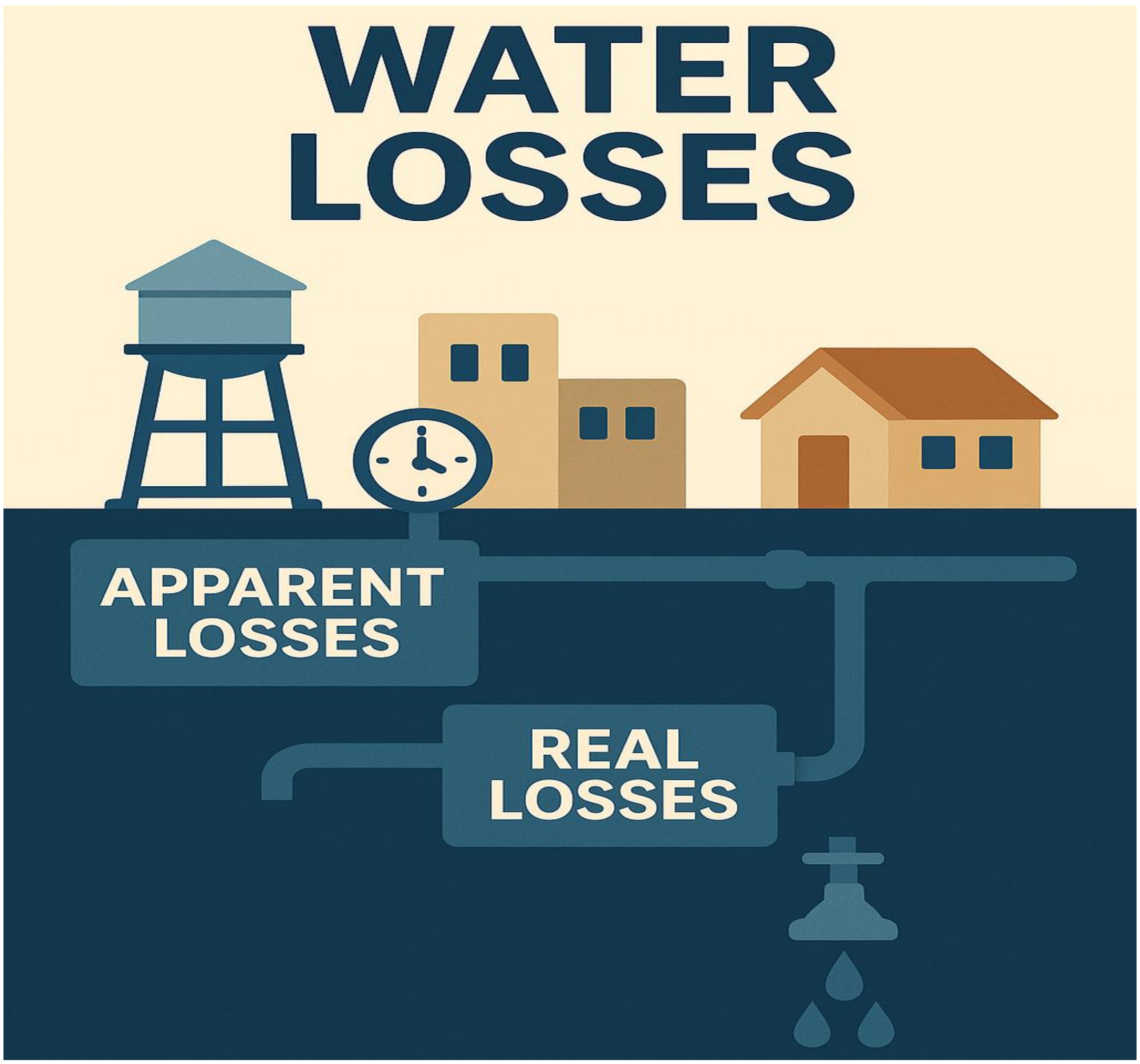
Practical Water Loss Performance Metrics & Benchmarks



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A. Key Performance Indicators (KPIs) for Water Losses in Distribution Systems

Water loss in distribution systems remains a significant challenge for utilities worldwide. To effectively monitor and manage these losses, it is essential to implement Key Performance Indicators (KPIs) that evaluate system performance, identify inefficiencies, and promote continuous improvement.

