# Exploring the Combined Real Loss Index: An Innovative Metric for Assessing Real Losses in Water Supply Systems

10th IWA Conference Benchmarking, Performance Assessment and Regulation of Water Services

Poznań / 10 June, 2025 / Daniel Zipperer

# Context of the Study – The Rhineland-Palatinate Municipal Water Sector Benchmarking

***Location of Rhineland-Palatinate 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 (7th cycle still ongoing).
- Special focus areas include:
  - Tariff structuring
  - Emergency preparedness
  - Corporate sustainability
  - Staffing level determination
  - …

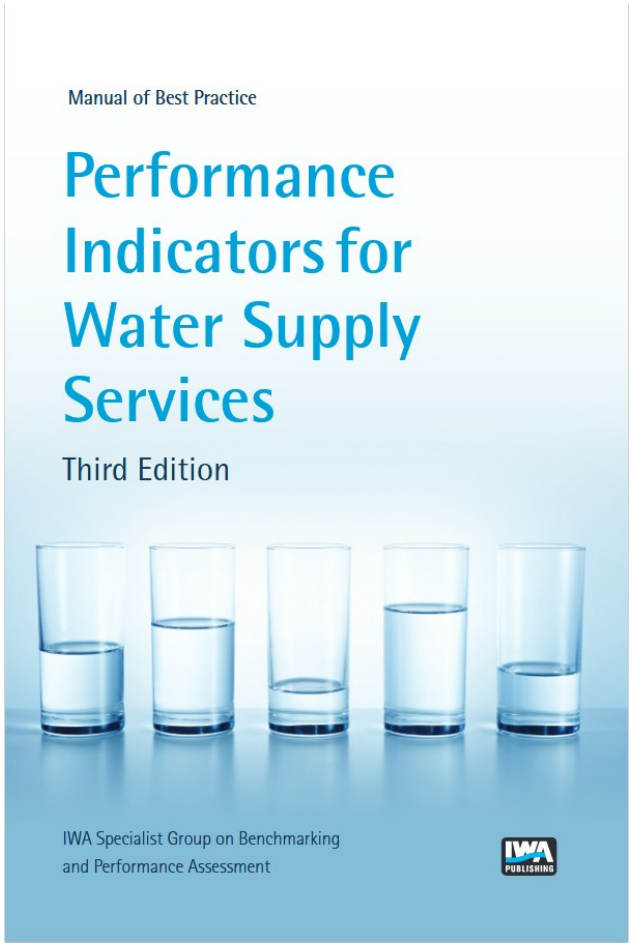
*Source: Wikipedia*

**Basic descriptive statistics of the data set:**

| | |
|---|---|
| Number of water supply systems | 70 (68) / 200 |
| Service connections | 1,100 – 70,000 |
| Mains length | 30 – 1,800 km |
| Average pressure | 30 – 75 m |
| Population served | 2,800 – 230,000 inh. |
| Authorized Consumption | 150,000 – 13.2 Mio. m³ |
| Total personnel | 0 – 103 FTE |
| Average mains age | 20 – 60 years |
| Customer meter replacement period | 6 years |
| Proportion of transmission mains | 0 % – 50 % |

# Towards a More Balanced Measure on Real Losses: From Op27–29 to CRLI

## *IWA Performance Indicators for Real Water Losses*




**Op27 – Real losses per connection**
[l/connection/d]

✓ Suitable for urban systems with high connection density

⚠ May overstate losses in rural areas

**Op28 – Real losses per mains length** *)
[l/km/day]

✓ Suitable for rural systems with low connection density

⚠ May overstate losses in dense urban networks

**Op29 – Infrastructure Leakage Index**
[-]

✓ Uses several system parameters

⚠ Complex to calculate and communicate; requires expert knowledge for correct application

**CRLI - Combined Real Loss Index**

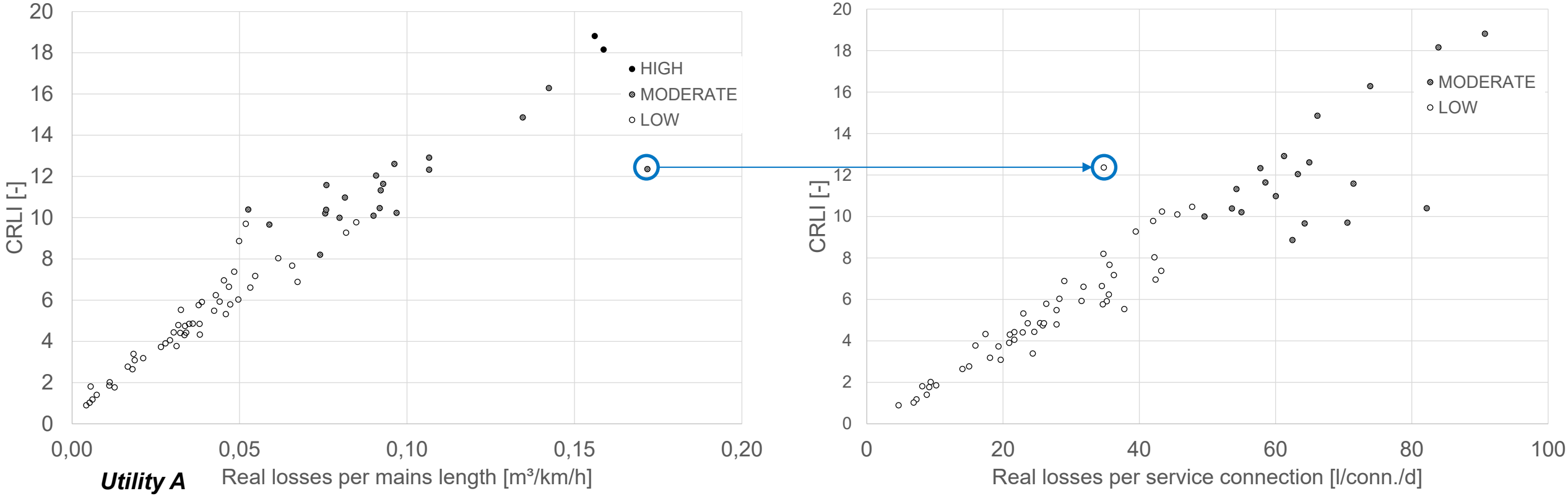
✓ Combines Op27 and Op28

✓ Easier than ILI, but better balanced for varying network structures

*) *Op28 applies if service connections density <20/km of mains (e. g. , bulk supply systems)*

