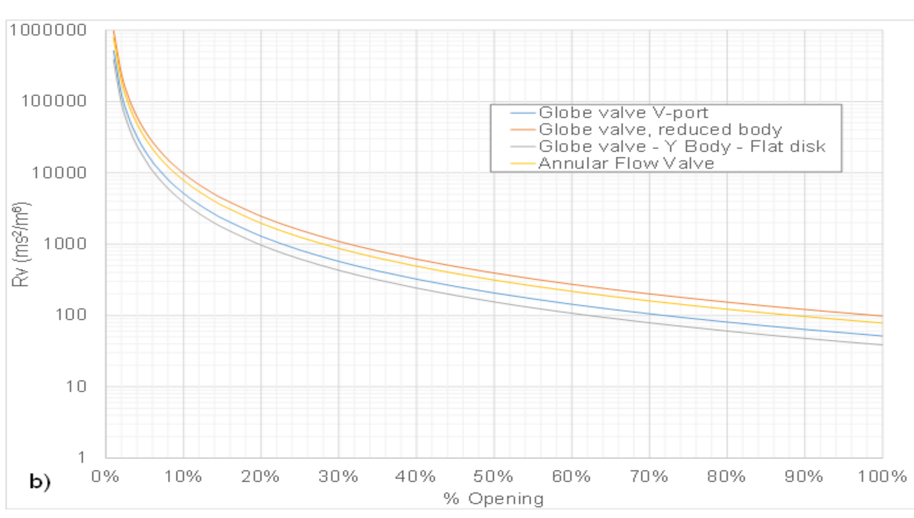
2. Valve Dynamics and Hydraulic Resistance (Stage I.3)

Eight valve types were analysed, including **globe, annular flow, Y-body, and butterfly valves**, classified as PRVs (Pressure Reducing Valves) and OVs (Operational Valves).

Valve motion was characterised by **dynamic resistance** $R_v(\tau, t)$, derived from manufacturer **Kv/Cv curves**:

$$R_v = \frac{16h(3600^2)A^2}{\pi^2 D^4 K_v^2}$$

This term quantifies the time-dependent head loss associated with valve operation and couples the physical and digital domains.



Fig, 2 - Performance curves for 12″ PRVs showing variation of hydraulic resistance $R_v$with opening degree.

3. **Mathematical Modelling**

- The **EPS** approach calculates quasi-steady states at fixed intervals (hourly or longer), underestimating transient leakage volumes.
- The **RWCM** includes the inertial term of the moving water column:

$$H_1 - H_2 = R_v Q\mid Q\mid + \sum k_m \frac{Q\mid Q\mid}{2gA^2} + \frac{L}{gA}\frac{dQ}{dt}$$

This allows accurate simulation of pressure and flow fluctuations during slow valve manoeuvres, capturing transient leakage phenomena that EPS neglects.

🧠 Key insight:

The RWCM generalises EPS — when inertia ($dQ/dt = 0$) is neglected, RWCM reduces to EPS

RESULTS & DISCUSSION

1 Extended Period Simulation (EPS) Baseline

Three leakage formulations — the **Power Leakage Equation** (α = 0.5 and 1.5) and the **FAVAD method** — were compared to establish a steady-state reference.

Friction losses were calculated via **Swamee–Jain**, using $K_f = 3.36$ *L/s/m*$^{0.5}$, $K_f = 0.18$ *L/s/m*$^{1.5}$, and $C_d = 0.868$; Results show that **α = 0.5** provides a physically consistent and operationally practical approximation for PVC pipelines; Differences between α = 1.5 and FAVAD were < 1.2 L/s, confirming negligible deviation and validating the baseline for transient analysis.

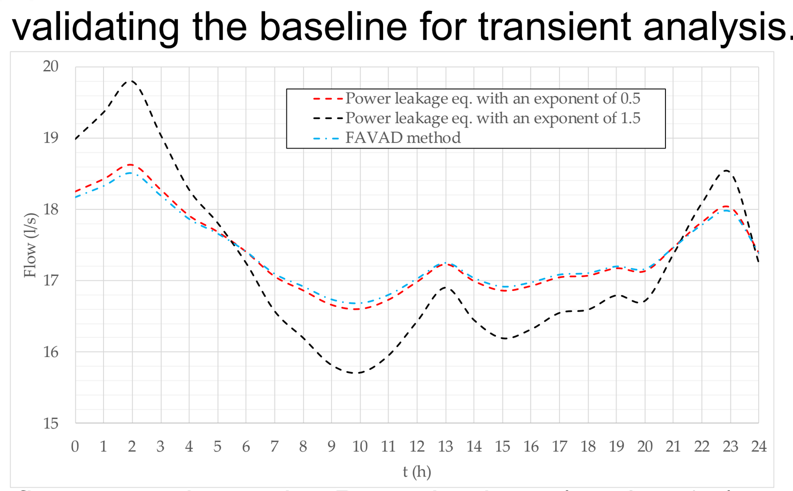


Fig. 3. Steady-state leakage flow comparison using Power Leakage (α = 0.5, 1.5) and FAVAD formulations under EPS conditions.

