Water Loss 2024
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Challenges in applying the Infrastructure Leakage Index as a water loss indicator to water utilities in Rheinland-Pfalz, Germany

WaterLoss 2024

San Sebastián / 15th of April 2024 / Daniel Zipperer & Joerg Koelbl

Context of the study – The Rheinland-Pfalz Municipal Water Sector Benchmarking programme

Location of the State of Rheinland-Pfalz within Germany

- Conducted by aquabench, a subsidiary of Germany's largest municipal water and wastewater companies.
- Participant-driven assessments, ongoing since 2004.
- Presenting findings from the 6th benchmarking cycle in this study, utilizing data from the financial year 2019.
- Key focus areas since 2004 include:
    - Tariff structuring and transparency
    - Emergency preparedness planning
    - Corporate sustainability
    - And more, with a distinctive yet variable scope.

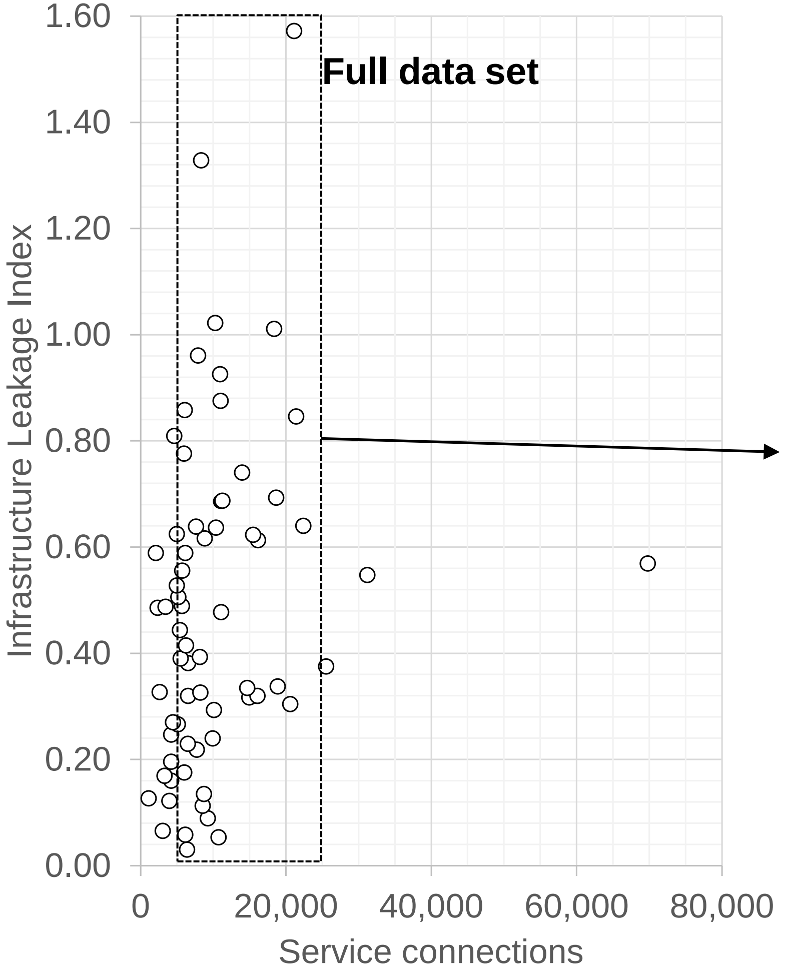
Source: Wikipedia

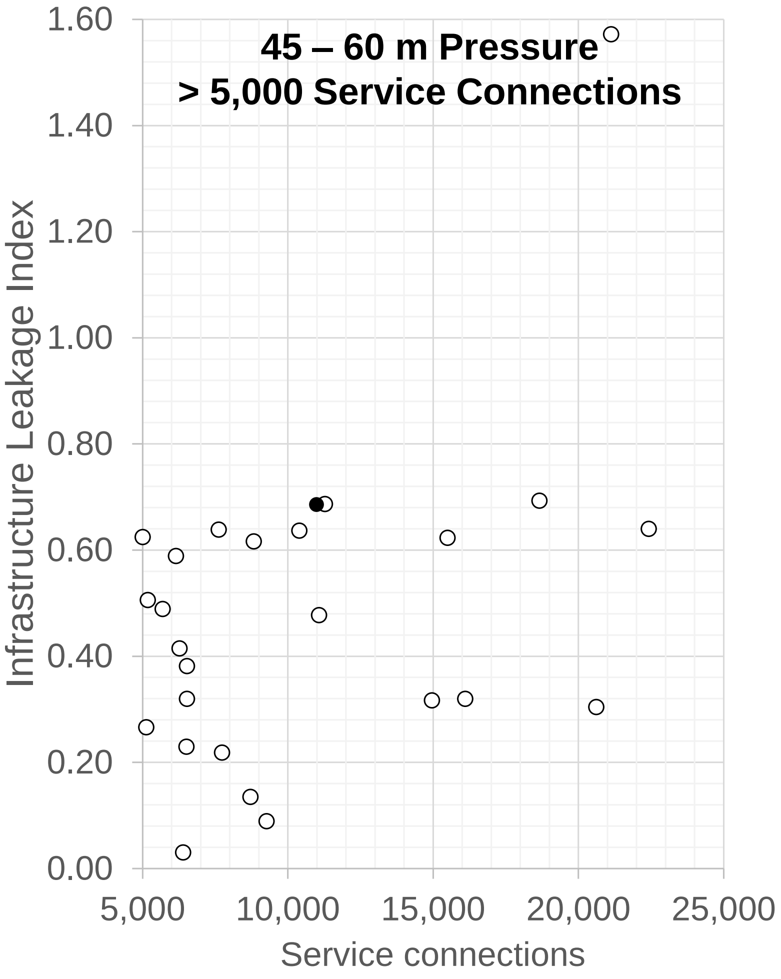
Some basic descriptive statistics of the data set:

Number of water supply systems	67 (200)
Service connections	1,100 – 70,000
Mains length	30 – 1,300 km
Service connection density	20 – 130 /km
Average service pressure	30 – 75 m
Population served	2,850 – 230,000
Authorized Consumption	150,000 – 13.2 Mio. m^3
Total personnel	(0) – 100 FTE
Average mains age	20 – 60 years
Customer meter replacement period	6 years
Proportion of transmission mains	0 % – 50 %

Starting Point: Most ILIs are below the Threshold Value of 1 – How Come?

ILIs Against Number of Service Connections for 67 Water Utilities (Left Figure) and for a Subset Focusing on Average Service Pressure Between 45 and 60 m and More Than 5,000 Service Connections (Right Figure)





Observations:

- Calculated ILIs are surprisingly low:

ILI ≥ 1:	4 (6%)
0.8 ≤ ILI < 1:	6 (9%)
0.6 ≤ ILI < 0.8:	12 (17.9%)
ILI < 0.6:	45 (67.2 %)

- Even if the limits of application of UARL Equation (Lambert, 2020) are applied in the figure to the right, this does not change:

ILI ≥ 1:	1 (3.8%)
0.8 ≤ ILI < 1:	0
0.6 ≤ ILI < 0.8:	9 (34.6%)
ILI < 0.6:	16 (61.5 %)

Potential reasons – manifold

Reasons for the Low ILI Values of the Rheinland-Pfalz Water Utilities, Aside from the Generally High Standards of Maintenance, as well as the Construction and Installation Quality.

$$ILI = \frac{CARL}{UARL}$$

- **A**: Generally favorable conditions that facilitate effective water loss management.
- **B**: Overvaluation of the Unavoidable Annual Real Losses (UARL) due to insufficient knowledge of operational data or other factors.
- **C**: Undervaluation of the current annual real loss volume (CARL).

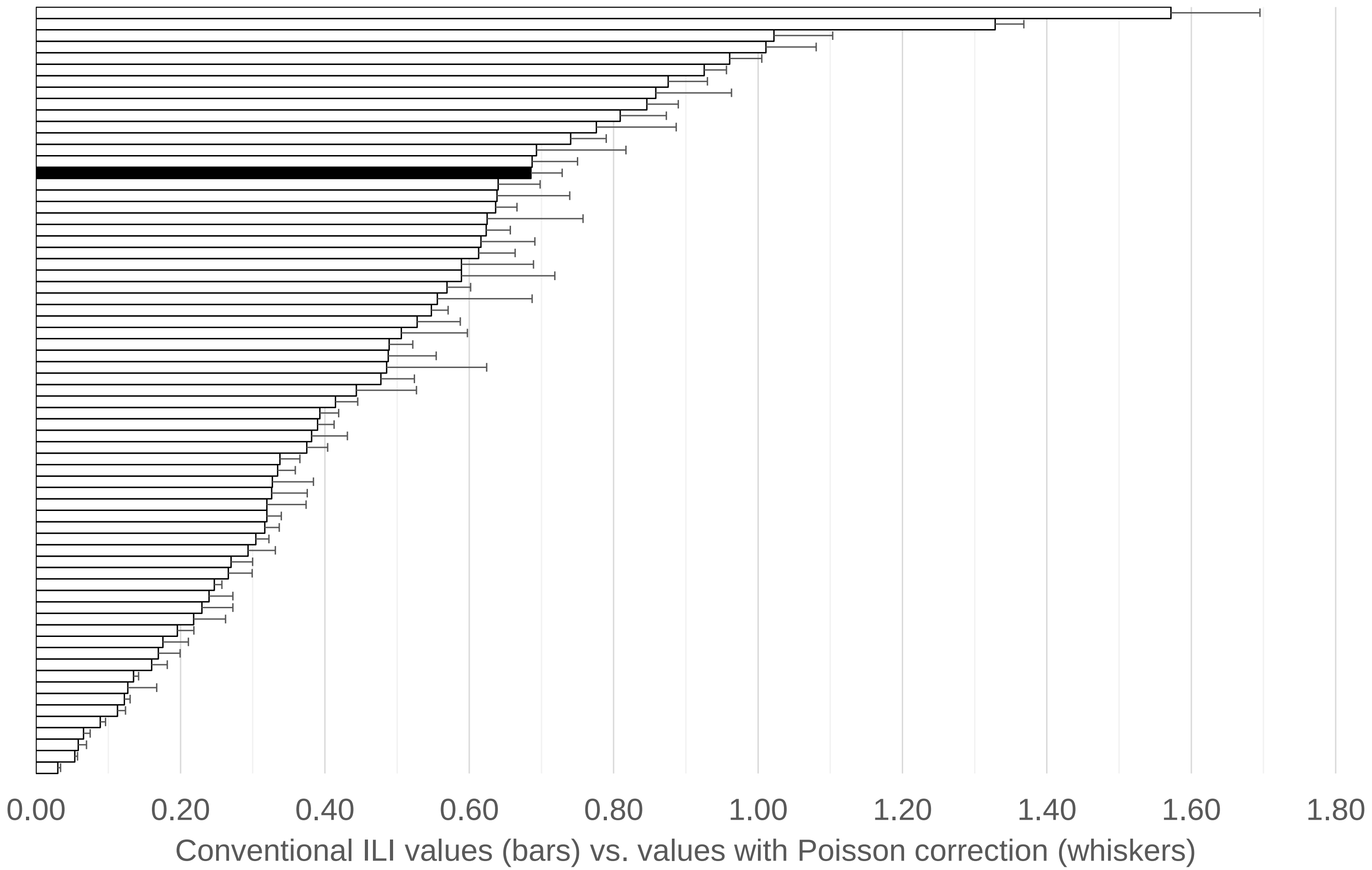
A1: *Small water supply systems* where leaks are detected rapidly.
A2: *Favorable soil conditions* where only a minority of leaks remain undetected.
A3: High proportions of *rigid pipe materials*.
A4: *Lower supply pressure* than the value used in the standard UARL calculation.
A5: New water supply systems that exhibit a *lower burst frequency* than assumed in the standard UARL calculation.