# Normalization Affects Perception

## *Urban Utility: Low Real Losses per Connection, Moderate per Mains Length – CRLI Reflects Both*

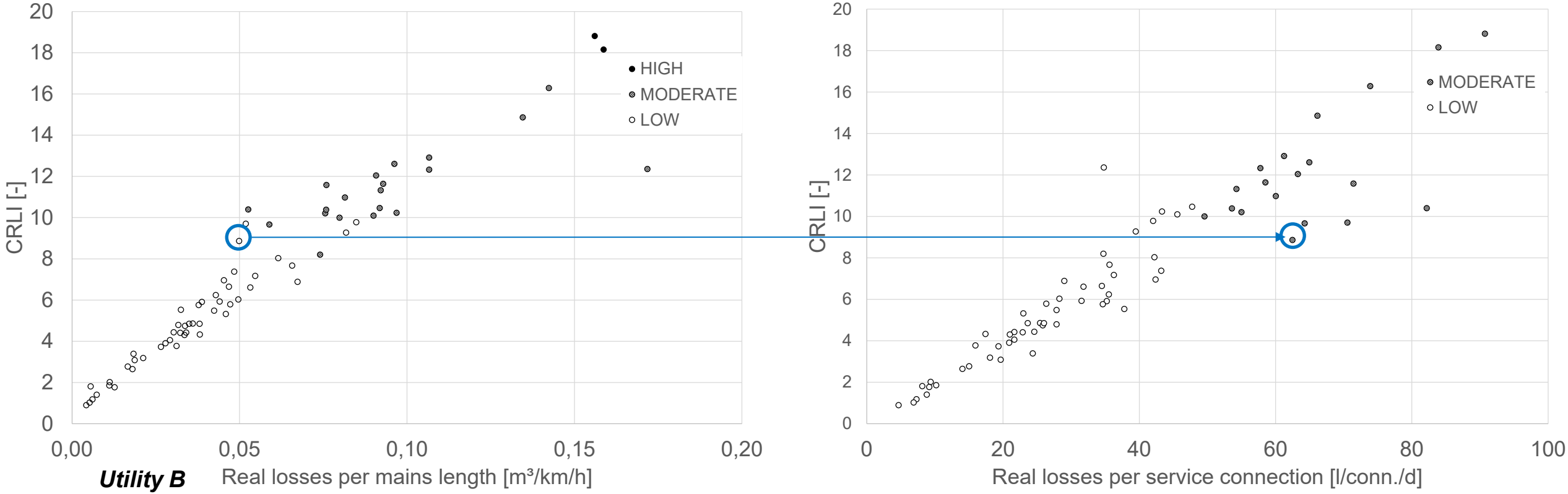



***Utility A***

- *Connection Density: 126 / km (Urban)*
- *Real Losses per Connection per Day: 35 l/connection/day (rank 38) „Low Real Losses“*
- *Specific mains supply: 18,973 m³/km (urban)*
- *Real losses per mains length: 0,17 m³/km/h (rank 70) “Moderate Real Losses”*
- *CRLI: 12,4 (rank 64)*

# Normalization Affects Perception

## *Rural Utility: Moderate Real Losses per Connection, Still Low per Mains Length – CRLI Reflects Both*




***Utility B***

- *Connection Density: 20 / km (Rural)*
- *Real Losses per Connection per Day: 62 l/connection/day (rank 60) "Moderate Real Losses"*
- *Specific mains supply: 4,379 m³/km (Rural)*
- *Real losses per mains length: 0,05 m³/km/h (rank 36) „Low Real Losses"*
- *CRLI: 8,86 (rank 46)*

# The CRLI Concept – A Combined Metric for Evaluating Real Water Losses

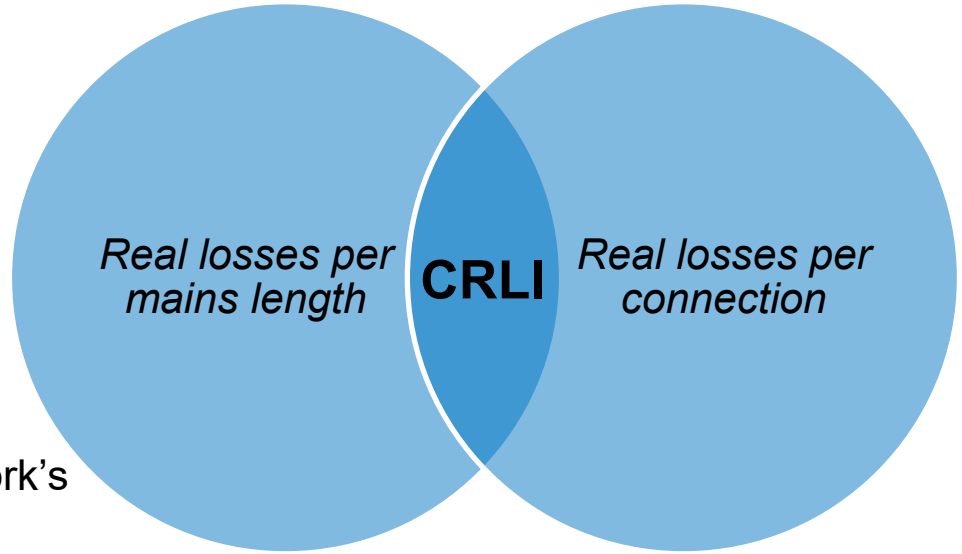
***A Best-of-Both-Worlds Combination***

**What is the CRLI?**

- Stands for **Combined Real Loss Index**
- Represents the **Geometric Mean** of two key IWA metrics
  - Real losses per connection per day
  - Real losses per mains length

**Key Benefits:**

- A **less density-sensitive** water loss metric
- **Easier to calculate** from available operational data
- **No pressure data** or service connection length needed
- It incorporates system context through normalisation to **connection count** and **mains length**, reflecting the network's structural exposure to losses.




**Calculation** (Wyatt & Pearson, 2020):

$$CRLI = \sqrt{Real\ losses\ per\ connection\ per\ day\ x\ Real\ losses\ per\ mains\ length}$$

## Benchmarking Superpowers: Who Really Performs Best?

***What Is the Geometric Mean?***

**Method of Addition**

Captain Velocity: 2 + 25 = 27

Doctor Elevate: 10 + 9 = 19

☞ A very high value simply compensates for a very poor ability.

**Geometric Mean**

Captain Velocity: $\sqrt{2\ x\ 25} = \sqrt{50} \approx 7.07$

Doctor Elevate: $\sqrt{10\ x\ 9} = \sqrt{90} \approx 9.49$

☞ If you have a superpower that is extremely weak, you can't just make up for it with another that is extremely strong – your overall performance will suffer.

The CRLI is the Geometric Mean of the two Performance Indicators:

- Real losses per connection per day [Litres/connection/day]
- Real losses per mains length [m³/km/day]

