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Study on the Application of the Infrastructure Leakage Index (ILI) in Germany – Calculation Methodology, Analysis & Recommendations

Executive Summary

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1 Introduction

1.1 Purpose of the Project

Water losses in the drinking water network are an important indicator of the technical condition of the pipes. An increase in the incidence of pipe damage and water loss rates can be indicative of an increasing deterioration of the condition of the pipes. In addition, the water losses themselves as well as measures to reduce them (pressure management, active leak control, repair, rehabilitation) are sometimes associated with high costs. The precise determination of water losses as a key performance indicator in asset management is therefore of great importance.

The revised version of the EU Drinking Water Directive [1] came into force in January 2021 and shows the increasing importance of the topic of "water losses". In order to improve the efficiency of the existing water infrastructure and to preserve drinking water resources, the member states should assess their level of water losses and possibly initiate measures to reduce them. The assessment is to be carried out using the Infrastructure Leakage Index (*ILI*) or any other appropriate method. Transparency regarding water losses was also increased as part of the revision of the German Drinking Water Ordinance in June 2023 [2] for water utilities of a corresponding size in § 46 (2). In view of the new legislation, the focus on water loss management will continue to increase in the coming years. Water utilities are required to form an appropriate database in order to be precise with regard to their water losses.

The *Infrastructure Leakage Index* is an internationally used water loss indicator. It was introduced in 1999, specifically for the comparison of water losses between water supply systems with different characteristics and has been included since 2017 as part of the Technical Regulations in DVGW W 392 [3]. The indicator correlates the real annual water losses with the so-called unavoidable water losses. Whereas the real water losses are calculated or delimited via the water balance, the unavoidable water losses are derived from international studies and describe the "best practice" in water loss management.

Despite the apparent simplicity of the *ILI,* challenges arise in practice with regard to the quality and determination of the input data and with the uncertainty in the classification of the results. The latter is due to the fact that, according to the experience of IWW, other institutes and water utilities, *ILI* values < 1 occur more frequently. In the logic of the index, this would mean that the company's water losses would be below the limit of "unavoidability“, and one could conclude that the maintenance effort of water utilities tends to be too high. However, this statement often does not correlate with other findings about the condition of the water distribution system, such as pipe burst rates. In addition, many *ILI* values < 1 call into question the indicator itself.

The circumstances and causes of *ILI* values < 1 and the resulting misinterpretations of the pipe network condition have not yet been scientifically conclusively investigated. It is therefore important to clarify and facilitate the application of the *ILI* in the overall context of pipe network operation and maintenance. DVGW and its members should also be better equipped with knowledge and able to speak based on facts. The current discussion in Europe and EurEau on the implementation of the EU Drinking Water Directive in this regard increases the urgency of this basic research.

1.2 Project Objectives

The findings outlined above have raised the following questions:

- whether there is sufficient transparency and knowledge to calculate the *ILI,*
- how error-prone the individual input variables for calculation are,
- how valid the calculations of the water suppliers are and
- whether and to what extent the current equation for calculating the *ILI* and the resulting classification of the *ILI* values is correct for German water suppliers or whether it needs to be modified.

To answer these questions, the following project objectives were defined:

- increase transparency of the history and calculation of the *ILI,*
- compare the basic assumptions of the *ILI* with typical values of German suppliers,
- check the sensitivity of the individual input variables / influencing factors,
- provide assistance in calculating the various input variables, and
- provide recommendations for action on the classification and handling of the *ILI* in Germany.

2 Results

2.1 Infrastructure Leakage Index

The Infrastructure Leakage Index was developed in 1999 [4]. From a mathematical point of view, the *ILI* is the ratio between the Current Annual Real Losses (CARL) and the Unavoidable Annual Real Losses (UARL):

$$ILI = \frac{CARL}{UARL} = \frac{Q_{VR}}{UARL} \quad (1)$$

CARL is equal to the Q_{VR}. A low *ILI* value (*CARL ≈ UARL),* according to the logic of the indicator, means that the water distribution system is in good condition, as the real losses are approximately the same as the unavoidable losses. With an *ILI* value of one, the real water losses correspond to the so-called unavoidable water losses. Mathematically speaking (and also observed in practice), the *ILI can* also take values smaller than one.