B1: Misjudgment in *estimating the average service pressure*.
B2: Misjudgment in *determining the length of service connections*, or through *estimating the length of the transmission and distribution network* if the system has not been fully digitalized.
B3: The presence of a *larger proportion of transmission mains* with lower failure rates

C1: Systematic *under-registration by intake or district meters*, caused by inherent measurement inaccuracies.
C2: *Boundary errors* when the reading period does not align with the chosen observation period.
C3: *Overestimation of unmeasured and unbilled consumption* in the water balance, as well as *misjudgment of apparent losses*.

As the Majority of the Utilities Operate Rather Small Water Supply Systems and Experience Lower Failure Rates, a Poisson Distribution Is Better Suited to Estimate Failure Rates for the UARL Calculation.

A1: Effect of Customizing the UARL Equation with Average Failures Derived from Poisson Frequencies Distribution



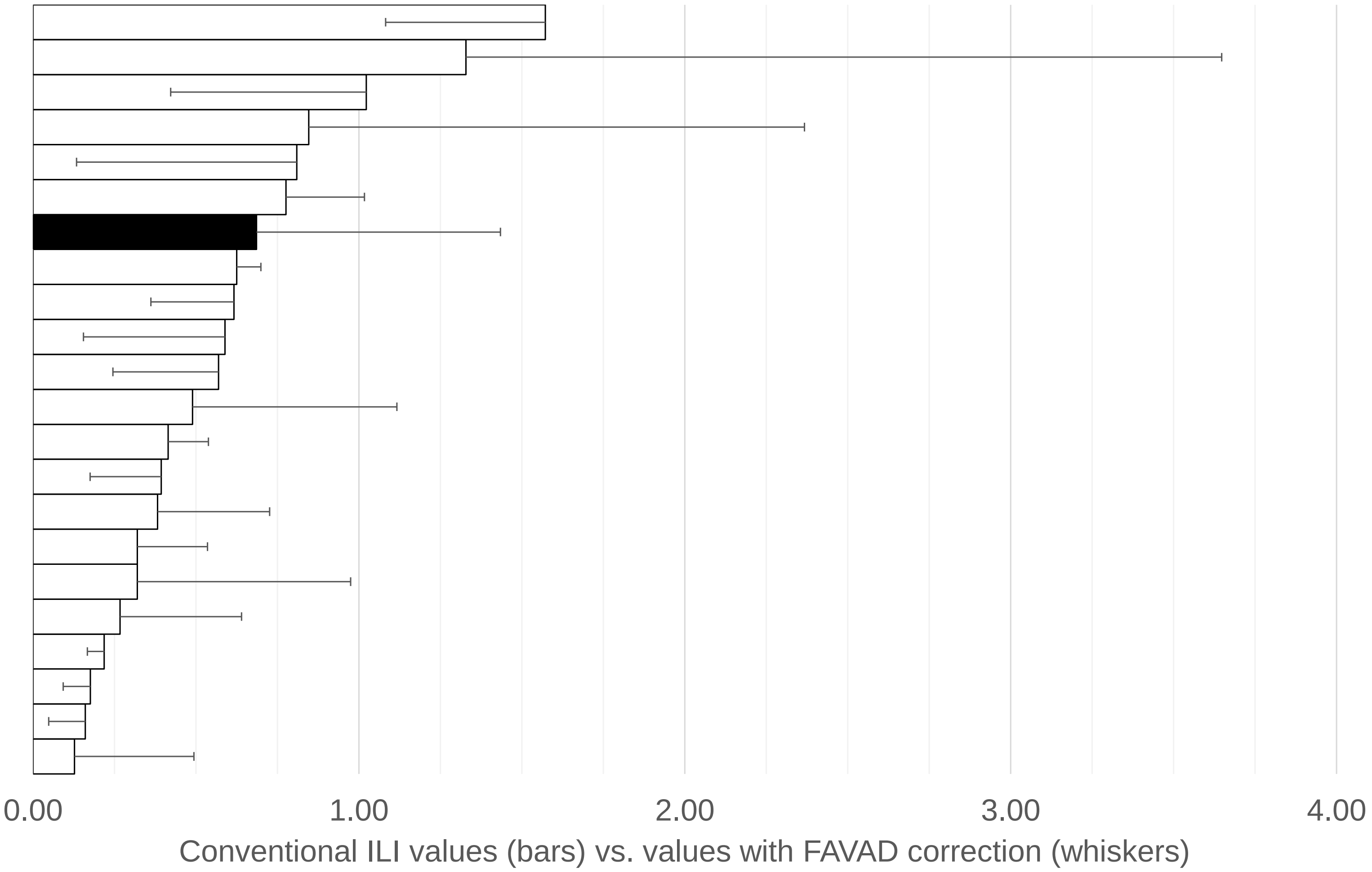
Observations

- The majority of utilities report failure rates lower than those assumed in the standard UARL equation: 75% for mains and 90% for service connections.
- All ILI values are increased compared to the standard UARL calculation.
- ILI values are adjusted within a range of 3.00% to 31.7%.