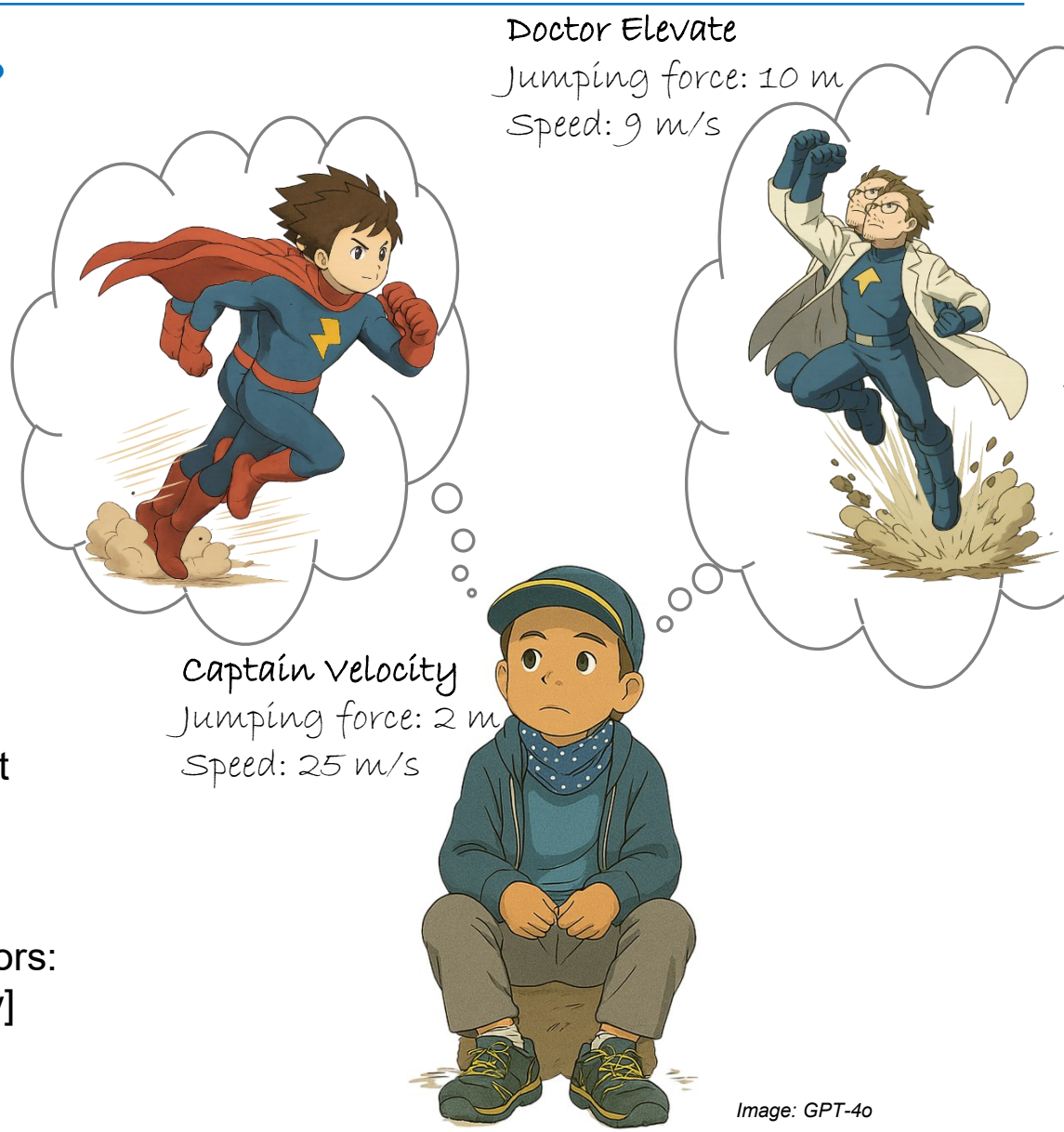



*Image: GPT-4o*

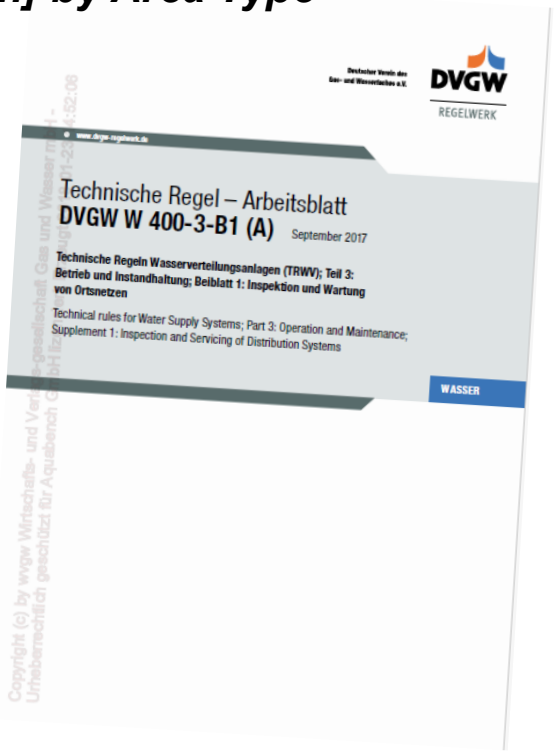
# Translating DVGW Guideline Values for Specific Real Water Losses into CRLI

## *Step 1: Understanding DVGW W 400-3-B1 (A) Guideline Values*

### *Specific Real Water Loss Ranges [m³/km/h] by Area Type*

| | LOW | MODERATE | HIGH |
|---|---|---|---|
| Urban | < 0.10 | 0.10 – 0.20 | > 0.20 |
| Semi-Urban | < 0.07 | 0.07 – 0.15 | > 0.15 |
| Rural | < 0.05 | 0.05 – 0.10 | > 0.10 |

*Source: DVGW (2017)*




### *Assumptions behind DVGW W392*

- Average pressure: 30 m
- Supply scale:
  - Urban: > 100,000 residents
  - Rural: < 10,000 residents
- Specific mains supply:
  - Urban: > 15,000 m³/km/a
  - Rural: < 5,000 m³/km/a
- Service connection supply:
  - Urban: 300 – 600 m³/conn./a
  - Semi-Urban: 200 – 400 m³/conn./a
  - Rural: 50 – 200 m³/conn./a
- Connection density:
  - Urban: > 40 conn./km
  - Rural: < 25 conn./km

*Source: German National Report, Weimer, D. (2001)*

# Translating DVGW Guideline Values for Specific Real Water Losses into CRLI

## *Step 2: Applying Typical Connection Densities*

### *Conversion of DVGW ranges for Specific Real Water Losses*

$$\textit{Real Losses per connection per day [Litres/conn./d]} = \frac{\textit{Real losses per mains length [m³/km/d]}}{\textit{Connection density [conn./km]}} \textit{ x 1,000}$$

### *Assumed Connection Density for each Area Type*

| | [conn./km] |
|---|---|
| Urban | 60 |
| Semi-Urban | 30 |
| Rural | 15 |

### *DVGW ranges for Specific Real Water Losses by Area Type interpreted in Litres/conn./d*

| | LOW | MODERATE | HIGH |
|---|---|---|---|
| Urban | < 40 | 40 – 80 | > 80 |
| Semi-Urban | < 56 | 56 – 120 | > 120 |
| Rural | < 80 | 80 – 160 | > 160 |

*Ranges derived from W392 values assuming standard densities.*

# Translating DVGW Guideline Values for Specific Real Water Losses into CRLI

## *Step 3: Deriving CRLI Benchmark Values*

***Guideline Values for Specific Real Water Losses interpreted in m³/km/d (Table, left) and Litres/conn./d (Table, right)***

| | LOW | MODERATE | HIGH |
|---|---|---|---|
| Urban | < 2.40 | 2.40 – 4.80 | > 4.80 |
| Semi-Urban | < 1.68 | 1.68 – 3.60 | > 3.60 |
| Rural | < 1.20 | 1.20 – 2.40 | > 2.40 |

| | LOW | MODERATE | HIGH |
|---|---|---|---|
| Urban | < 40 | 40 – 80 | > 80 |
| Semi-Urban | < 56 | 56 – 120 | > 120 |
| Rural | < 80 | 80 – 160 | > 160 |

***Resulting CRLI scores***

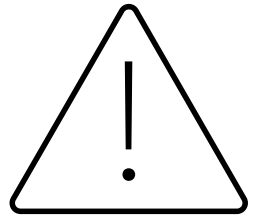
| | LOW | MODERATE | HIGH |
|---|---|---|---|
| Urban | < 10 | 10 – 20 | > 20 |
| Semi-Urban | < 10 | 10 – 21 | > 21 |
| Rural | < 10 | 10 – 20 | > 20 |

***Possible preliminary CRLI reference bands:***

**Low < 10 | MODERATE 10 – 20 | High > 20**

***Caution!***

- These values are only indicative;
  - based on German data and; and
  - a 30 m average pressure.
- They may require local validation before use in other geographical contexts.