The *ILI* is a component-based approach that takes into account different infrastructure components (water mains and service connections) and types of water losses (visible, non-visible but detectable and background losses) for the determination of the *UARL*, which gives this water loss indicator an advantage over the others. In addition, a comparatively large number of network structure parameters (pipe network length without service connection pipes, length and number of service connections), as well as the average operating pressure are included in the calculation as parameters.

As part of the empirical study on the development of the *UARL* equation, assumptions were made regarding pipe burst rates, leakage duration and leakage rates for the different infrastructure components and water loss types. They are included in the equation in the form of coefficients, with the data on water mains coming mostly from Germany, on service connections mostly from Great Britain and background losses mainly from England and Wales.

In the development of the original *UARL* equation, there was a differentiation between the length of the service connections to and from the property boundary. This *UARL* equation has been further developed to take into account the total length of the service connections and is also used in DVGW W 392 [3]. This equation is as follows:

$$UARL\left[\frac{m^3}{a}\right] = \left(6{,}57\left[\frac{m^3}{km*a}\right] * L_m\,[km] + 0{,}256\left[\frac{m^3}{a}\right] * N_c\,[-] + 9{,}125\left[\frac{m^3}{km*a}\right] * L_t\,[km]\right) * p\,[mWS] \quad (2)$$

Whereby:

L_m = Pipe network length without service connections
N_c = Number of service connections
L_t = Total length of service connections
p = Average operating pressure in the pipe network

2.2 Plausibility Check of the *UARL* assumptions

The *UARL* coefficients are calculated from the burst frequency, flow rate of leaks and duration of leaks at a given pressure. The question arises as to the extent to which the values from the 1990s on which the *UARL* is based are still applicable to today's German water distribution systems. For this purpose, comparative data from German water supply companies were compiled for damage rates, duration and leak rates and compared with the *UARL* input data.

Table 1 shows the limits of low damage rates according to DVGW W 402-B1 [5], the original assumptions of the *UARL* as well as the average values from the GaWaS (from German: Gas and Water Statistics) survey 2016 / 2017 [6] for different infrastructure components. This is an indication that the actual loss rates in Germany are below those for the *UARL* equation. No general statement can be made for duration and leak rates due to a lack of data. However, the sample data from two German water supply companies do not contradict the *UARL* assumptions regarding the duration of leaks and leak flow rates.

Table 1: Comparison of damage rates (Sources: [7], [8] and [6])

Infrastructure component	**W 400-3-B1 (excl. valve damage)**	**UARL1999 (incl. valve damage)**	**GaWaS 2016/2017 (excl. valve damage)**
Mains	Limit low: < 0.1 bursts/(km*a)	Total reported + unreported: 0.13 bursts/(km*a)	Average: 0.078 bursts/(km*a)
Service connections (total)	Limit low: < 5 bursts/(1,000 pcs.*a)	Total reported + unreported: 5,0 bursts/(1,000 pcs.*a)	Average: 2.7 bursts/(1,000 pcs.*a)
Service connections, Main to edge of the street	Not recorded separately	Total reported + unreported: 3,0 Bursts/(1,000 pcs.*a)	Not recorded separately
Service connections, edge of the street to meter (for 15 m avg. length)	Not recorded separately	Total reported + unreported: 2,0 bursts/(1,000 pcs.*a)	Not recorded separately
Shut-off valves and hydrants	Limit low: < 25 bursts/(1,000 pcs.*a)	Are taken into account in the lines	Not evaluated (survey error)

2.3 Sensitivity of *UARL* input variables

The above-mentioned basic assumptions of the *UARL* equation were tested for their sensitivity. The aim was to determine, among other things, how sensitive is the *ILI* on a change in the values of the four input variables of the *UARL* equation. For this purpose, the values of the *UARL* input variables are varied from -100% to +100% (Figure 1). The real losses *CARL* were kept constant. The calculation was made based on a sample water utility with the following characteristics:

- L_m= 170 km
- N_c= 7,000 pcs.
- *CARL* = 350,000 m³/a
- *p*= 50 m
- L_t= 100 km
- *UARL* = 191,070 m³/a (at 0% change)
- *IL I*= 1.83 (at 0% change)

