German National Report
Water Loss Management and Techniques

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1. Introduction

In Germany, the DVGW Worksheet W 392 "*Monitoring of Pipework and Water Losses - Measures, Procedures and Analyses"* has now been redrafted. The reworked version leans strongly on the contents of the IWA Blue Pages "Losses from Water Supply Systems".

The usual figures for water losses previously found acceptable in Germany were in the order of 0.05 to 0.6 m^3/h x km depending upon the type of ground in which the pipework was installed. These have now been replaced by new figures for technical losses (see Figs. 2 and 3). Based on the data contained in the IWA Blue Pages, they take into account the density of the housing area connected to the system and the differing levels of mains supply. The limitation to specific loss levels of max. 0.25 m^3/h x km (corresponds to a percentage loss of max. 15%) was set particularly with the 3 bar average supply pressure customary in Germany in mind.

2. Components of Water Balance and Calculations

The main definitions in the new DVGW Worksheet W 392 are (Fig 1):

- *System Input Volume Q_N* is the annual volume input to a transmission and/or a distribution system, including water exported to other supply systems.
- *Authorised Consumption Q_A* is the annual volume of metered and unmetered water by authorised customers. It includes exported water and items such as fire-fighting, flushing of mains and sewers, watering of public gardens, public fountains etc.
- *Water Losses Q_V* for a whole system or for a partial system are calculated as the difference of Systems Input Volume and Authorised Consumption. The Water Losses consist of Real and Apparent Losses.
- *Real Losses Q_{VR}* are physical losses of leaks, bursts and overflows from the pressurised system, up to the metering point on the service connections.
- *Apparent Losses Q_{VS}* consist of all types of inaccuracies (input, output, customer meters) and unauthorised consumption (theft, any illegal use).
- *Non Revenue Water Q_{NR}* is the annual volume of Water Losses and Unbilled Authorised Consumption.

<table>
<tr><td rowspan="10">System Input Volume Q_N</td><td rowspan="4">Authorised Consumption Q_A</td><td rowspan="2">Billed Authorised Consumption Q_{AI}</td><td>Billed Metered Consumption</td><td rowspan="2">Revenue Water Q_{IR}</td></tr>
<tr><td>Billed Unmetered Consumption</td></tr>
<tr><td rowspan="2">Unbilled Authorised Consumption Q_{AN} (1)</td><td>Unbilled Metered Consumption</td><td rowspan="8">Non Revenue Water Q_{NR}</td></tr>
<tr><td>Unbilled Unmetered Consumption</td></tr>
<tr><td rowspan="6">Water Losses Q_V</td><td rowspan="3">Apparent Losses Q_{VS}</td><td>Metering Inaccuracies</td></tr>
<tr><td>Unavoidable Losses</td></tr>
<tr><td>Unauthorised Consumption</td></tr>
<tr><td rowspan="3">Real Losses Q_{VR}</td><td>Leakage on Transmission Mains
Leakage and Overflows at Utility's Storage Tanks</td></tr>
<tr><td>Leakage on Distribution Mains</td></tr>
<tr><td>Leakage on Service Connections up to the meters point</td></tr>
</table>

All quantities Q in m^3 / year

(1) e.g. fire fighting requirements, sewer and street cleaning, hydrant and pipe flushing, frost protection, return flushing water, watering public areas.

Fig 1: DVGW Worksheet W 392: Components of Water Balance for Distribution- and/or Transmission Systems.

3. The Factors Affecting Real Water Losses Q_{VR}

There are several decisive local factors that affect real water losses. These are:

- The length of mains L_N,

- The length and the number of service connections between the mains and the metering point. The service connections can be considered to be the weak point of most distribution systems, as they lead to high failure rates and large loss volumes (leaks are usually low but they have a flow rate of long duration),

- The average operating pressure, when the system is pressurised. With increasing pressure, leakage rates rise to a much larger extent than would be predicted by the theoretical "square root relationship" between pressure and leakage rates. Opportunities for pressure management are usually restricted by local topography and standards of service,

- Infrastructure conditions, e.g. materials, frequencies of leaks and bursts,

- The type of soil
  Within the various types of soil, there are three parameters - which can overlap - of importance, namely:

  Corrosion
  (soil aggressivity generally increases from non-binding to binding soil types, see also DIN 50 949)

  Movement processes in soil
  (binding soil types tend more than non-binding types to ground movement, as their water content fluctuates)

  Detection of leaks
  (the detectability of damage by water leaking to the surface is considerably more difficult e.g. in gravel and fissured rock than in other types of earth).