Establishing a robust performance indicator system is crucial for enhancing operational efficiency, ensuring sustainable improvements, and delivering higher-quality service. By using appropriate indicators, utilities can assess progress, monitor trends, and benchmark against best practices.

The goal of benchmarking is to identify and adopt proven methods that lead to improved performance and operational excellence. Setting realistic targets based on internationally recognized benchmarks provides a clear pathway toward achieving sustainable, long-term goals.

The most used KPIs include:

1. The IWA Water Balance

A significant contribution to reaching the point of water accountability was the establishment of the International Water Association's (IWA) Water Balance, Figure 1, that is a useful tool in analysing the various components of water production, storage and distribution. Through this analysis the **magnitude of the water loss problem is identified**, and priorities are set for rectifying the situation based on the component analysis of the Revenue and NRW components. The IWA Water Balance and **relevant KPIs** have become international standard and are promoted by many regional and national professional associations and international financing institutions around the world.

The following are simplified definitions of the Water Balance's principal components:

- ***System Input Volume***: the annual input to a defined part of the water supply system.
- ***Authorized Consumption***: the annual volume of metered and/or unmetered water taken by registered customers, the water supplier and others authorised to do so.
- ***Non-Revenue Water (NRW)***: the difference between System Input Volume and Billed Authorised Consumption.

- ***Water Losses***: the difference between System Input Volume and Authorised Consumption, consisting of Apparent (Commercial) Losses and Real (Physical) Losses.
- ***Apparent (Commercial) Losses***: consist of Unauthorized Consumption, Customer Metering Inaccuracies and Data Transfer errors.
- ***Real Losses (Physical)***: the annual volumes lost through all types of leaks, bursts on mains, and service connections and overflows from service reservoirs, up to the point of customer meter.

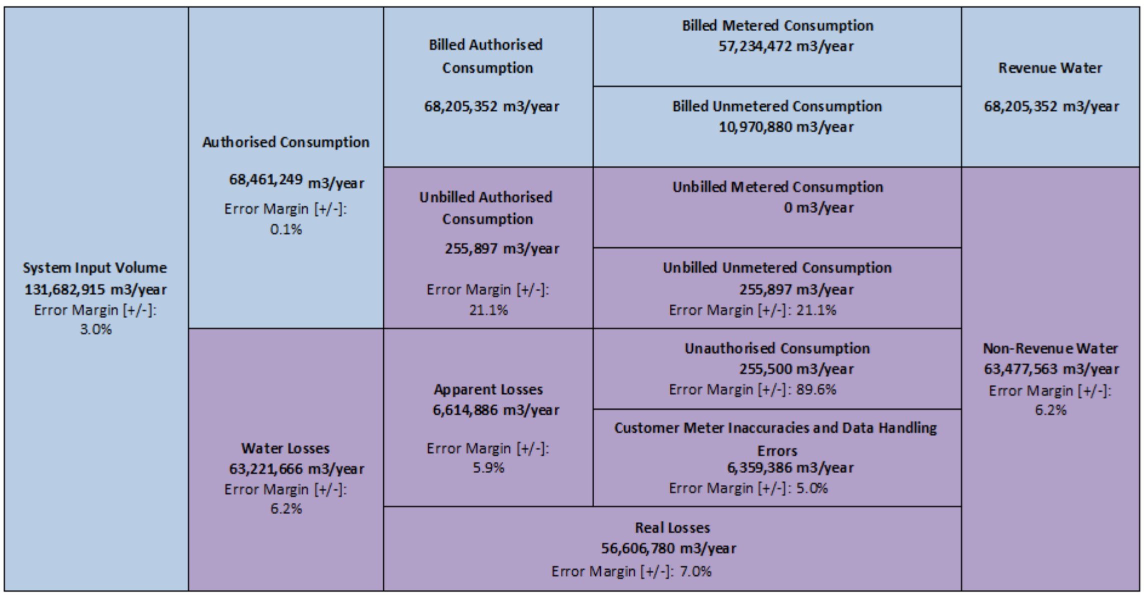

Figure 1: A standardized IWA Water Balance

2. Non-Revenue Water (NRW) (%)

- **Definition:** Percentage of the total water supplied that does not generate revenue due to physical losses (leakage) or commercial losses (theft, meter inaccuracies).
- **Formula:**