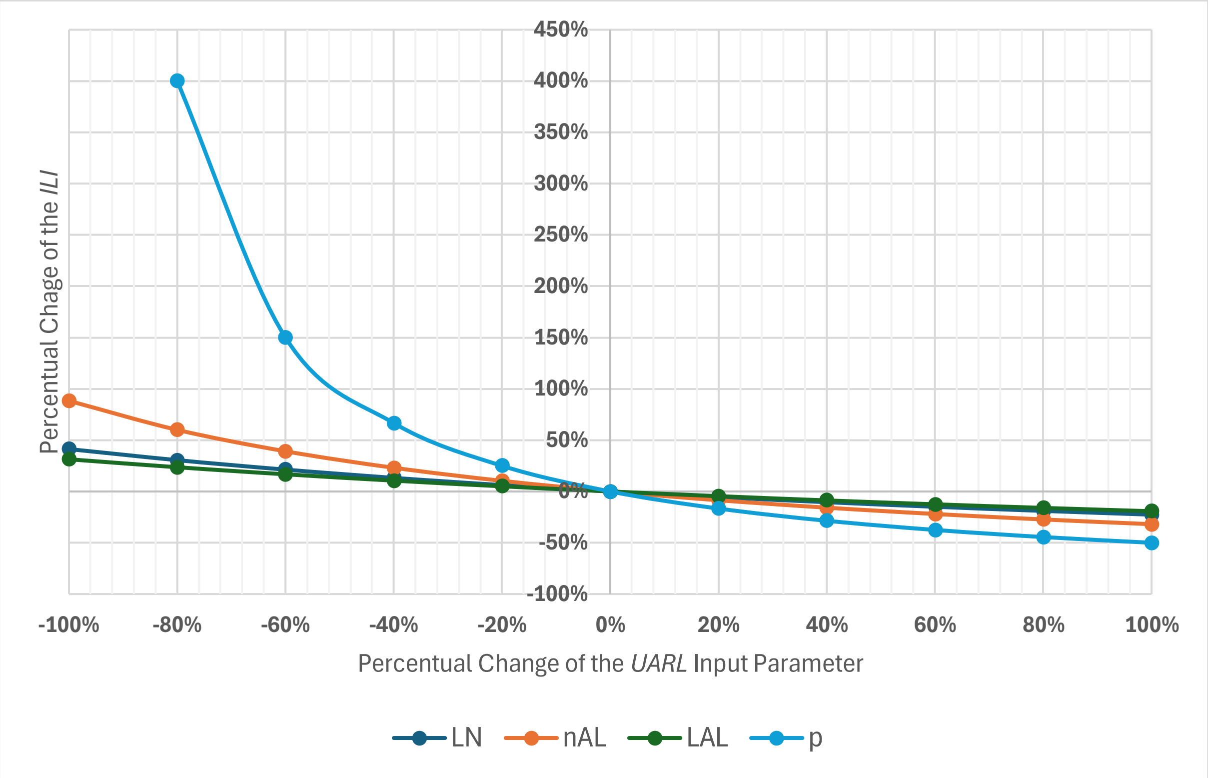

Figure 1: Sensitivity of the *UARL*-Input variables (Source: IWW)

The analysis shows that the average operating pressure is by far the most sensitive input variable. This is followed by the number of service connections. However, the sensitivity of the pressure increases sharply with an increase in the percentage change (non-linear behaviour). If the pressure is varied in a small interval of -10% to +10%, there is still an almost linear relationship with a change in the *ILI* of +11% to -9%. However, a greater underestimation of the mean operating pressure in particular leads to a sharp increase in the *ILI.*

2.4 Calculation Guidelines

Calculation guidelines were included for the most sensitive input variables of the *UARL* equation (operating pressure, number and length of service connections). These are intended to further reduce errors and uncertainties in the calculation of the *ILI*. Approaches of varying complexity for the calculation of the average operating pressure and the number or length of the service connections were demonstrated. The digitization of pipe network plans is the prerequisite for determining the input variables of the *ILI.*

To determine the average operating pressure, different approaches were investigated that can be implemented without a digital pipe network plan by using individual pressure measurements, as well as those that can be implemented with the help of digital pipe network plans or computer network models. Between the approaches for determining the mean operating pressure, deviations in accuracy of up to 5 % could be observed on the basis of an example. Table 2 summarizes the advantages and disadvantages of the proposed methods for determining the mean operating pressure.