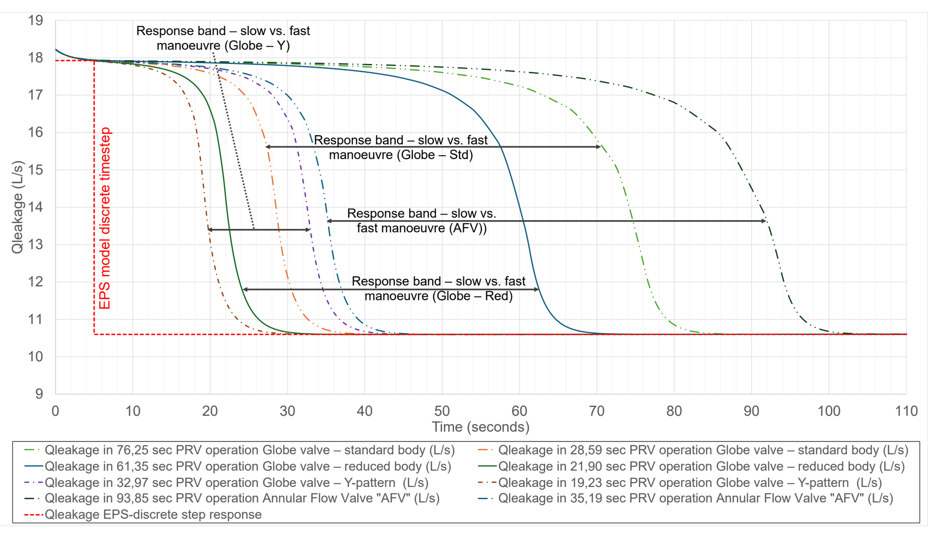
🧩 ***Interpretation:***

The near-equivalence between FAVAD and α = 0.5 confirms that simpler orifice-type formulations can represent leakage accurately in steady-state, facilitating the integration of transient models like RWCM.

2 Rigid Water Column Model (RWCM) – Transient Leakage Analysis

Transient simulations were conducted for PRV operations under dynamic conditions.

Closure times: 19–94 s (manual and actuator-driven); Pressure drop: 29.3 → 10 m;Emitter settings: $K_f = 3.36 L/s/m^{0.5}$, $\alpha = 0.5$.



Valve Type	Operation Time (s)	Leakage EPS (m³)	Leakage RWCM (m³)	Difference (m³)	NRW Baseline (%)	Instantaneous NRW (%)
Globe Std Body	76 → 29	0.94 → 0.46	1.46 → 0.66	+0.52 → +0.20	36 → 45	55 → 45
Globe Reduced	61 → 22	0.78 → 0.38	1.20 → 0.54	+0.42 → +0.16	41 → 54	54 → 42
Annular Flow	94 → 35	1.13 → 0.53	1.77 → 0.78	+0.64 → +0.25	47 → 56	56 → 47

Fig. 4. RWCM transient leakage envelopes compared to EPS discrete responses during fast and slow PRV manoeuvres.

3 Key Findings

- RWCM predicted **40–60 % higher instantaneous leakages** than EPS, confirming the **systematic underestimation of quasi-steady models**.
- Leakage magnitude and duration were highly dependent on **valve type** and **operation time**; slower manoeuvres dissipated energy gradually, reducing transient leakage peaks.
- Instantaneous **NRW increased up to 56 %** during valve operations, evidencing the hidden contribution of operational transients to total real losses.
- RWCM successfully reproduced **inertia-driven leakage dynamics** without elastic complexity, ensuring numerical stability and physical accuracy.

🧠 **Key Insight**

The RWCM reproduces dynamic leakage behaviour neglected by EPS.

By integrating inertial effects and valve motion, it provides a physically sound representation of leakage evolution — a key enabler for **Digital Twins** and **data-driven NRW optimisation**, directly contributing to **SDG 6 (Clean Water & Sanitation)**.

CONCLUSION

- The RWCM consistently predicts higher leakage volumes than EPS, revealing the systematic underestimation of transient losses in quasi-steady models.
- Leakage magnitude depends strongly on valve type and operation time; slower and well-controlled manoeuvres reduce transient leakage peaks.
- Instantaneous NRW can rise up to 56 % during PRV operations, indicating that operational transients contribute significantly to total real losses.
- Integrating RWCM with real-time data enables smarter valve control and leakage management with minimal economic investment.
- These results establish a solid foundation for Physics-Informed Machine Learning (PIML) and support SDG 6 – Clean Water and Sanitation by improving hydraulic efficiency and resilience in urban water networks.

FUTURE WORK / REFERENCES

- Experimental validation will continue in the EPM Hydraulic Sandbox, expanding to more than 120 scenarios that combine PRV and isolation valve operations under controlled transient conditions.
- Next steps include the integration of real-time monitoring, smart valve control, and Physics-Informed Machine Learning (PIML) for predictive leakage management.
- The long-term goal is to develop digital twins of distribution networks, enabling operational optimisation and contributing to SDG 6 – Clean Water and Sanitation.

•Coronado-Hernández, O. E. *et al.* (2024). *Dynamic Effects of a Regulating Valve in the Assessment of Water Leakages. Water Resour. Manag.*, 38(8), 2889–2903.
•Fuertes-Miquel, V. S., Arrieta-Pastrana, A. J., & Coronado-Hernández, O. E. (2024). *Analysing Water Leakages in Parallel Pipe Systems with Rapid Valve Maneuvers. Water*, 16(7), 926.