NRW (% of SIV) = [System Input Volume – Billed Authorised Consumption] / [System Input Volume (SIV)] ×100

- ***Authors' Tip:***

The use of percentage (%) to express Non-Revenue Water (NRW) is generally discouraged because it can be misleading and does not accurately reflect the actual volume of water losses or the efficiency of the system.

Comparing NRW as a percentage between systems of varying sizes can be misleading. A system with a small distribution network and lower water production may show a high NRW percentage despite losing a relatively small *volume of water. Conversely, a large system with a lower percentage may be losing a much higher volume of water.*

NRW as a percentage is affected by changes in customer consumption patterns. If water consumption decreases, the percentage of NRW may appear to increase, even if the actual volume of losses remains unchanged.

Benchmark Values

Volume-based KPIs, like real losses per service connection per day or losses per kilometer of network per day, provide a clearer picture of system performance.

Percentage NRW should be used as a basic financial indicator to indicate the volume of water which is not yielding revenue and not as an operational indicator.

3. Non-Revenue Water (l/connection/day)

An indicator which is used to better demonstrate the overall operational performance of a network, compared to the %, is volumetric based and is expressed in m^3 / service connection / day.

- **Formula:**

  NRW (l/connection/day) = [NRW volume/Number of Service Connections/No. of Days]

- ***Authors' Tip:***

  *Care must be taken that the number of **service connections (SC)** is used as opposed to the number of billed accounts. The former is not generally known whereas the latter is more commonly available and so a realistic estimate of the connection ratio (number of service connections/number of billed accounts) should be made based on knowledge of the characteristics of the network (e.g. blocks of flats, illegal connections etc.). The number of service connections is normally lower than the number of customer meters, billed accounts, since one service connection may supply more than one customer meter, Figure 2.*

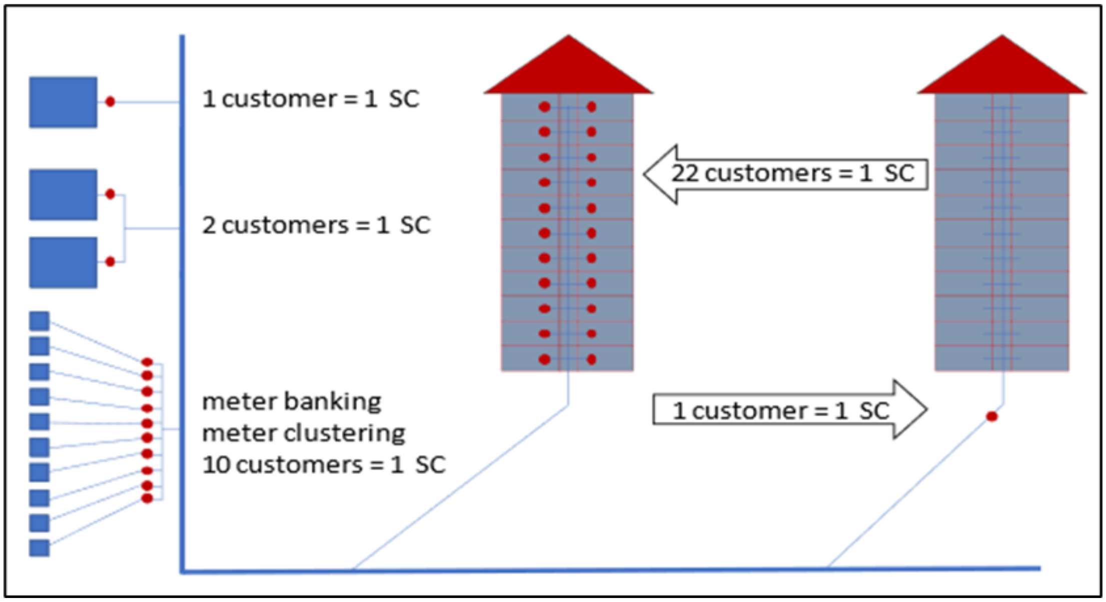

Figure 2: Service Connections vs Customer Meters
Source: WB Easy Calc software

- **Benchmark Values:**

  For high income countries:

  - Highly Efficient System: NRW <150 l/connection/day
  - Moderately Efficient System: NRW between 150–275 l/connection/day
  - Inefficient System: NRW between 275–450 l/connection/day
  - Highly Inefficient System: NRW > 450 l/connection/day

  For Low- and Middle-income countries:

  - Highly Efficient System: NRW <300 l/connection/day
  - Moderately Efficient System: NRW between 300–550 l/connection/day
  - Inefficient System: NRW between 550–900 l/connection/day
  - Highly Inefficient System: NRW > 900 l/connection/day

  The above values are based on the International NRW Assessment Matric, Table 2

4. Infrastructure Leakage Index (ILI)

- **Definition:** Ratio of the current annual real losses (CARL) to the unavoidable annual real losses (UARL).

- **Formula:**

  ILI=CARL/UARL

  CARL= Current Annual Real Losses

  UARL= Unavoidable Annual Real Losses

- ***Authors' Tip:***

  Strictly, the ILI is a measure of leakage detection efficiency and effectiveness at the current pressure and therefore the ILI can be used for the technical performance comparison of different systems but only when all justifiable pressure management is completed.

- **Benchmark Values:**

  For high income countries:

  - Highly Efficient System: ILI ≤ 2
  - Moderately Efficient System: ILI between 2–4
  - Inefficient System: ILI between 4–8
  - Highly Inefficient System: ILI > 8

  For Low- and Middle-income countries:

  - Highly Efficient System: ILI ≤ 4
  - Moderately Efficient System: ILI between 4–8
  - Inefficient System: ILI between 8–16
  - Highly Inefficient System: ILI > 16

  The above values are based on the Real Losses Assessment Matric, Table 1.

5. Real Losses per Service Connection per Day (l/connection/day)

- **Definition:** Volume of water lost due to leaks from a distribution network (Real Losses) expressed per service connection per day.

- **Formula:**

  Real Losses = Real Losses/Number of Service Connections/No. of Days

  Note: Choose this KPI if the service connection density is >20/km. With lower densities it would be advisable to use m3/km of mains/day, **Real Losses per Service Connection per Day (m^3/connection/day)***,*

- **Benchmark Values:**

  Again, an estimate of the true number of service connections should be used (see Non-Revenue Water (l/connection/day)).

  For high income countries:

  - Highly Efficient System: NRW <100 l/connection/day
  - Moderately Efficient System: NRW between 100–200 l/connection/day
  - Inefficient System: NRW between 200–350 l/connection/day
  - Highly Inefficient System: NRW > 350 l/connection/day

  For Low- and Middle-income countries:

  - Highly Efficient System: NRW <200 l/connection/day
  - Moderately Efficient System: NRW between 200–400 l/connection/day
  - Inefficient System: NRW between 400–700 l/connection/day
  - Highly Inefficient System: NRW > 700 l/connection/day

6. Real Losses per Service Connection per Day (m^3/connection/day)

Where the connection density is less than 20/km, the Real Loss per Kilometer of Network per Day (m^3/km/day) is best used

- **Definition**:

  Real losses expressed as volume of water lost per kilometer of the pipeline per day.

- **Benchmark Values**:

  Indicative benchmarks for best and poorly managed distribution systems

  - Best Practice: < 5 m^3/km/day for efficient systems
  - Moderately Efficient Systems: 5 – 20 m^3/km/day
  - Poorly Managed Systems: > 20 m^3/km/day

7. Apparent Losses per Service Connection per Day (l/connection/day)

- **Definition:** Volume of water lost due to unauthorized consumption, customer meter inaccuracies and billing errors (Apparent Losses), expressed as loss per service connection per day.