Table 2: Comparison of approaches to pressure determination (Source: RBS wave)

<table>
<tr><th>Determination based on topography</th><th>Individual measured values in the pipe network</th><th>Computational network model</th></tr>
<tr><th colspan="3">Advantages</th></tr>
<tr><td>Applicable when a digital plan of the pipe network is not available</td><td>Applicable when a digital plan of the pipe network is not available</td><td rowspan="3">Highest accuracy, as the pressure is calculated to all pipe sections</td></tr>
<tr><td rowspan="2">Can be used for simple water supply structures and simple topography</td><td>No computational pipe network model necessary</td></tr>
<tr><td>Pressure losses in the network are taken into account</td></tr>
<tr><th colspan="3">Disadvantages</th></tr>
<tr><td>Pressure losses in the network are not taken into account</td><td>Additional effort needed to obtain the measurements</td><td rowspan="3">If necessary. Increased effort for the annual simulation or the modelling of a typical diurnal cycle</td></tr>
<tr><td>A possible source of error is the weighting of the reference points by the associated pipe sections</td><td rowspan="2">Sources of error, if the measuring points are poorly chosen and the network topology is not fully represented,</td></tr>
<tr><td>Additional pressure measurements may be necessary to determine the difference between static and operating pressure at reference points</td></tr>
</table>

The estimation of the average operating pressure on the basis of individual measurements is possible, but not recommended. Reliable results are achieved with a (calibrated) pipe network models and the highest possible resolution modelling of consumption patterns (e.g. annual cycle of pressures). Various approaches were also shown for determining the length and number of service connections. It is also the case that greater accuracy can be achieved with increasing digitization of the network plans. In the digitization of pipe network plans, approaches for the semi-automatic generation of the service connections can be applied.

2.5 Case studies and analyses

Practice shows that even with a data set with verified customer data from GIS systems and existing calibrated hydraulic pipe network models, *ILI* values < 1 can occur. In the data set examined, a total of 35 of the 49 water utilities had a calculated *ILI* value < 1. According to this, 71 % of the water utilities are below the so-called unavoidable losses (according to the *ILI* concept) defined for them. On the other hand, strictly speaking, the definition of so-called unavoidable water losses only applies to the remaining 29% of water utilities. Despite known reasons for the occurrence of such values, the proportion appears too high. Table 3 shows the essential statistical parameters of the determined *ILI* values on the 49 water utilities analysed.

Table 3: Statistical classification of the calculated *ILI* values (Source: RBS wave)

	Calculated *ILI* values					
Specific System Input Volume[1]	**MIN**	**10%-Percentile**	**MEDIAN**	**AVERAGE VALUE**	**90%-Percentile**	**MAX**
Total (n = 49)	0,13	0,39	0,71	1,18	2,36	8,61
High (n = 9)	0,58	0,69	1,42	2,29	4,57	8,61
Medium (n = 35)	0,13	0,37	0,71	0,99	1,93	4,94
Low (n = 5)	0,22	0,24	0,40	0,44	0,65	0,67
Low + Medium (n = 40)	0,13	0,34	0,66	0,92	1,93	4,94

[1]: Classification according to DVGW W 400-3-B1 Table 2b

If the water losses are compared on the basis of various water loss indicators, with the help of case studies it can be shown that highly divergent network structures can lead to high deviations between different water loss indicators, despite significant correlation between them.

2.6 Classification of *ILI* values

Using the classification of the *ILI* according to DVGW W 400-3-B1 [7] Table 2a, 100 % of the 6 water utilities with low, 88 % of the 34 utilities with medium and 78 % of the 9 utilities with high specific system input and fall into the range of low water losses (Table 4). In addition to the occurrence of *ILI-Values* < 1, the associated classification also leads to a certain scepticism towards the *ILI* as a performance indicator.

Table 4: Classification of the examined water utilities according to the *ILI* (Source: RBS wave)

Water losses according to *ILI*	**Specific system input volume**		
	Low	**Medium**	**High**
Low	100 %	88 %	78 %
Medium	0 %	9 %	11 %
High	0 %	3 %	11 %

The classification of water losses based on the q_{VR} according to DVGW W 400-3-B1 [7] Table 2b is different in comparison (Table 5). Although 100 % of the water utilities with low specific system input volume are in the range of low water losses, only about 20 % of those with medium and high specific system input volume are classified as low. It should be noted here that the q_{VR} does not include pressure as an input variable. According to the DVGW W 400-3-B1 [7] the classification of the q_{VR} is related to an average operating pressure of 3.5 bar[1]. Thus, the comparison of water utilities with large pressure differences with this indicator is rather problematic.

