MODERN METHODS TO DETECT AND REDUCE WATER-LOSS - (MONITORING, MEASUREMENT, PRESSURE CONTROL, ETC.)

SAVREMENE METODE ZA OTKRIVANJE I SMANJENJE GUBITKA VODE - (PRAĆENJE, MERENJE, KONTROLA PRITISKA, ITD.)

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Abstract: Water network leakage management is crucial for conserving water resources and ensuring efficient water distribution. It involves a systematic approach to reduce water loss from pipeline systems. Key strategies include accurate leakage assessment, advanced detection techniques (like acoustic sensors and satellite imagery), and proactive control measures. These measures range from infrastructure maintenance and pressure management to rapid repair and rehabilitation programs. Effective leakage management minimizes non-revenue water, lowers operational costs, and improves the sustainability of water supply systems.
Key Words: Non-Revenue-Water, water-loss, Leakage Control, Water network management

Rezime: Upravljanje curenjem u vodovodnoj mreži je ključno za očuvanje vodnih resursa i obezbeđivanje efikasne distribucije vode. To podrazumeva sistematski pristup smanjenju gubitka vode iz cevovodnih sistema. Ključne strategije uključuju preciznu procenu curenja, napredne tehnike detekcije (kao što su akustični senzori i satelitski snimci) i proaktivne mere kontrole. Ove mere se kreću od održavanja infrastrukture i upravljanja pritiskom do brzih programa popravke i rehabilitacije. Efikasno upravljanje curenjem minimizira vodu koja ne donosi prihode, smanjuje operativne troškove i poboljšava održivost sistema vodosnabdevanja.
Ključne reči: neprihodna voda, gubitak vode, kontrola curenja, upravljanje vodovodnom mrežom

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1. The Experiences of Water Utility Firms in Water Loss Reduction Practices

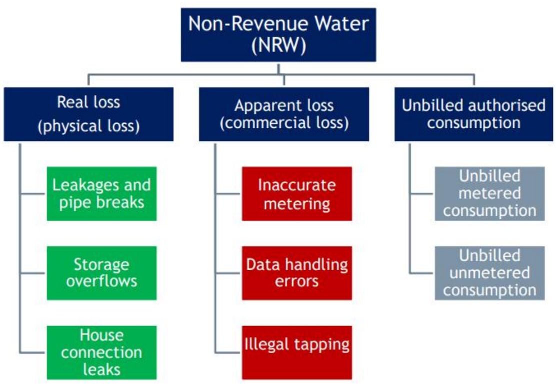
Water utility firms play a crucial role in ensuring the sustainable management of water resources. One of the significant challenges they face is water loss, which refers to the volume of water abandoned during the process of conveyance and distribution, often due to leaks, theft, or measurement inaccuracies.

Understanding the origins of water losses, recognizing their importance, and implementing systematic reduction practices are vital for improving water efficiency and service delivery.

2. Origin of Water Losses

Water losses in utility systems predominantly arise from physical leakage, commercial factors, and operational inefficiencies. Water loss is defined as the difference between water pumped into system and billed water. Water loss occurs in every water distribution system during its overall operational lifetime.

- Physical losses, also known as real losses, are primarily due to aging infrastructure, pipe deterioration, and pressure variations leading to leaks. For instance, old pipelines are more susceptible to deterioration, resulting in frequent bursts and leaks.
- Commercial losses, or apparent losses, include unauthorized consumption, meter inaccuracies, and billing issues. These often stem from illegal connections or deliberate tampering, which undermine the integrity of water billing systems.
- Additionally, operational inefficiencies such as poor maintenance, inadequate pressure management, and lack of monitoring exacerbate water losses.



Recognizing these origins helps utility firms formulate targeted strategies to mitigate each type of loss effectively.