- **Formula:**

  Apparent Losses (l/connection/day) = [Apparent Losses / Number of Service Connections/No. of Days]

- **Benchmark Values:**

  Again, an estimate of the number of service connections should be used (see comment under Non-Revenue Water (l/connection/day)).

  For high income countries:
  - Highly Efficient System: Apparent Losses <50 l/connection/day
  - Moderately Efficient System: Apparent Losses between 50–75 l/connection/day
  - Inefficient System: Apparent Losses between 75–100 l/connection/day
  - Highly Inefficient System: Apparent Losses > 100 l/connection/day

  For Low- and Middle-income countries:
  - Highly Efficient System: Apparent Losses <100 l/connection/day
  - Moderately Efficient System: Apparent Losses between 100–150 l/connection/day
  - Inefficient System: Apparent Losses between 150–200 l/connection/day
  - Highly Inefficient System: Apparent Losses > 200 l/connection/day

8. Apparent Losses (% of total consumption)

A simplified indicator that may be used to provide an overall efficiency of the NRW financial stream is the percentage of the apparent losses compared to the total consumption.

Indicative benchmarks for best and poorly managed distribution systems

- Best Practice: < 5% of Total Consumption for efficient systems
- Poorly Managed Systems: > 10 % of Total Consumption

B. Acceptable Benchmark Values for Water Losses[1]

1. Main Pipes

Internationally accepted reporting value:

- **Definition:** The number of leaks on the transmission and distribution network (main pipes).

[1] Lambert et al, A Review of Performance Indicators for Real Losses from Water Supply Systems, AQUA, December 1999

- **Formula:**

  Number of leaks on main pipes / 100 km length of mains = Total number of leaks/100km of mains

- **Benchmark Values:**

  A benchmark for main pipelines which is internationally accepted as representing a system in a very good operational condition is of the order of **13 leaks per 100km of mains**.

2. Service Connections

Internationally accepted reporting value:

- **Definition:** The number of leaks on the Service Connections.
- **Formula:**

  Number of leaks on Service Connections / 1000 service connections.

- **Benchmark Values:**

  Again, an estimate of the number of service connections should be used (see comment under Non-Revenue Water (l/connection/day).

  A benchmark which is internationally accepted as representing a system in very good operational condition is of the order of **3 leaks per 1,000 service connections.**

- ***Authors' Tip:***

  *International benchmarks vary by region, system condition, and regulatory requirements. However, the best practices from a leading group of water loss professionals, namely the **Water Loss Specialist Group**, of the International Water Association (IWA), provide useful guidelines.*

C. Intermittent Water Supply

Intermittent Water Supply (IWS) refers to a water distribution system where water is provided to consumers for limited hours each day or on specific days of the week. It is common in regions facing water scarcity, infrastructure limitations, or high demand.

While IWS helps manage shortages, in the short term, it can lead to water quality issues, pipe damage, and inequitable access. Sustainable solutions focus on improving infrastructure, demand management, and transitioning to continuous supply systems.

In the case of systems with intermittent water supply, the flow and pressure measurements need to be considered during periods when the system is pressurized, w.s.p., although even then customer tanks may still be filled and therefore the measurements must be interpreted with care.

Reducing NRW in IWS networks is crucial for improving efficiency and sustainability.

1. Need for a Standardised Approach[2]

It is well known that expressing water losses (or NRW) in percentage of system input is misleading in the best case and doesn't work at all in IWS situation (no wonder that % water loss can be low if a utility has only a few hours water supply per day).

Water loss performance indicators, for example physical losses in litres/connection/day, always need to be adjusted to continuous supply (the acronym used is "w.s.p." – referring to "when the system is pressurized").

For example:

a system with 10,000 service connections and IWS of 4h/day has physical losses of 3,000 m3/d the correct performance indicator would be:

- 3,000 m3/d /10,000 connections = 0.3 m3/conn/d = 300 l/conn/d
- = [300 l/conn/d / 4h] x 24h = **1,800 l/conn/d** (w.s.p.)