Further Reading:
For more on the issue, refer to Kölbl & Lambert (2015, 2019) and Lambert (2020).

Depending on the proportion of flexible piping materials, the corrected ILI values are either below or above the resulting values from the standard calculation.

A3: Impact of Customizing the UARL Equation Based on Pipe Materials and FAVAD



$$UARL = (6.57\,L_M + 0.256\,n_{Sc} + 9.13\,L_{Sc})\,p^{N1}$$

Based on the Converted UARL formula in accordance with DVGW W392 standard

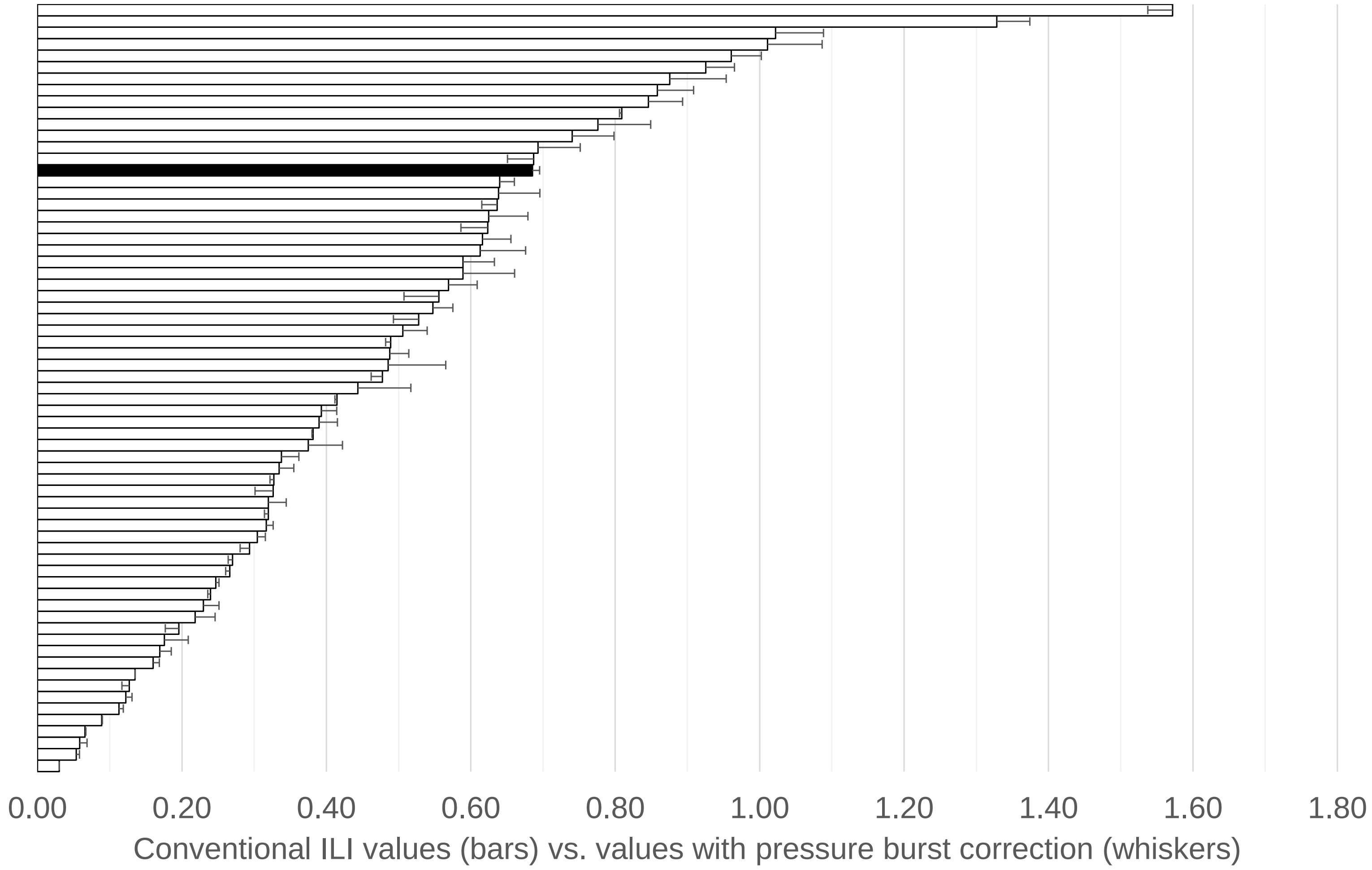
Observations:

- Proportion of Flexible Mains Materials: 17% to 96%
- N1 Exponent Linearly Interpolated with Flexible Mains Materials Proportion
- Significant Impact on UARL and Corresponding ILI Values
- ILI Values Show Wide Variation: -83.6% to 289% Based on Flexible Mains Proportion
- Potential for Further Reduction in Small ILI Values

References:
For theoretical background on the FAVAD concept and calculation details, see original sources including May (1984), Thornton & Lambert (2005), Lambert & Fantozzi (2010), and Lambert (2020).