Water loss causes not only additional operating costs but also has negative social and ecological impacts 25-50% of all distributed water globally is lost or never invoiced due to:

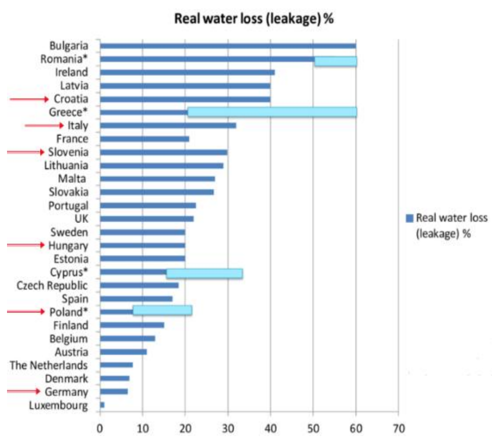
- Leakages
- Deteriorating infrastructure
- Incorrect water pressure management
- Inaccurate billing systems
- Inaccurate metering
- Illegal connections

3. Importance of Water Loss Reduction

Reducing water loss is essential for several reasons.

- Ecological aspects: it conserves a vital and often scarce resource, especially in arid and semi-arid regions where water scarcity impacts social, economic, and environmental stability.
- Economic aspects: lower water loss translates into economic benefits for utility firms by reducing the cost associated with sourcing, treating, and pumping water. It also improves financial sustainability, enabling investments in infrastructure upgrades.
- Security and Hygienic aspects of supply: minimizing water losses enhances service reliability for consumers and reduces the risk of infrastructure failure.

The aim to eliminate water loss completely, despite their environmental benefits, is economically unprofitable. Therefore, water utilities aim to limit water loss to an economically reasonable level, since further reduction would generate higher costs than profits made from water saved.



The estimated economically reasonable level of water loss is approx. 8 - 10% or 5 - 6%, depending on the water source. Despite the increase in detection methods to reduce water losses, their exact evaluation is still impossible. To reduce water losses more effectively, it is best to localise the sources which generate the biggest losses.

An estimated 80% - 100% of real water losses are caused by water leakages from pipes.

Moreover, effective loss reduction supports environmental sustainability by decreasing the energy demand associated with water production and distribution, thereby reducing greenhouse gas emissions. Therefore, water loss reduction is not merely an operational goal but a strategic component of sustainable water resource management.

Physical loss reduction – Benefits

- Saves Water
- Saves Energy and water Treatment costs
- Less Bursts
- Less Assets Maintenance/Replacement
- Better Service to clients

4. Step-by-Step Practice in Water Loss Reduction

The International Water Organisation (IWA) WLSG has developed a water audit methodology ("Water Balance") accounting for all water entering a water supply system, which has been accepted worldwide.

The IWA Water Balance provides a standardised approach using a common international terminology based on best practice for many countries. An annual water balance is normally used to assess NRW and its components.

It is a useful tool to analyse the various components of water production, storage and distribution processes. This analysis helps identify water loss problems and set priorities.

A provision for entering 95% confidence limits for all data entry items also exists to indicate the reliability of calculated NRW and leakage volumes

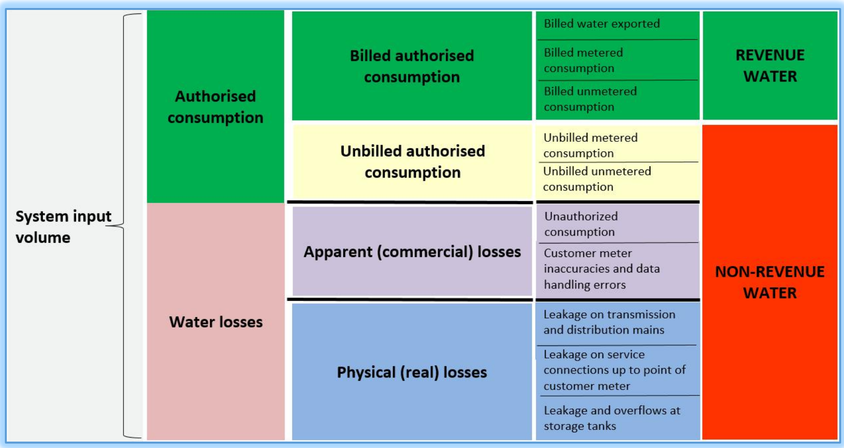
Implementing water loss reduction practices involves a systematic approach comprising several key steps.