Table 5: Classification of the examined water utilities according to the q_{VR} (Source: RBS wave)

Water losses according to q_{VR}	Specific system input volume		
	Low	**Medium**	**High**
Low	100 %	21 %	22 %
Medium	0 %	50 %	33 %
High	0 %	29 %	45 %

The comparison between the q_{VR} and the *ILI* of the examined data set shows that the classification of water losses with the q_{VR} according to Table 2b in DVGW W 400-3-B1 [7] is much stricter than the classification by means of the *ILI* in Table 2a. Thus, the *ILI* with the current classification of water losses shows a significantly "better", i.e. lower classification of water losses than the q_{VR}. For example, there are cases in the data set under investigation in which the losses of a water utility according to the *ILI = 1.92* are classified as low and, on the other hand, according to the q_{VR} with 0.25 m³/(h*km) classified as high. The percentage water losses in the example are 23 %. These discrepancies occur in particular with low specific system input volumes.

Certain differences in the classification of *ILI* and q_{VR} are not surprising in view of the different parameters used in the formation of the indicators. Nevertheless, the question arises as to the extent to which the classification of different indicators can be carried out in such a way that misinterpretations of the amount of water losses depending on the performance indicator used don't occur and thus obtaining a more uniform picture of the situation.

It is recommended to use other water loss indicators, such as the q_{VR}, to check the plausibility of the absolute classification of the *ILI*. In general, interpretations and decisions derived from performance indicators should never be based on just one. For this reason, useful contextual information in the form of environmental, maintenance and condition data were presented for a better interpretation of water losses. In combination, this contextual information allows an assessment of the difficulty in reducing water losses, possible causes and appropriate maintenance measures to reduce them.

Although the basic information mentioned above helps to better classify the result of the water loss indicators in the overall context, they do not address the contradictions in the classification. Figure 2 clarifies the general relationships between various performance indicators. It shows the determination of the percentage of water losses as a function of the specific system input volume and the specific *UARL* (based on the length of the pipe network without service connections) with a *ILI* = 1 (*CARL* = *UARL*). For the average spec. system input volume (10,432 m³/(km VL * a)) and the average spec. *UARL* (1,221 m³/(km VL * a)) of the 49 water utilities examined, this would mean that the "unavoidable" percentage losses are 11.70%. However, if one assumes a smaller specific system input volume of 5,000 m³/(km VL * a), the percentage water losses would be approx. 24 % with an *ILI* = 1.

[1] It is unclear what the assumption of 3.5 bar is based on.