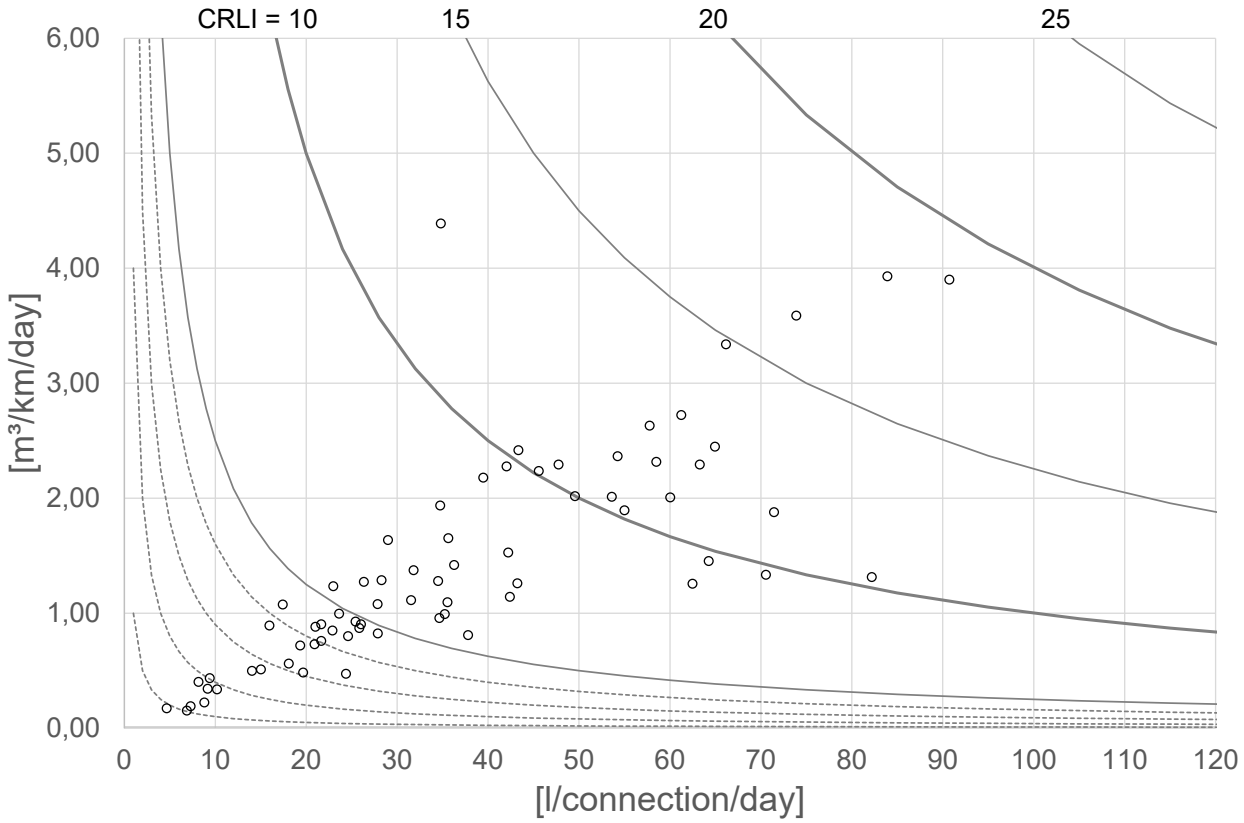


# Rhineland-Palatinate Utilities Show Low to Moderate CRLI Scores

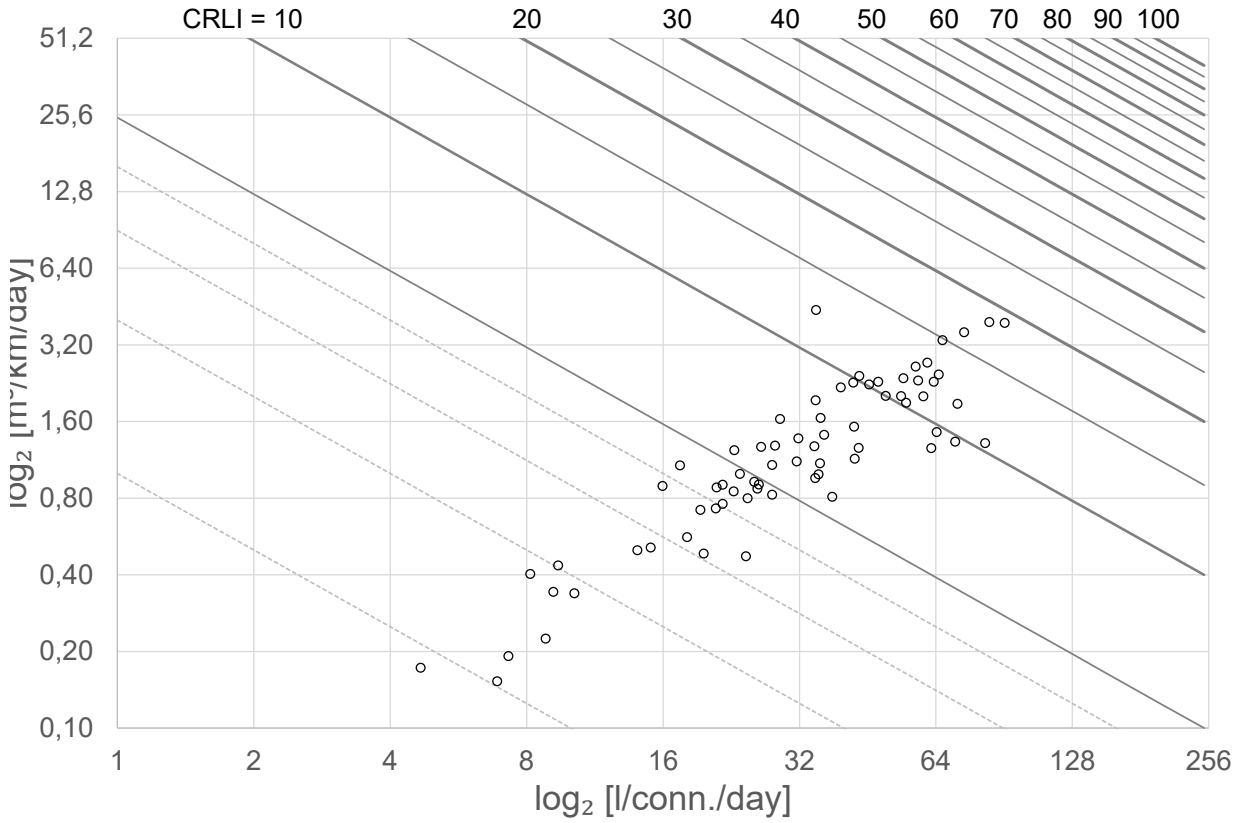
## *Distribution of CRLI Scores for 70 Utilities in Rhineland-Palatinate Shown on Linear and $Log_2$ Scales*