4.1. Assessment and Data Collection:

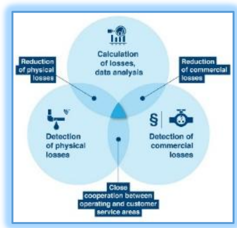
The process begins with a comprehensive assessment of the existing system. Utility firms conduct leak detection surveys, flow measurements, and data collection to establish baseline water loss levels. Installing Advanced Metering Infrastructure (AMI) and system monitoring tools provides accurate data on flow patterns and leak locations.

4.2. Water Loss Audit and Verification

Next, firms perform water audits following internationally recognized standards such as the International Water Association's (IWA) methodology. This step helps quantify real and apparent losses accurately, identify the major sources of water withdrawals, and verify the audit results through field inspections.



4.3. Prioritization and Planning:



Based on audit results, utility firms prioritize areas with high losses for intervention. Strategic planning involves setting realistic targets, allocating resources, and designing specific interventions like pipe repairs or active leak detection programs.

4.4. Implementation of Technical Measures:

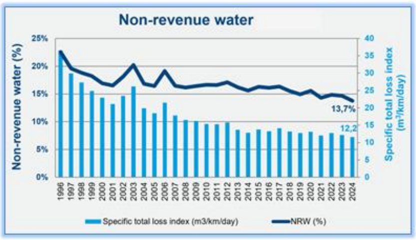
Intervention measures include replacing aging pipelines, installing pressure management systems, and utilizing leak detection technologies such as acoustic sensors and correlators. Modernization efforts also encompass improving meter accuracy and restoring unauthorized connections.

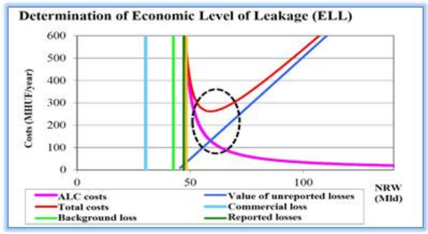
4.5. Monitoring and Evaluation:

Continuous monitoring ensures the effectiveness of implemented measures. Utility firms use key performance indicators (KPIs) such as Non-Revenue Water (NRW) ratio, leakage levels, and customer complaints to evaluate progress. Regular reporting and data analysis facilitate adaptive management.

Applied indicators:

- Non-revenue water (%, m^3)
- Total loss projected to the distribution length index (m^3/h/km)
- Total loss projected to the service connections (m^3/conn/day)
- Infrastructure leakage index (ILI)
- Economic level of leakage





4.6. Community Engagement and Capacity Building

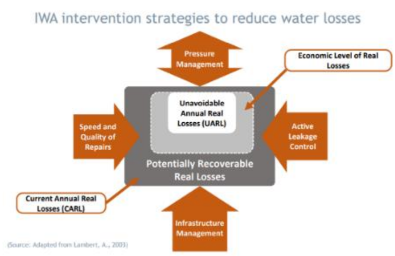
Engaging consumers through awareness campaigns reduces illegal connections and encourages water conservation. Training personnel on best practices and new technologies enhances operational efficiency.

5. Advances in Methodologies for Water Network Monitoring and Loss Reduction: The Role of Pressure Management and Active Leakage Control

Effective management of water utilities necessitates sophisticated methodologies to monitor water networks, quantify water losses, and implement strategies for their reduction.

The IWA-WLSG group has also identified four intervention strategies to reduce real water losses:

- Pressure management (PM)
- Active leakage control (ALC)
- Infrastructure and asset management
- Speed and quality of repairs



The four leakage management strate-gies interact with each other.

For example, pressure management reduces real losses since decreasing pressure directly diminishes leakage from pipelines and household connections.

A single method or a combination of different methods will constitute the most efficient and economic instrument for water loss reduction depending on the local situation.