Only with this adjusted indicator (and the average operating pressure) can the level of water loss be understood, and the transformation from IWS to 24x7 planned.

In summary, the IWA water balance methodology and the IWA water loss PIs can also be used in IWS systems – **IF the supply time is properly considered**.

Once the water loss situation is properly understood, forecasts can be made how much water will be required to supply the network in its present condition on a 24x7 basis and how much will be needed after network rehabilitation.

Transitioning from IWS to 24x7 will be different depending on the type of IWS:

- If the system was designed for IWS (like most in South Asia) one needs to start with pressurizing the system 24x7 on a zone by zone or DMA by DMA basis starting from the zone or DMA closer to the water source.

[2] Charalambous B. & Liemberger R., Dealing with the complex Interrelation of Intermittent Supply and Water Losses, IWA WWC&E Brisbane, September 2016

- In systems where IWS was not planned but became a reality in fringe areas of the system, water loss reduction (again, zone by zone) must be started in the part of the network with best supply and highest water losses and the water saved can then be pushed to the poorly supplied areas.

2. Water Loss Reduction in IWS Systems

Calculating water loss reduction in IWS systems is challenging due to irregular flow patterns, fluctuating pressures, and varying supply durations. Traditional NRW assessment methods rely on continuous supply data, which is often unavailable in IWS networks.

Inaccurate metering, unauthorized connections, and storage at the household level further complicate measurement. Additionally, leakages may only occur during supply hours, making detection intermittent. Advanced modeling, real-time monitoring, and specialised NRW assessment approaches are required to accurately quantify any water loss reductions achieved.

A practical and transparent methodology that has been developed and is currently being applied with success on systems with IWS to calculate the water loss achievement is based on the concept of a **rolling baseline** which takes into consideration differences in the supply time, pressures, consumption, etc.

This concept considers the water loss reduction for a period equal to the billing cycle and uses the consumption data recorded in the utility's billing system. If the water loss reduction activities extend beyond a single billing cycle the new baseline for the next billing cycle is the water loss at the end of the previous billing cycle, thus the **rolling baseline concept**[3].

Example calculation of a rolling baseline water loss reduction achievement:

- 1st Billing Period (BP1)
  - System Input Volume
    - System Input Reading at the start of BP1 (m3)
    - System Input Reading at the end of BP1 (m3)
    - System Input Volume during BP1 (IV1) (m3/day)
  - Consumption
    - Consumption Readings at the start of BP1 (m3)
    - Consumption Readings at the end of BP1 (m3)
    - Consumption during BP1 CV1 (m3/day)
  - Supply Time
    - Average Supply time during BP1 ST1 (hours/day)

[3] Charalambous B., Hamilton S. & Dalton J., Rolling Baseline Concept in IWS System, IWA WWC&E, Bangkok, 2025

Note: To be obtained from online measurement records or manually kept records

- Average Operating Pressure
  - Average Pressure during BP1 Pav1 (m)
    Note: To be obtained from online measurement records at the average zone point

- 2nd Billing Period (BP2)
  - System Input Volume
    - System Input Reading at the end of BP1 (m3)
    - System Input Reading at the end of BP2 (m3)
    - System Input Volume during BP2(IV2) (m3/day)
  - Consumption
    - Consumption Readings at the end of BP1 (m3)
    - Consumption Readings at the end of BP2 (m3)
    - Average Consumption during BP2(CV2) (m3/day)
  - Supply Time
    - Average Supply time during BP2 (ST2) (hours/day)
      Note: To be obtained from online measurement records or manually kept records
  - Average Operating Pressure
    - Average Pressure during BP2 (Pav2) (m)
      Note: To be obtained from online measurement records at the average zone point
- 3rd Billing Period (BP3)
  - System Input Volume
    - System Input Reading at the end of BP2 (m3)
    - System Input Reading at the end of BP3 (m3)
    - System Input Volume during BP3 (IV3) (m3/day)
  - Consumption
    - Consumption Readings at the end of BP2 (m3)
    - Consumption Readings at the end of BP3 (m3)
    - Average Consumption during BP3 (CV3) (m3/day)
  - Supply Time
    - Average Supply time during BP3(ST3) (hours/day)
      Note: To be obtained from online measurement records or manually kept records
  - Average Operating Pressure
    - Average Pressure during BP3 (Pav3) (m)
      Note: To be obtained from online measurement records at the average zone point

The above values and data are used in the Rolling Baseline Concept to calculate the Water Loss Reduction achievement during the periods under consideration.