***Basic descriptive statistics for the Rhineland-Palatinate CRLI dataset:***

- *min: 0,90*
- *max: 18,8*
- *Average: 7,16*
- *Median: 6,14*




○ *Rhineland-Palatinate*



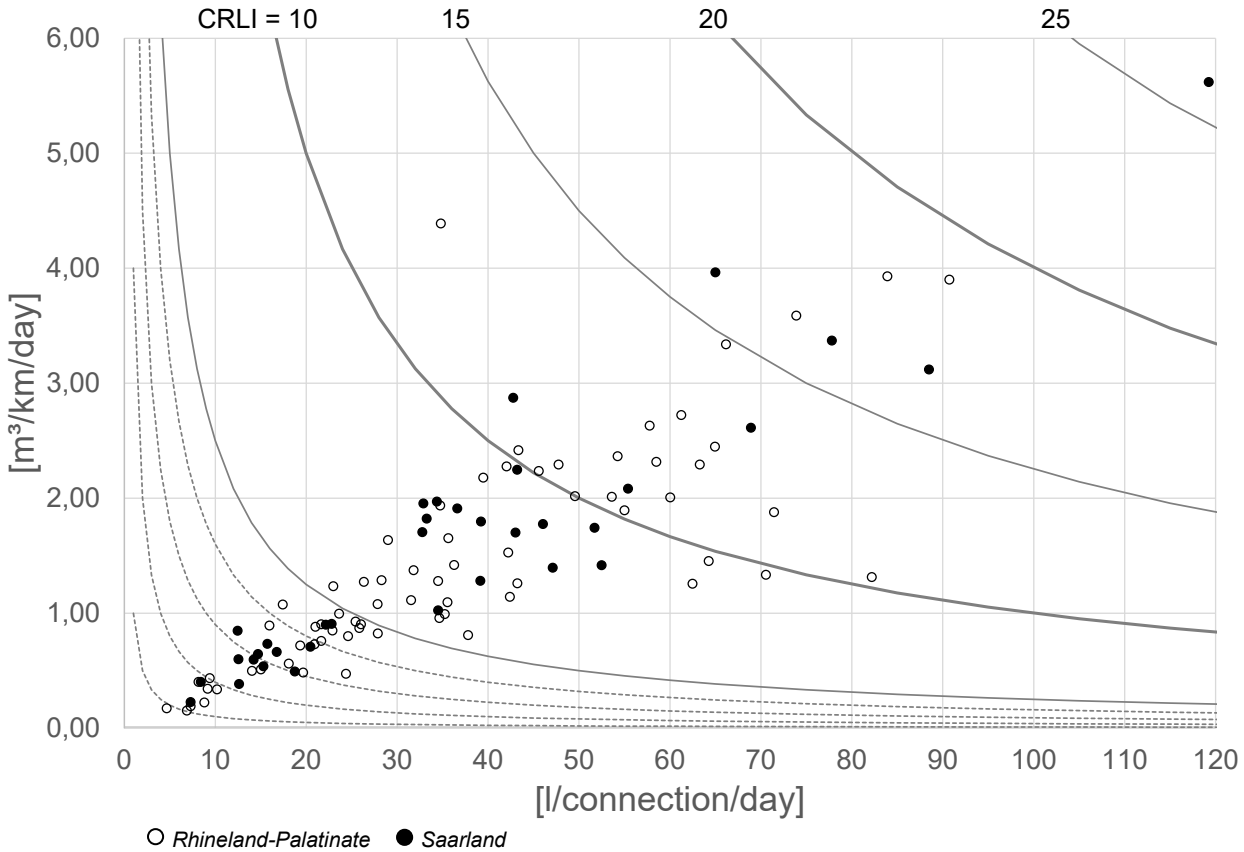

*Nomogram based on Wyatt & Pearson, 2020*

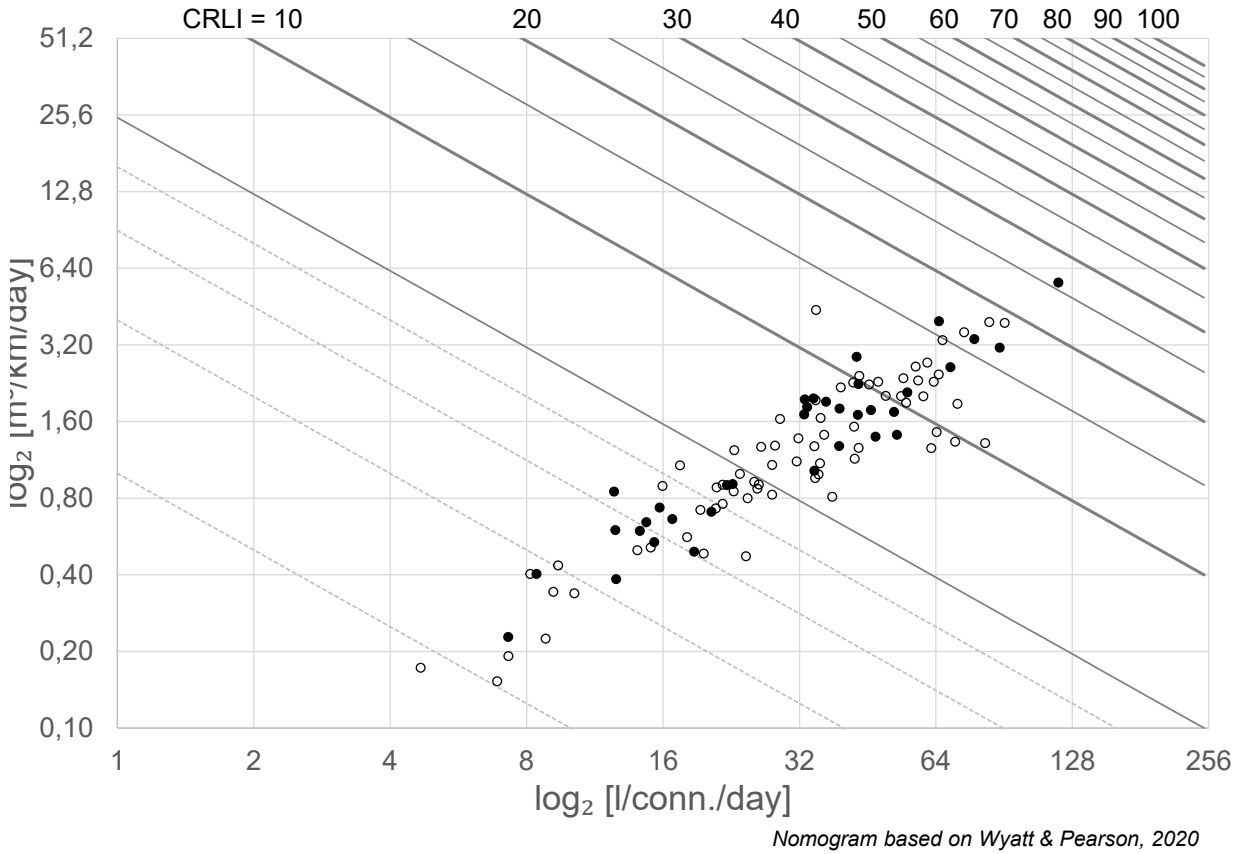
# Saarland Utilities Show Similar CRLI Levels Compared to Rhineland-Palatinate