The separation of NRW into its components should always be attempted. The components of the water balance should always be calculated and expressed as volumes (usually in m^3) over a given period of time (usually per year).

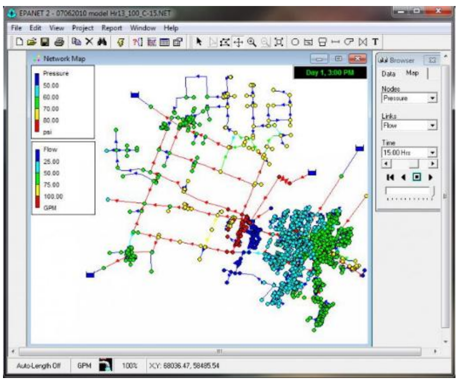
NRW expressed as a percentage of system input volume is not very useful when comparing the water loss performance between utilities. The most correct figure for NRW is m^3/h/km of pipe/day or litre/service connection/day

Recent advancements in these areas have revolutionized water utility practices, enabling more precise detection of leaks, better pressure control, and targeted interventions. This essay provides a detailed overview of state-of-the-art methodologies in water network monitoring, water loss and pressure measurements, the critical role of pressure management, and the significance of active leakage control (ALC).

6. Water Network Monitoring Methodologies

Modern water network monitoring hinges on the integration of advanced technological tools that facilitate real-time data collection and analysis. Supervisory Control and Data Acquisition (SCADA) systems form the backbone of network monitoring, allowing utilities to remotely observe flow, pressure, and operational status across entire distribution systems. By utilizing sensors embedded within the network, these systems provide continuous, accurate data streams that enable prompt detection of anomalies.

6.1. SCADA and Hydraulic modelling

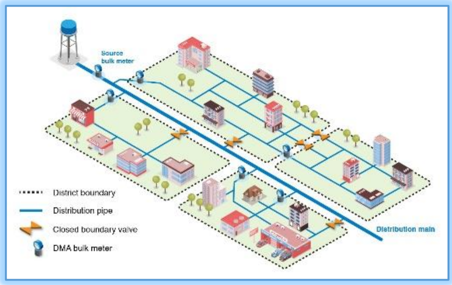


Complementary to SCADA are data-driven approaches such as „hydraulic modeling“ and digital twins. Hydraulic models simulate the behavior of the water network under various conditions, predicting flow rates and pressure distributions. When calibrated with real-time data, they serve as valuable tools for identifying system vulnerabilities and planning interventions. Digital twins—virtual replicas of physical networks—offer an even more dynamic platform, integrating GIS data, sensor inputs, and predictive analytics to optimize network operations.

6.2. Leak monitoring and localisation

The purpose is to identify the area of the network in which leakage is occurring in order to prioritise field survey.

A popular approach is to divide the network into District Metered Areas (DMAs) by shutting valves permanently and installing meters equipped with telemetry data loggers, allowing continuous monitoring of zone consumption from which an estimate of leakage can be made.



Another method, the mobile waste metering, involves valves being shut temporarily and mobile meters installed in vans and connected via flexible hoses to permanent connections in the network, being used to measure flows.

A hybrid system involves permanently installed meters with the boundary valves being closed temporarily to measure a night flow. Recent developments in software linked to hydraulic network models or artificial intelligence routines use flow and pressure data to identify new leaks and suggest hot spots where field surveys should be carried out.

In areas where it is not practical or economic to install DMAs or waste meter areas, such as in city centres or within larger DMAs, leaks may be localised using acoustic data loggers which can be installed permanently or temporarily. There are various systems on the market, some of which automatically send an alarm when a new leak occurs

Another alternative to DMAs is the use of so-called virtual DMAs (or virtual zone monitoring) which monitor flow only or combinations of flow and/or pressure and/or noise at strategic points, with software identifying any changes from the normal pattern which could indicate a new leak („multiparameter measurement“).