3. Rolling Baseline Calculations

The rolling baseline operates on the principle that a new baseline is established at the beginning of each billing cycle. This dynamic approach allows for real-time adjustments, ensuring that fluctuations in supply duration and pressure are accounted for within each cycle. One of its key advantages is its ability to adapt to changing supply conditions, minimizing inaccuracies in water loss assessment. By continuously updating the baseline, this method enhances the reliability of consumption analysis and improves the detection of anomalies, ultimately leading to more effective water management.

1. **Water Loss Reduction (WLR) Calculations**
   - **First Billing Period (WLRBP1) (m3/day) =** Input Volume during BP1(IV1) - Consumption during BP1(CV1)

     WLRBP1 (m3/day) = IV1-CV1 at ST1 and Pav1

     Adjusting water loss reduction to the supply time and pressure:

     WLRBP1adjusted (m3/day) = (WLRBP1) *(24hrs/ST1hrs) at Pav1

   - **Second Billing Period (WLRBP2) (m3/day) =** Input Volume during BP2(IV2) - Consumption during BP2(CV2)

     WLRBP2 (m3/day) = IV2-CV2 at ST2 and Pav2

     Adjusting water loss reduction to the supply time and pressure:

     WLRBP2adjusted (m3/day) = (WLRBP2) *(24hrs/ST2hrs) *(Pav2/Pav1) ^{N1}

     Notes:

     - Apply pressure correction factor if the average pressure variation is more than +/- 1m
     - For N1, use the value of 1 in the absence of a more reliable value for the system under consideration

   - **Third Billing Period (WLRBP3) (m3/day) =** Input Volume during BP3(IV3) - Consumption during BP3(CV3)

     WLRBP3 (m3/day) = IV3-CV3 at ST3 and Pav3

     Adjusting water loss reduction to the supply time and pressure:

     WLRBP3adjusted (m3/day) = (WLRBP3) *(24hrs/ST3hrs) *(Pav3/Pav2) ^{N1}

- .... and so on for following billing periods....

Authors' Tips:

- Apply pressure correction factor if the average pressure variation is more than +/- 1m
- For N1, use the value of 1 in the absence of a more reliable value for the system under consideration

2. **Aggregate Water Loss Reduction**

   The total water loss reduction over the evaluation period will be the cumulative sum of the reductions achieved in each individual billing period. By aggregating these incremental improvements, a more accurate and comprehensive assessment of overall water savings is obtained, ensuring a clear measure of efficiency gains throughout the period.

   WLRtotal (m3/day) = WLRBP1+ WLRBP2+ WLRBP3+ .... WLRBPn

D. Other KPIs for Water Loss Control

Authors' Tips:

1. ***Average Pressure Management (m)***
   - *Managing pressure reduces leakage and burst frequencies.*
   - *Optimal range: 20–50 meters of head.*
2. ***Leakage Detection and Repair Time (hours/days)***
   - *Lower response time improves overall system efficiency.*
   - *Best practice: Average repair time to be within 24–48 hours.*
3. ***Customer Metering Accuracy (%)***
   - *Higher metering efficiency reduces apparent losses.*
   - *Revenue meter accuracy: 2% - 5%.*