Since most of the specified values for the average pressure fall within the range of 40 to 60 m, changes in ILI values due to the pressure-to-burst correction are less severe for most cases of the data set.

A4: Influence of Customising the UARL Equation for Pressure-to-Bursts Frequency



Observations

- Utilities reported average supply pressures ranging from 30.6 to 76.5 meters.
- Most reported values fall within a 40 to 60 meters average service pressure range.
- ILI value changes range from -9.70% to 18.9%, depending on the specified average pressure.
- Existing pressure conditions most often closely align with the 50-meter used in UARL standard calculations.
- Consequently, the pressure-to-bursts correction yields less significant variations in calculated ILI values.

References:
Refer to Lambert et al. (2013) and Lambert (2020) for the theory behind the concept and the method of calculating the UARL correction.

Inaccuracies in Estimating Average Service Pressure Have Significant Impacts on the Resulting UARL.

B1: Pressure dependence in the UARL calculation for the case of the reference water utility, assuming a 10% over- or underestimation of the average supply pressure.

UARL-Component	Calculation	∆p (-10%)	p = 49,4 m	∆p (+10%)
Mains length L_M = 486 km	6.57 x 486	141,866	157,629	173,392
No. of service connections n_{Sc} = 10,993	0.256 x 10,993	125,004	138,893	152,782
Lenght of service connections L_{Sc} = 154 km	9.13 x 154	62,454	69,393	76,332
Σ UARL		329,324	365,915	402,507
ILI		0.76	0.69	0.62

Observations:

- Average service pressure is the most uncertain variable in UARL calculations.
- Often overestimated due to reliance on reported static pressure, not accounting for consumption-related fluctuations.
- DVGW recommends estimating average pressure using population-weighted simplified pressure line maps, but adherence is low.
- Hydraulic models for precise pressure determination are rarely used by utilities in the dataset

Improper Estimation of Undocumented Mains and Service Connections Can Hinder Accurate UARL Calculation.

B2: Impact of errors in determining the mains length or the total service connection length on resulting UARL values.

UARL-Component	per m pressure	$\Delta L = 0$	ΔL_{Sc} (-25 %)	ΔL_N (-10 %)	ΔL_N (+10 %)	ΔL_{Sc} (+25 %)
Mains length L_M = 486 km	6.57 m³/km	3,194		2,874	3,513	
No. of service connections n_{Sc} = 10,993	0.256 m³/Sc	2,814				
Length of service connections L_{Sc} = 154 km	9.13 m³/km	1,406	1,055			1,758

- Resulting value of the UARL [m³] without incorrectly estimating mains length and service connections length: 365,915 m³ *(ILI = 0.69)*

- Scenario 1: Determination of the mains length without errors but incorrect estimation of the average service connection length
  - by *-25%:* 348,567 m³ *(ILI = 0.72)*
  - by +*25%*: 383,264 m³ *(ILI = 0.65)*

- Scenario 2: Incorrect determination of the mains length and incorrect estimation of the average service connection length
  - mains – *10%* and service connections *-25%*: 332,804 m³ *(ILI = 0.75)*
  - mains +*10%* and service connections +*25%*: 399,026 m³ *(ILI = 0.63)*

ILI Value Changes Based on UARL Allocation: Transmission vs. Distribution Networks

B3: Change in Calculated ILI Values Based on UARL Allocation Between Transmission and Distribution Networks

Parameter		100 %	10 % *
Mains length [km]	486		
Distribution mains [km]	309		
Transmission mains [km]	177		
Average service pressure [m]	49.4		
Current annual real losses [m³/km/h]	250,809		
Service connections [n]	10,993		
Length of service connections [km]	154		
UARL (complete network)	m³	365,915	
UARL (only distribution network)	m³	308,585	308,585
UARL (only transmission network)	m³	57,331	5,733
UARL (complete network $_{corrected}$)	m³	365,915	314,318
ILI		0.69	0.80

Failure rates per 100 km of the data set:

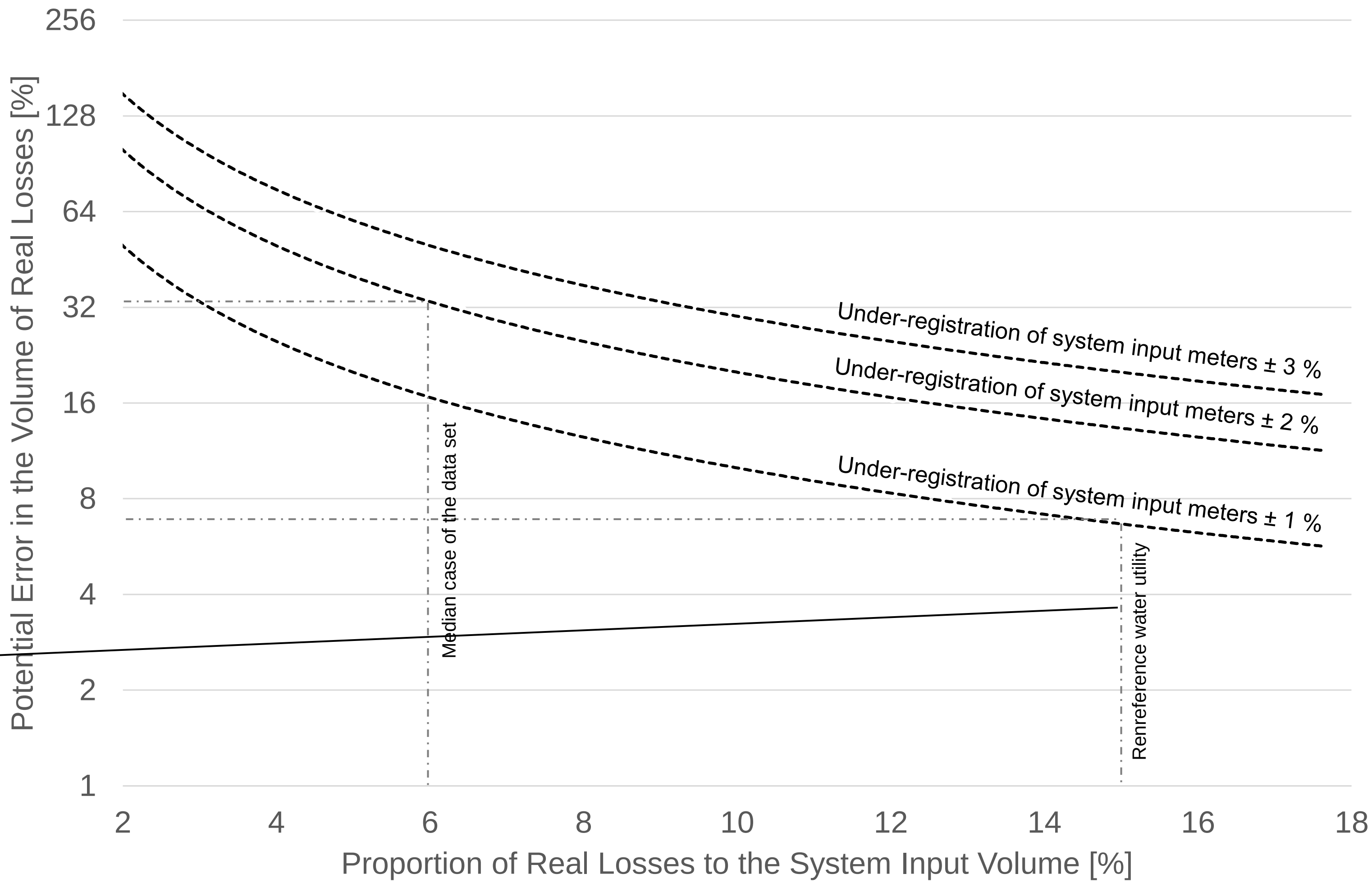
	Transmission mains	Distribution mains
min	0.00	0.75
max	20.5	85.9
mean	0.00	7.74
avg	1.77	12.5

* Assuming that failure rates on transmission mains are only 10% of distribution mains failure rates

Systematic and Random Errors of System Input Measurements Affect the Current Annual Real Loss Volume (CARL) in the Water Balance.

C1: Impact of random errors in measuring the system input volume

	Input	Uncertainty of Input Measurement (m³)	Uncertainty of Input Measurement (%)	Squares of Uncertainties (m³)
Pumping Station	463,574	3.00	7,096	50,346,518
Pumping Station	23,851	3.00	365	133,279
Pumping Station	46,898	3.00	718	515,285
Pumping Station	123,843	3.00	1,896	3,593,134
Storage Tank	35,251	3.00	540	291,128
Spring Discharge	63,307	5.00	1,615	2,608,140
Spring Discharge	52,722	5.00	1,345	1,808,922
Pumping Station	41,985	3.00	643	412,977
Storage Tank	11,359	3.00	174	30,227
Spring Discharge	11,625	5.00	297	87,945
Pumping Station	34,064	3.00	521	271,851
Pumping Station	20,475	3.00	313	98,215
Storage Tank	39,832	3.00	610	371,704
Storage Tank	118,945	3.00	1,821	3,314,535
Storage Tank	9,283	3.00	142	20,188
Storage Tank	124,432	3.00	1,905	3,627,366
Pumping Station	126,880	3.00	1,942	3,771,527
Pumping Station	239,177	3.00	3,661	13,402,043
Storage Tank	76,382	3.00	1,169	1,366,828
Total		1.09	9,277	86,071,812
Most Likely Value		1,663,888		
Minimum		1,645,704		
Maximum		1,682,072		



Depending on the Applied Statistical Methods and Hydrological Conditions of the Assessment Period, the Resulting Error Due to Extrapolation of Consumption Can Have a Perceptible Influence on CARL.