## *Distribution of CRLI Scores for 35 Saarland Utilities (Black Dots) Shown on Linear and $Log_2$ Scales*

***Basic descriptive statistics for the Saarland CRLI dataset:***

- *min: 1,29*
- *max: 25,9*
- *Average: 7,65*
- *Median: 7,79*

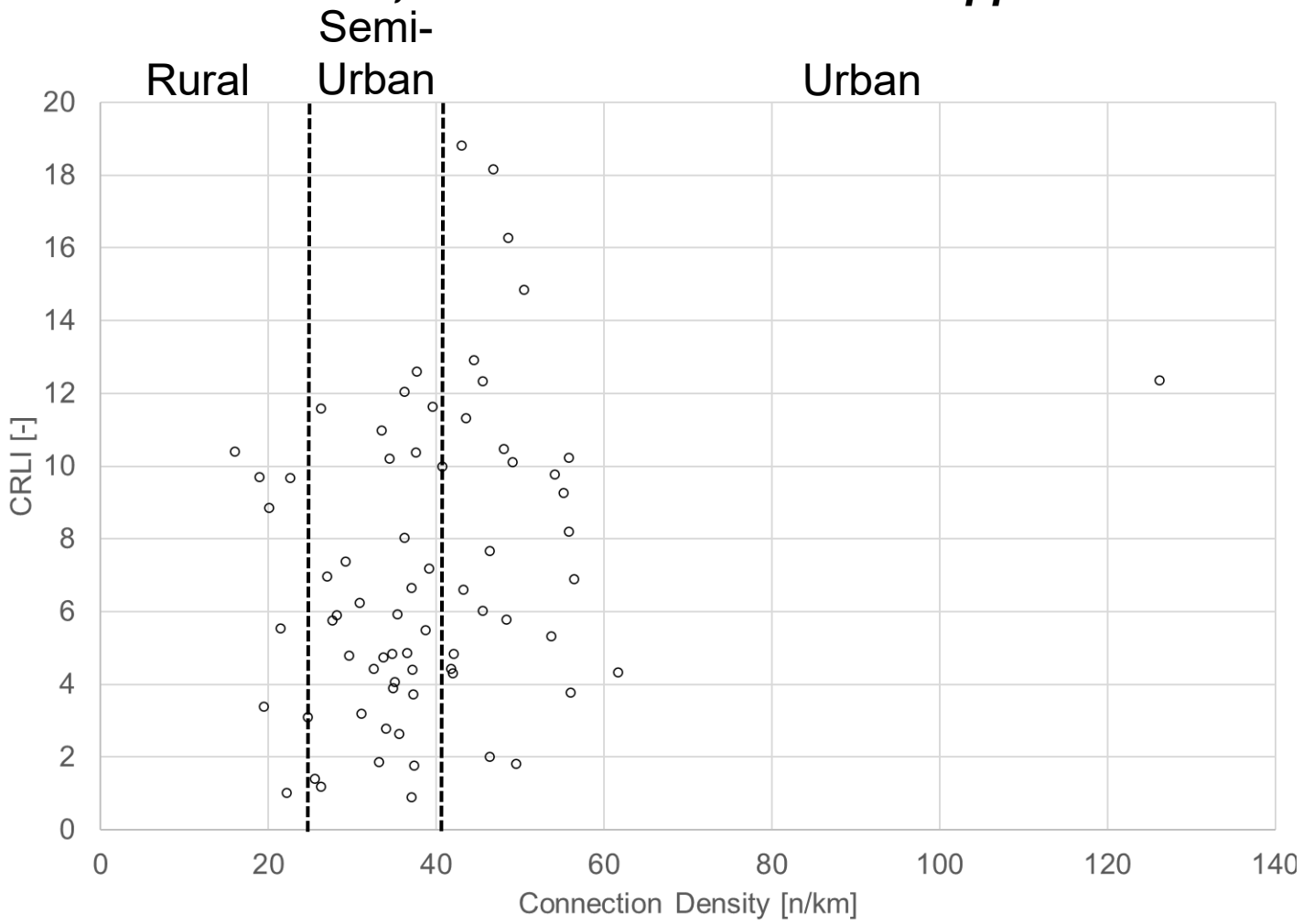



*Nomogram based on Wyatt & Pearson, 2020*

# CRLI Remains Robust Across Diverse Network Densities – Minor Systematic Differences Only

## *Weak Correlation, Stable Variance – CRLI Supports Fair Cross-Utility Comparison*




**A. Variance & Robustness**
**Brown-Forsythe Test** (variant of Levene's test using medians):
**p = 0.17 > 0.05**
→ No significant difference in CRLI variance across rural, semi-urban, and urban areas.
→ CRLI shows consistent variability, confirming its robustness across network types.

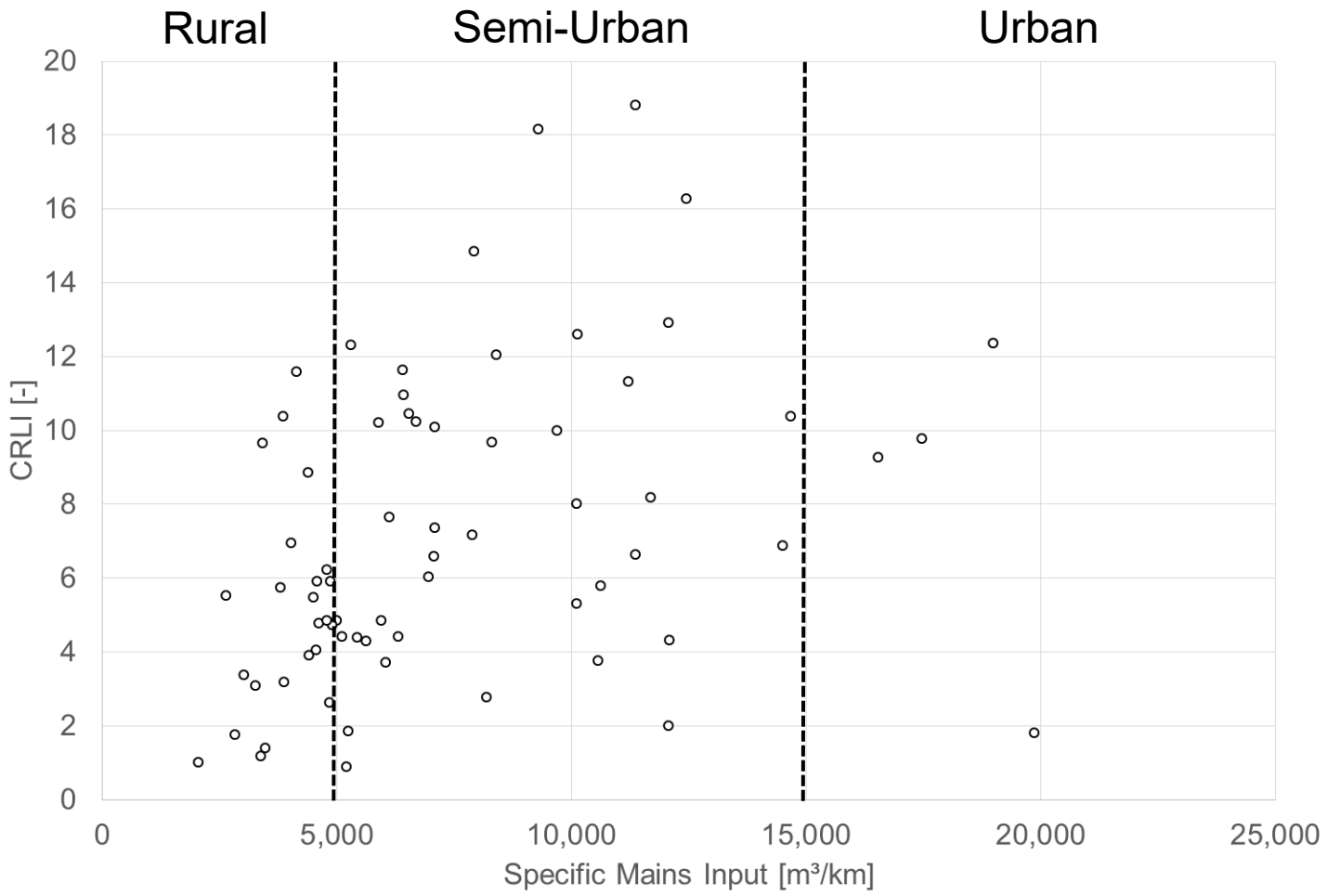
**B. Group Differences (Central Tendency)**
**Kruskal-Wallis Test**: H = 6.63, df = 2, **p = 0.04**
→ Statistically significant differences in CRLI distribution.
→ Mean ranks: rural = 31.9 | semi-urban = 30.1 | urban = 43.1
→ CRLI tends to be higher in urban systems.

**C. Correlation with Connection Density**
**Pearson r = 0.27 (p = 0.02)** | **Spearman's rank correlation ρ = 0.29 (p = 0.02)**
→ Weak, but statistically significant correlations.
→ CRLI is partly influenced by connection density but remains a comparatively stable benchmarking metric.

**D. Distribution Characteristics**
**CRLI**: slightly right-skewed (Skew = 0.69), near-normal peak (Kurt = 0.14)
**Connection Density**: strongly right-skewed (Skew = 2.88), sharply peaked (Kurt = 16.10)
→ Justifies nonparametric and rank-based methods.

# CRLI Shows Structural Differences, Yet Remains Robust Across System Types

## *Significant Group Differences and Moderate Correlation with Specific Mains Input – Variance is Stable*




**A. Variance & Robustness**
**Brown-Forsythe Test** (variant of Levene's test using medians):
**p = 0.058 > 0.05**
→ No significant difference in CRLI variance across rural, semi-urban, and urban areas.
→ CRLI shows consistent variability, confirming its robustness across network types.