E. Conclusion and Recommendations

1. Reducing water losses requires a combination of **effective monitoring**, appropriate **customer meter management**, **leakage control** and **pressure management.**
2. **Benchmarking against international standards** helps identify areas for improvement and adopt best practices. By implementing these KPIs and benchmarking regularly, utilities can enhance water distribution efficiency, reduce costs, and ensure sustainable water supply.
3. Water loss indicators and benchmark values are **dynamic and evolving**, influenced by advancements in technology, improved methodologies, and practical field experience. The authors are committed to keeping this paper **current and relevant**, and will provide updates as **new, validated, and proven benchmarks** become available through ongoing research and industry practice.
4. The authors welcome comments, thoughts, suggestions, and contributions from readers. Your **practical experience** and input are invaluable in helping **refine and advance** the understanding of effective water loss performance metrics and benchmarks.
5. The authors would like to clarify that this publication, shared with the broader water loss community, **is not intended to pre-empt or replace** the outcomes of any ongoing efforts currently being undertaken by the IWA Water Loss Specialist Group (WLSG) KPI Initiative.
6. The authors were motivated to compile this publication following **repeated discussions and inquiries** asking: *"Is there a simple summary of the most commonly used NRW key indicators and benchmarks?"* Rather than directing colleagues to search through **lengthy and complex publications**, we felt it would be helpful to create a **concise and accessible reference** for anyone seeking **practical, proven KPIs and measurable targets** in the field of water loss management.

Appendix – IWA Assessment Matrices

Table 1: Real Loss Assessment Matrix

Technical Performance Category		ILI	Real Losses in litres/service connection/day when the system is pressurized at an average pressure of:				
			10 m	20 m	30 m	40 m	50 m
High Income Countries	A1	<1.5		< 25	<40	<50	<60
	A2	1.5–2		25-50	40-75	50-100	60-125
	B	2–4		50–100	75–150	100–200	125–250
	C	4–8		100–200	150–300	200–400	250–500
	D	> 8		> 200	> 300	> 400	> 500
Low and Middle Income Countries	A1	<2	<25	<50	<75	<100	<125
	A2	2–4	25-50	50-100	75-150	100-200	125-250
	B	4–8	50–100	100–200	150–300	200–400	250–500
	C	8–16	100–200	200–400	300–600	400–800	500–1,000
	D	> 16	> 200	> 400	> 600	> 800	> 1,000

Technical Performance Categories are defined as follows:

Category A1: *World* class leakage management performance; the potential for physical loss reductions is small unless there is still potential for pressure reductions.

Category A2: *Further* water loss reduction may be uneconomic unless there are shortages; careful analysis needed to identify cost-effective improvement.

Category B: *Potential* for marked improvements; consider pressure management, better active leakage control practices and better network maintenance.

Category C: Poor leakage record. Tolerable only if water is plentiful and cheap; even then, analyze level and nature of leakage and intensify leakage reduction efforts.

Category D: *Highly* inefficient; leakage reduction programs imperative and high priority.

Table 2: International NRW Assessment Matrix

NRW Management Performance Category		NRW in litres/service connection/day when the system is pressurized at an average pressure of:				
		10 m	20 m	30 m	40 m	50 m
High Income Countries	A1		< 50	<65	<75	<85
	A2		50-100	65-125	75-150	85-175
	B		100-350	125–250	150–300	175–350
	C		200–200	250–450	300–550	350–650
	D		> 350	> 450	> 550	> 650
Low and Middle Income Countries	A1	<55	<80	<105	<130	<155
	A2	55-110	80-160	105-210	130-260	155-310
	B	110-220	160–320	210–420	260–520	310–620
	C	220-400	320–600	420–800	520–1000	620–1,200
	D	> 400	> 600	> 800	> 1000	> 1,200

NRW Management Performance Categories are defined as follows:

Category A1: World class NRW management performance; the potential for further NRW reductions is small unless there is still potential for pressure reductions or the accuracy improvement of large customer meters.

Category A2: Further NRW reduction may be uneconomic unless there are water shortages or very high-water tariffs; a detailed water audit is required to identify cost-effective improvements.

Category B: Potential for marked improvements; establish a water balance to quantify the components of NRW; consider pressure management, better active leakage control practices and better network maintenance; improve customer meter management, review meter reading, data handling and billing processes and identify improvement potential.

Category C: Poor NRW record; tolerable only if water is plentiful and cheap; even then, analyze level and causes of NRW and intensify NRW reduction efforts.

Category D: Highly inefficient; a comprehensive NRW reduction program is imperative and of high priority.