C2: Impact of Inaccuracies During Meter Reading and Data Handling or Errors Due to Extrapolation of Consumption

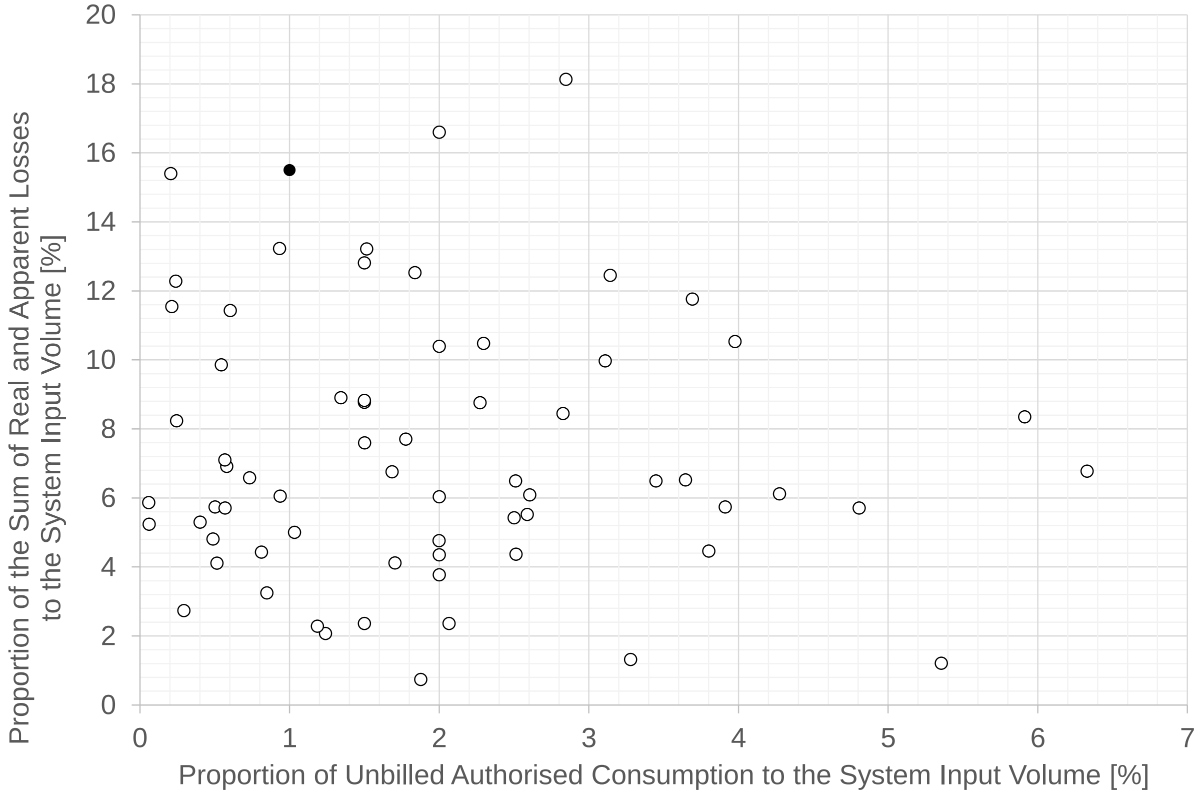
		Actual consumption (– 1%)	Actual consumption (+ 1%)
System Input Volume [m³]	1,663,888		
Billed Authorised Consumption [m³]	1,389,366	1,375,472	1,403,260
Unbilled Authorised Consumption [m³]	16,639		
Apparent Losses [m³]	7,074		
Real Losses [m³]	250,809	264,703	236,915
UARL [m³]	365,915		
ILI	0,69	0,72	0,65

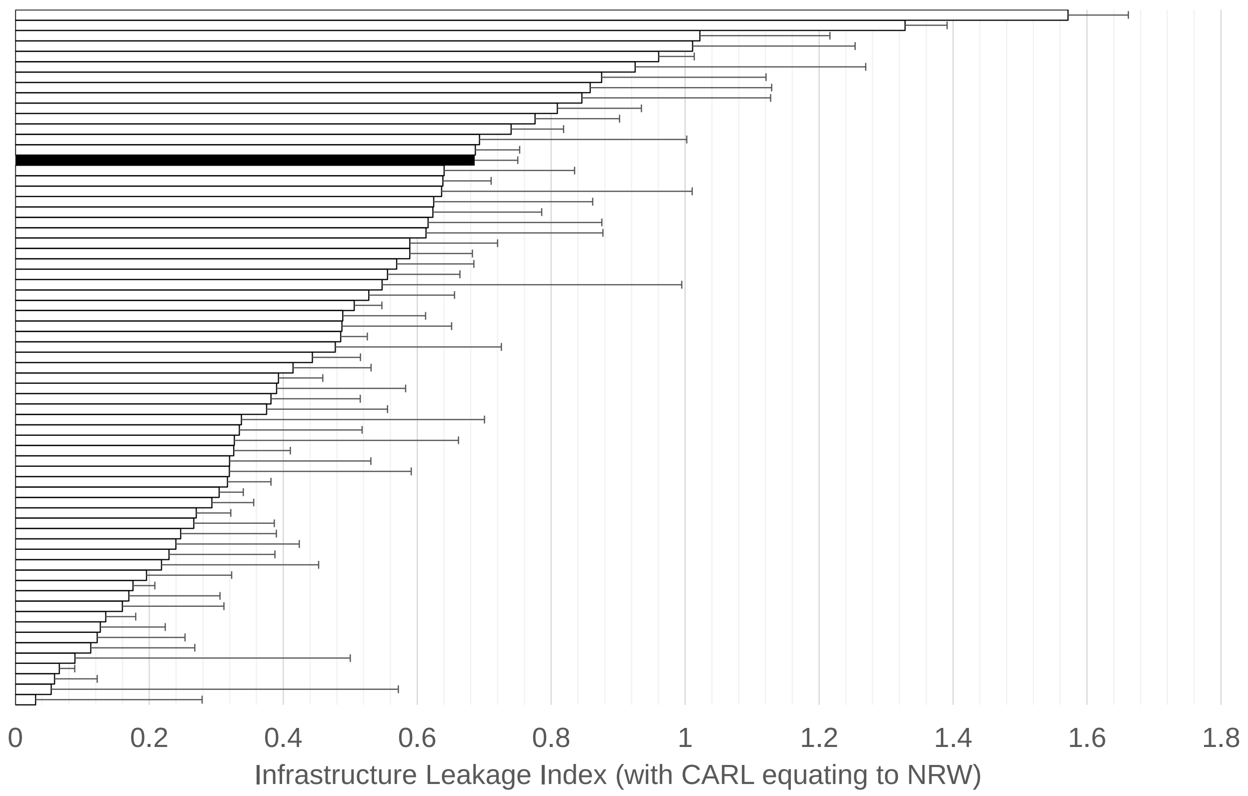
<table>
<tr><td rowspan="9">System Input Volume</td><td rowspan="4">Authorized Consumption</td><td rowspan="2">Billed Authorized Consumption</td><td>Billed Metered Consumption</td><td rowspan="2">Revenue Water</td></tr>
<tr><td>Billed Unmetered Consumption</td></tr>
<tr><td rowspan="2">Unbilled Authorized Consumption</td><td>Unbilled Metered Consumption</td><td rowspan="7">Non-Revenue Water</td></tr>
<tr><td>Unbilled Unmetered Consumption</td></tr>
<tr><td rowspan="5">Water Losses</td><td rowspan="2">Apparent Losses</td><td>Unauthorized Consumption</td></tr>
<tr><td>Metering Inaccuracies and Data Handling Errors</td></tr>
<tr><td rowspan="3">Real Losses</td><td>Leakage on Transmission and/or Distribution Mains</td></tr>
<tr><td>Leakage and Overflows at Utility's Storage Tanks</td></tr>
<tr><td>Leakage on Service Connections up to Point of Customer Metering</td></tr>
</table>