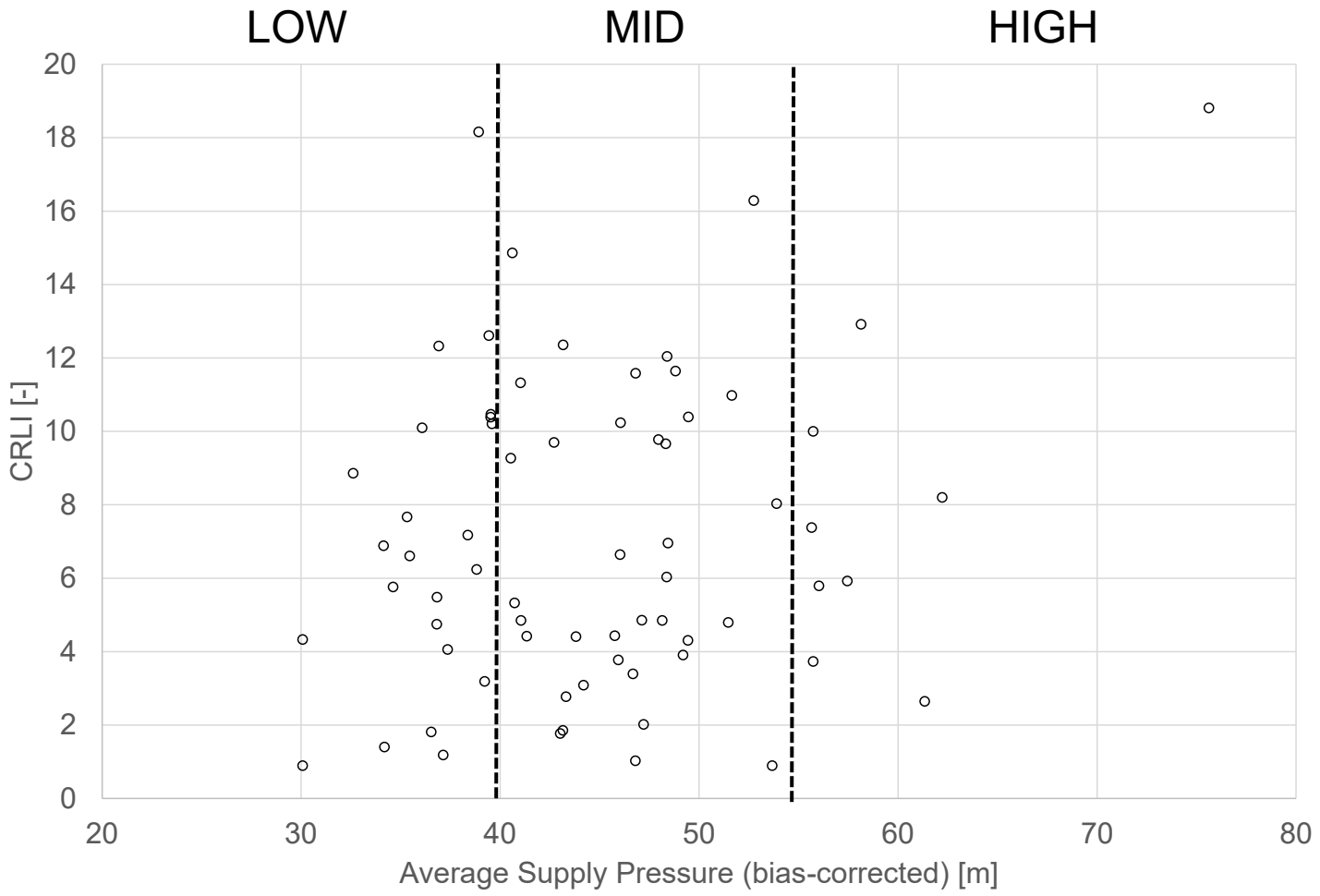
**B. Group Differences (Central Tendency)**
**Kruskal-Wallis Test:** H = 9.58, df = 2, **p = 0.01**
→ Statistically significant differences in CRLI distribution.
→ Mean ranks: rural = 25.4 | semi-urban = 41.0 | urban = 41.8
→ CRLI tends to be lower in rural systems.

**C. Correlation with Specific Mains Input**
**Pearson r = 0.35 (p = 0.003) | Spearman's rank correlation ρ = 0.44 (p = 0.0001)**
→ Moderate, significant correlations.
→ CRLI is partly influenced by network input but remains a stable benchmarking metric.

**D. Distribution Characteristics**
**CRLI:** slightly right-skewed (Skew = 0.69), near-normal peak (Kurt = 0.14)
**Mains Input:** clearly right-skewed (Skew = 1.20), slightly peaked (Kurt = 1.05)
→ Justifies nonparametric and rank-based methods.

# CRLI and Average Supply Pressure: No Statistically Significant Relationship

***No Justification for Adjusting CRLI Evaluation Based on Pressure Classes***




**A. Variance & Robustness**
**Levene's Test:** p = 0.85
→ CRLI variance does not differ significantly.
→ → Robustness confirmed across pressure levels.

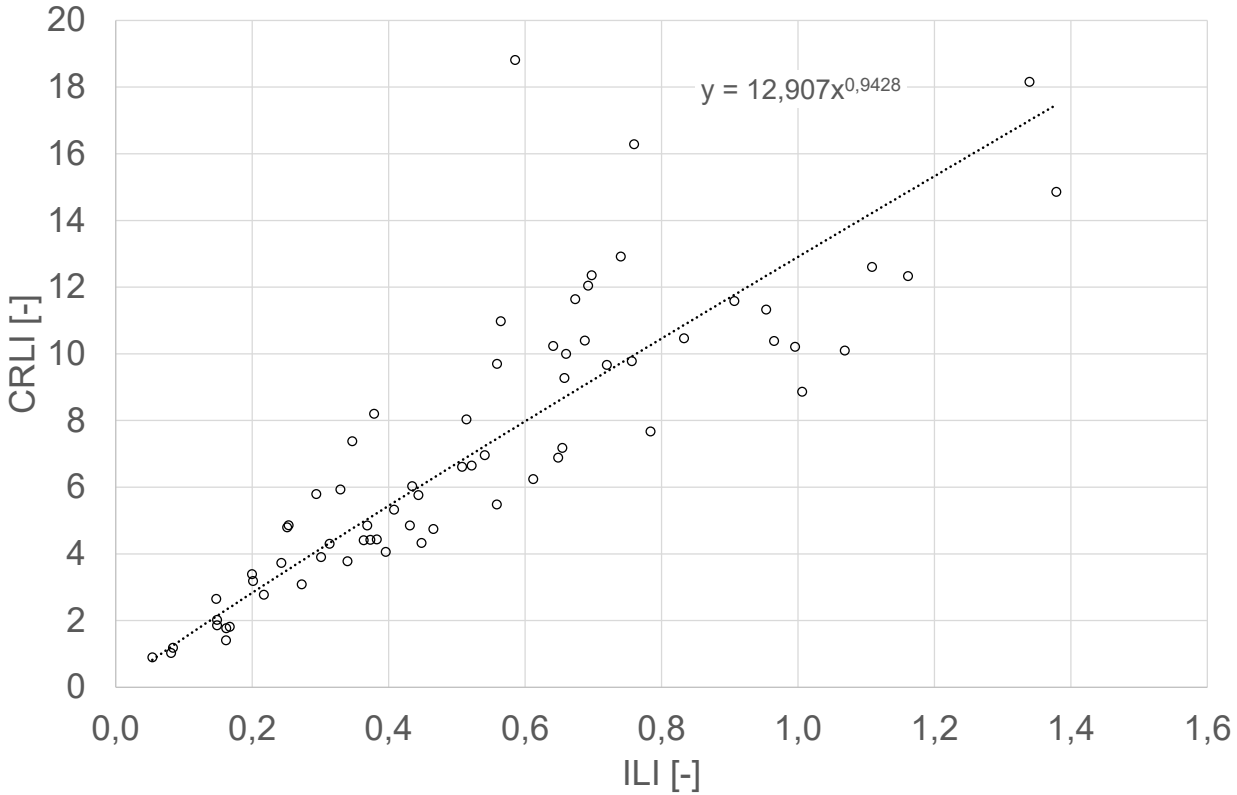
**B. Group Differences (Central Tendency)**
**ANOVA:** F = 0.46, p = 0.63
**Kruskal-Wallis-Test:** H = 0.66, p = 0.72
→ No significant group differences.
→ Mean CRLI: Low = 7.26 | Mid = 6.88 | High = 8.38
→ No support for pressure-based CRLI differentiation.