Within a DMA, the leak can be further localised by shutting valves inside the DMA to isolate sections of main, or by operating valves to move the boundary of the DMA temporarily, in a process known as step testing. When the section of network containing the leak is isolated the drop in flow rate into the DMA will be greater than that which would be expected due to isolating customer consumption alone

6.3. District Metered Areas (DMAs)

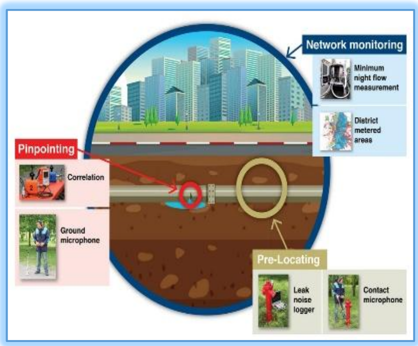
A hydraulic model can be used to calculate the optimal design of a DMA. The optimum size of a DMA depends on a number of factors including:

- The operating environment, whether it is urban, sub-urban or rural
- The configuration of the distribution network taking into account natural breaks created by rivers, major roads and open spaces
- The balance between a preference for single feed DMAs and the need to include multiple feeds for added security of supply
- The rate of rise of unreported leakage and the required economic frequency of ALC intervention
- The method of data collection and analysis

IWA proposes in its DMA Guidance Notes a zone size of 500 up to 3,000 connections. In large zones, leakage-related flow rate changes are difficult to detect.

6.4. Active Leakage Control - Leak location and pinpointing

Once a leak has been localised it can be located and pinpointed using a variety of techniques to indicate the general leak location, or to pinpoint it prior to excavation in order to conduct repairs.



As well as being used for un-reported leaks, these techniques are also used for reported leaks, around where water is present on the surface.

Location and pinpointing techniques include acoustic and non-acoustic techniques.

Advanced acoustic leak detection technologies—including correlators and listening devices - are employed for pinpointing leaks. These devices analyze the acoustic signals generated by leaks, enabling precise localization. The integration of smart meters and real-time monitoring sensors further enhances the capacity for network surveillance, providing granular data that supports proactive maintenance.

6.5. Water Loss and Pressure Measurement Methodologies

Quantifying water loss precisely is fundamental for effective management. The Water Audit Methodology, primarily standardized by the International Water Association (IWA), involves comprehensive accounting of total water inputs, authorized consumption, and unbilled or unauthorized consumption, leading to the calculation of Non-Revenue Water (NRW).

For physical water loss measurement, acoustic leak detection techniques are predominant. These utilize sensitive sensors that detect sound waves emanating from leaks, with correlators estimating leak location based on the time difference of acoustic signals. Tracer gas methods, where inert gases like sulfur hexafluoride are introduced into the system, assist in leak detection by observing their emergence at suspected leak points.

Pressure measurements are pivotal as well. Pressure loggers and sensors installed at various points within the network provide detailed pressure profiles. These measurements can be used to construct pressure gradient maps, revealing areas where pressure is excessively high-a common cause of leaks. Flow meters strategically placed within the system facilitate measurements of flow rates and help verify water balance calculations during audits.

Advanced techniques such as distributed fiber optic sensing enable continuous, high-resolution monitoring of both pressure and flow over long distances, increasing the sensitivity and accuracy of leak detection efforts. Data from these measurements inform decisions to optimize system operation.

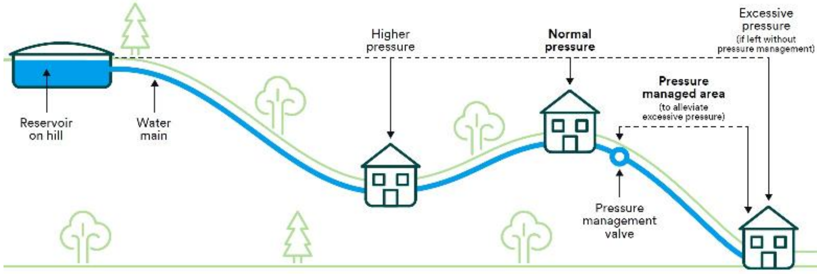
Leak detection methods		Suitability for		
		Service pipes	Distribution mains	Trunk mains
Acoustic techniques	Basic Listening stick	Yes	Yes	
	Electronic listening stick	Yes	Yes	
	Leak noise correlator		Yes	Yes
	Noise loggers		Yes	
	Multi acoustic sensor strip	Yes	Yes	
	In pipe sounding			Yes
Non-acoustic techniques	Gas injection	Yes	Yes	
	Ground penetrating radar	Yes	Yes	Yes
	Infrared photography			Yes
	In pipe hydraulic plug	Yes		