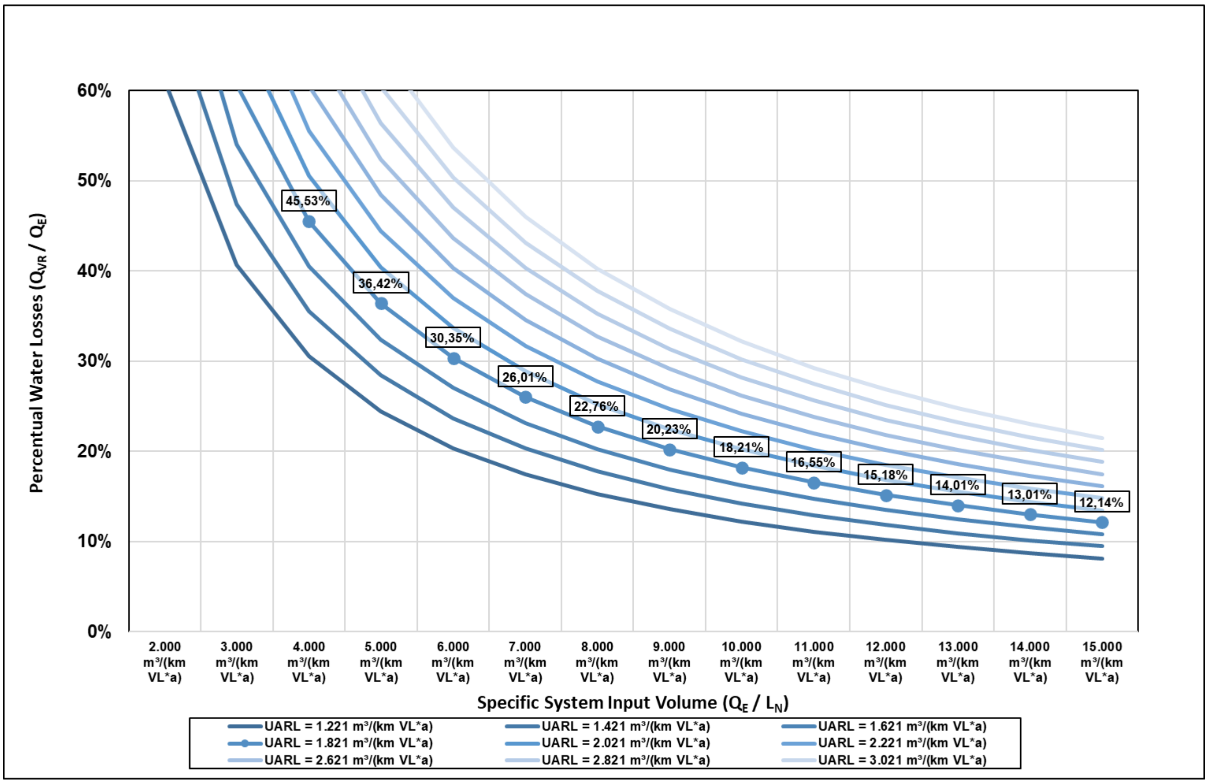

Figure 2: Determination of the percentage of water losses depending on the specific system input volume and the specific *UARL* with a *ILI* = 1 (Source: Kukuczka)

With regard to these contradictions in the classification of the *ILI* compared to other water loss indicators, there are various options for action. On the one hand, you can calculate the *ILI* so that it results in different values, or you can adjust the classification so that the interpretation of the values changes. The advantages and disadvantages of various options for action were discussed. Overall, adaptations of the classification are preferable because they can take into account country-specific conditions, so that average water losses due to a high service standard in a given country are low by international standards. The comparability of the values is maintained due to the use of the same equation and allows interpretation in different contexts. The example of an adaptation of the classification of the *ILI* with regard to the classification according to system structure size and changed classification limits, can be found in the ÖVGW guideline W 63 [9]. However, even this classification system would not change the fact that the *ILI* values of a large part of the water utilities of the investigated data set is in the range of low water losses.

3 Conclusions and outlook

3.1 Conclusions

When choosing a (water loss) indicator, one should first be clear about the intended use. This applies to both the systems considered (internal / external comparison) and the dimensions (technical, economic, ecological).

The *ILI* is particularly suitable for comparison between water utilities. Other indicators can also be used for internal comparisons if the framework conditions remain constant. In an absolute comparison, the *UARL* value should be seen as a reference value (year 1999 and a specific data set). Even the developers of the *ILI* are now critical of the term "unavoidability".

In general, interpretations and decisions derived from indicators should never be based on only one. It is recommended to use other (water loss) indicators to check the plausibility of the absolute classification of the *ILI*. The advantages and disadvantages of different indicators were discussed extensively. Even if water losses are classified as low from a technical point of view, there may still be economic or ecological reasons (e.g. water scarcity) for further reduction.

The *ILI* is an established indicator that takes into account most of the influencing variables of water losses compared to other indicators. Especially when looking at different systems with different characteristics, a fair (at least relative) comparison is thus made possible, while taking into account the "aggravating factors" for water losses. The comparison of the basic assumptions of the *ILI/UARL* (damage rates, leak rates, duration) with existing data gives reason to assume that the "unavoidability" of water losses in Germany is to be assessed as lower. However, this could not be conclusively assessed due to the lack of comprehensive data on leak rate and duration.

The data from the 49 water utilities examined confirm the assumption that *ILI* values <1 are not the exception in Germany but are fairly common. In comparison with other water loss indicators, there is currently no uniformity, which is due on the one hand to the different concepts and data used in the formation of the indicators, but also to their classification. In practice, this leads to problems of interpretation and evaluation.

There is a need for a joint classification and interpretation of the indicators in relation to each other. It should be noted that both solutions in the direction of a modification of the *ILI* and *UARL* equations as well as the classification of the *ILI* has an influence on the comparability of *the ILI* values (national / international). However, adaptations to classification are preferable.

3.2 Outlook

There is a need for further research and adaptation of the DVGW regulations with regard to i) the joint classification and interpretation of water loss indicators, ii) the classification of contextual information for better interpretation of indicators, iii) the improvement of the database and iv) the investigation of the uncertainties of water balances.

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