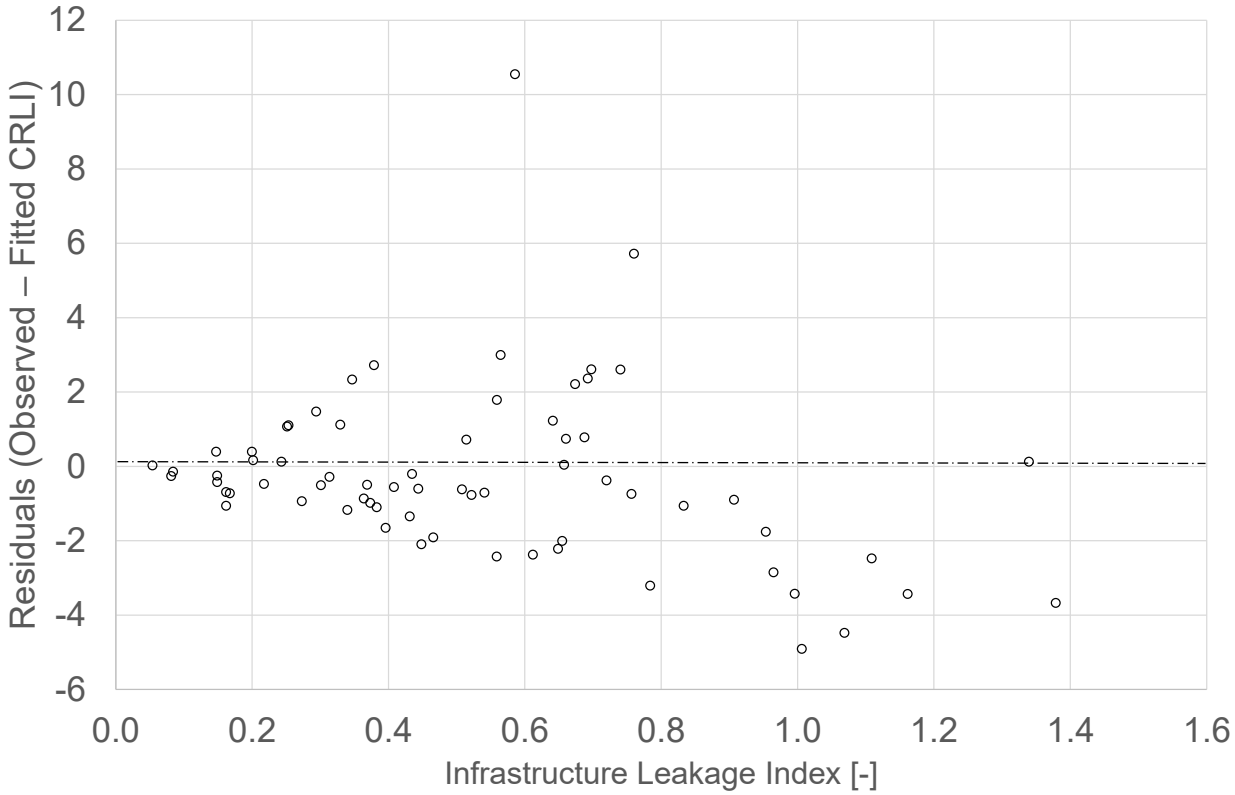
**C. Correlation with Pressure (continuous)**
**Pearson r = 0.18 (p = 0.13) | Spearman's rank correlation ρ = 0.09 (p = 0.47)**
→ Weak, non-significant correlations.
→ No clear link between pressure and CRLI.

**D. Distribution Characteristics**
**CRLI:** right-skewed (Skew = 0.66), near-normal peak (Kurt = 0.05)
**Pressure:** right-skewed (Skew = 0.75), moderate kurtosis (Kurt = 1.02)
→ Justifies parametric and nonparametric methods.

# CRLI Responds Strongly to ILI – Confirmed by Model Fit

***Fit and Residuals of CRLI–ILI Relationship***




*<u>Model parameters</u>*

*$R^2 = 0.87$*

*$CRLI = 12.907 \times ILI^{0.9428}$*

*<u>Model validation (residuals)</u>*

*Residual analysis confirms consistent fit*

*No systematic pattern in residuals across ILI range*

# Wrap-Up

## *CRLI – A Practical and Fair Real Loss Metric*

| | |
|---|---|
| Why it matters | • Bridges the urban / rural gap → connection-density neutral<br>• Needs only data utilities already track<br>• Strongly correlated with ILI ($R^2 \approx 0.87$) – yet simpler |
| Evidence from 105 German utilities | • *70* Rhineland-Palatinate + *35* Saarland utilities<br>• Typical CRLI range: *0.90* – *25.9* (Mean ≈ *6.14* for RP and *7.79* for SL, respectively) |
| Robust across contexts | • Variance stable across rural → urban (Levene's and Brown-Forsythe test $p \geq 0.05$)<br>• Weak, non-significant link to pressure ($p \geq 0.05$)<br>• Weak but significant link to connection density ($\rho \approx 0.3$, $p = 0.02$)<br>• Moderate and significant link to mains input ($\rho \approx 0.4$, $p < 0.01$) – still robust |
| Practical implications | • Benchmark & track performance without extra pressure data<br>• Supports fair regulation & incentive schemes<br>• Identifies outliers where ILI pressure data may be suspect (large residuals) |
| Still ahead | • Define reference bands for the classification of CRLI scores<br>• Promote CRLI understanding among (German) asset-management teams as a more nuanced alternative to the traditional used metric *real losses per mains length*<br>• Position the CRLI as a practical and accessible alternative to the ILI for EU policy makers, enabling more robust data collection and better-informed decisions. |

**CRLI Enables Fair and Consistent Benchmarking Across Diverse Utilities – Without Requiring Complex Data!**

## References


- Alegre, H., Baptista, J. M., Cabrera, E., Cubillo, F., Duarte, P., Hirner, W., Merkel, W., & Parena, R. (2006). *Performance indicators for water supply services* (2nd ed.). IWA Publishing. ISBN 1843390515
- DVGW. (2017a). *Guideline W 392: Water losses in distribution networks – assessment, monitoring, classification, water balance, performance indicators.* DVGW.
- DVGW. (2017b). *Guideline W 400-3-B1: Technical rules for water supply systems; Part 3: Operation and maintenance; Supplement 1: Inspection and servicing of distribution systems.* DVGW.
- Lambert, A., & Hirner, W. (2000). *Losses from water supply systems: Standard terminology and recommended performance measures.* IWA Blue Pages.
- OVGW. (2009). *W 63: Water losses in water supply systems – assessment, evaluation and measures for water loss reduction.* OVGW.
- Wyatt, A., & Pearson, D. (2020, July 10). *Introducing the Combined Real Loss Indicator (CRLI)* [Video]. YouTube. <https://www.youtube.com/watch?v=jrs1V-eDitU\>
- Zipperer, D., & Koelbl, J. (2024a). Anwendung des Infrastruktur-Leckage-Index (ILI) als Wasserverlustkennzahl am Beispiel rheinland-pfälzischer Wasserversorgungsunternehmen – Teil 1: Einflussfaktoren auf die unvermeidbaren realen Verluste (UARL). *gwf-Wasser | Abwasser, 165*(10), 65–74.
- Zipperer, D., & Koelbl, J. (2024b). Anwendung des Infrastruktur-Leckage-Index als Wasserverlustkennzahl am Beispiel rheinland-pfälzischer Wasserversorgungsunternehmen – Teil 2: Methodische und datenbezogene Herausforderungen. *gwf-Wasser | Abwasser, 165*(12), 63–72.

# Contact

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

**aquabench GmbH**
Cologne Branch

Am Westhover Berg 30
51149 Köln
Germany

www.aquabench.de