6.6. Role of Pressure Management in Water Loss Reduction

Pressure management is recognized as one of the most effective strategies for reducing physical water losses in distribution networks. Excessive pressure in pipelines increases the likelihood and severity of leaks and bursts. Conversely, controlled pressure reduction reduces stress on infrastructure, thereby lowering the frequency of leaks and the volume of water lost.

Modern pressure management involves pressure reduction valves, pressure zone management, and automated pressure control systems. These tools dynamically adjust pressure based on real-time data, maintaining optimal pressure levels tailored to system demand. The proper implementation of pressure management can lead to significant reductions in leakage, decreased pipe bursts, and extended infrastructure lifespan.

Empirical studies demonstrate that pressure management can reduce leakage by up to 20-30%, and substantially decrease energy consumption due to lower pumping requirements. Moreover, pressure management improves water service reliability and customer satisfaction, illustrating its integral role in holistic water loss control strategies.



7. The Significance of Active Leakage Control Works

Active Leakage Control (ALC) comprises proactive measures to identify, locate, and repair leaks within the water network. It encompasses techniques such as leak noise correlation, acoustic sensors, and behavioral analysis of water consumption patterns to detect anomalies indicative of leaks.

The importance of ALC lies in its targeted approach. Instead of relying solely on reactive repairs after pipe bursts or visible leaks, ALC aims for early detection of non-visible leaks, reducing water loss at its source. Regular ALC activities include systematic leak surveys, pressure monitoring, and repair campaigns which significantly diminish the volume of unaccounted-for water.

Moreover, ALC fosters a data-driven maintenance environment, where insights gleaned from monitoring tools inform strategic prioritization of infrastructure upgrades. It reduces operational costs by preventing large-scale failures, decreases environmental impact by conserving water, and enhances the economic efficiency of water utilities.

Benefits of a water loss reduction (WLR) programme for consumers and utilites

- Reduced water losses and increased revenues
- Reduced stress on local water resources
- Reduced energy consumption for abstraction, treatment and distribution
- A more stable water supply
- Better support for decision making and customer service due to new management systems
- Improved water quality due to optimised water distribution
- A strong basis for setting up a long-term rehabilitation and investment plan for the network

Overcoming barriers and creating political awareness

- Failure to successfully reduce NRW is often casued by:

    - An underestimation of the technical difficulties
    - Complexity of the NRW management
    - Lack of understanding of the potential benefits of taking actions
- Subsidised water prices may also act as barriers (costs and benefits of investing in NRW reduction will be less transparent)
- Overcoming barriers requires involvement of several stakeholders (politicans, water utilities, consumers), as well as new partnerships
- The right framework conditions can create incentives for innovation and optimisation as well as increase public awareness on the value of having a stable and efficient water supply

Barriers to WLR reduction in a water utility:

- Lack of political awareness
- Inaccurate data
- NRW is ususally not connected to overall sustainability goals
- Focus on purchasing price rather than Total Cost of Ownership
- Fear of a negative image
- Corruption leads to inefficent NRW projects

8. Conclusion

The journey of water utility firms in water loss reduction is complex but critical for sustainable water management. By understanding the origins of water losses, emphasizing their importance, and adhering to systematic, step-by-step practices, utility firms can significantly reduce non-revenue water, conserve resources, and improve service delivery. Ultimately, addressing water losses not only benefits utility operations but also contributes to broader environmental and societal goals, ensuring water security for future generations.