IWA Standard Water Balance

Most Water Utilities Overestimate the Volume of Unbilled Authorized Consumption in Their Annual Water Balance by Applying a Fixed Value Uniformly.

C3: Potential Impact of Inaccurate Estimation of the Volume of Unbilled Authorized Consumption and the Volume of the Apparent Losses in Calculation of the Annual Water Balance





#	Summary of the Effects of the Various Influencing Factors for the Reference Utility	ILI	Change
A1	Small water supply systems (*10,993 Service Connections und 486 km Mains)*	0.73	6.30 %
A2	Favorable soil conditions where only a minority of leaks remain undetected	not quantifiable	
A3	High proportions of rigid pipe materials (*Proportion of Flexible Mains Materials: 31%)*	1.43	109 %
A4	Lower supply pressure than those used in the standard UARL calculation (*Average Service Pressure: 49.4 m)*	0.70	1.43 %
A5	Reduced Frequency of Reported and Detected Main Failures Due to Newer Systems	not quantifiable	
B1	Inaccuracies in Estimating Average Service Pressure *Assumed to be overestimated by 10%*	0.76	10.1 %
B2	Improper Estimation of Undocumented Mains and Service Connections *Length of mains assumed to be underestimated by 10% and the average length of service connections by 25%*	0.63	-8.70 %
B3	Allocation of the UARL for the Transmission Network *With the UARL for transmission mains assumed to amount to only one-tenth of the value for distribution mains*	0.80	17.6 %
C1	Impact of random errors in measuring the system input volume *Combined error of all system input meters assumed to be -1%.*	0.73	6.63 %
C2	Inaccuracies during meter reading and data handling or errors due to extrapolation of consumption *1% of authorized consumption assumed to be under-billed*	0.65	-5.54 %
C3	Inaccurate Estimation of Unbilled Authorized Consumption *If the originally recognized rate of 5% is applied instead of 1% of the system input volume*	0.50	-26.5 %

A Few Conclusion for the Application of the ILI in the Context of Benchmarking Initiatives

- The Infrastructure Leakage Index (ILI) serves as a key measure for assessing both water loss management practices and the overall condition of water infrastructure.
- Accurate input data is crucial for ILI calculations.
- Combining ILI with other indicators and context provides a fuller picture of the water loss situation.

- Adopting customized UARL calculations with a System Correction Factor (referencing Kölbl & Lambert, 2019; Stanton-Davies et al., 2019; Lambert & Stanton-Davies, 2023) enhances accuracy and insights at the system level.
- Due to the complexity of the analysis, using ILI as a benchmarking indicator is challenging.
  - Verifying the required input data is only possible to a limited extent.
  - Exact interpretation requires deep expertise.
- It is advised to focus on leveraging ILI's unique strengths for conducting detailed water loss analyses.

- The growing importance of ILI in shaping EU regulations highlights the need for rigorous data validation and an expanded understanding of water loss metrics for informed policy discussions.
  - Questions arise as to who will verify the plausibility of the collected ILI data, especially when used for setting targets.

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Contact

Daniel Zipperer, M.Sc., MBA
Tel.: +49-2203-35929-15
d.zipperer@aquabench.de

aquabench GmbH
Niederlassung Köln

Am Westhover Berg 30
51149 Köln
Germany

www.aquabench.de

Dipl.-Ing. Dr.techn. Joerg Koelbl
Tel.: +43 664 88795883
koelbl@bluenetworks.at

Blue Networks e.U.
Ingenieurbüro für Kulturtechnik, Wasserwirtschaft und Technische Geologie

Römerstraße 18
A-8430 Leibnitz/ Kaindorf
Austria

www.bluenetworks.at