4. Technical Performance Indicators for Real Losses Q_{VR}

Traditional Pis of water losses are frequently expressed as a percentage of Input Volume. This indicator however fails to take account of any of the main local influences.
When losses are given in per cent of input volume, major input volumes (e.g. municipal systems with correspondingly high specific network supply rates per km of pipework) lead to lower percentage water loss levels. Lower input volumes (e.g. rural supplies with correspondingly low specific network supply rates per km of pipework) lead to higher percentage water loss levels. When comparing water losses given in percentages it would appear that a water supply with higher specific network supply rates is always more favourable as one with lower specific network supply rates.

As a result, the ratio of real losses to the length of the mains network L_N is used as the technical indicator for the specific real losses q_{VR}. This technical indicator can thus be calculated using the following formula:

$$\text{spec. real losses } q_{VR} = \frac{Q_{VR}}{8760 * L_N} \quad (m^3 / h * km)$$

where
Q_{VR} = real losses in m^3/a
q_{VR} = spec. real losses in $m^3/h * km$
L_N = the length of mains in km, without service connections

With the connection density (number of service connections, SC per km on the mains) the specific real loss q_{VR} (m^3 / km h) can also be expressed by the unit m^3 / SC d, often used internationally.

5. A Rough Numerical Guide for Water Losses

As a rough guide framework, Fig. 3 gives figures for specific real losses for the categories city, town, and rural supply structures. The nominal figures in Fig. 2 show how a water supply relates to each of these supply structures. The main factor when deciding under which supply structure a mains network is to be classified in the table in Fig. 2, is the nominal volume of the specific mains supply q_N in m^3 / km a.

Nominal Volume	Supply Structure		
	City	Town	Rural
Residents supplied 1000 E	> 100	10 - 100	< 10
Spec.mains supply (1),q_N 1000 m^3/km a	> 15	5 -15	< 5
Spec.service connection supply m^3/SC a	300 - 600	200 - 400	50 - 200
Service connection density (2) SC/km	> 40	25 - 40	< 25

Fig 2. Nominal volumes for each supply structure

Water loss category	Approximate spec. water losses q_{VR} in m^3/km a		
Low water loss	< 0.13	< 0.07	< 0.05
Medium water loss	0.13 – 0.25	0.07 – 0.15	0.05 – 0.10
High water loss	> 0.25	> 0.15	> 0.10

Fig. 3: Approximate figures for real spec.water losses q_{VR} in distribution networks.

(1) Excluding supply to sub-distributors and major customers; q_N varies within a bandwidth of 2000 to 40000 m^3/km a

(2) Greater fluctuation ranges occur in individual cases; the service connection density varies within a bandwidth of 5 to 60 SC/km.

An assessment of specific real water losses q_{VR} in mains supplies can be given for the following ranges:

Low losses:
In pipework systems that have developed over a considerable period of time, low real loss levels can occur, even when the system is in good condition. Generally, minimal losses of this kind cannot be reduced further.
Expressed as a percentage of the input volume, minimal losses fall roughly in the range of less than 8%, irrespective of the supply structure.

Medium losses
The specific water loss established in a pipework system should at least be within this range, i.e. not exceed twice the minimal loss rate.
Expressed as a percentage of the input volume, such medium losses fall roughly in the range of from less than 8% to less than 15%.

High losses
Specific water losses at this level call for special action to reduce them.
Expressed as a percentage of the input volume, such high losses fall roughly in the range above 15%.

6. Monitoring the Pipework Systems Relative to Real Water Losses

High levels of damage and water loss require frequent monitoring and necessitate loss reduction or a regime for continuously monitoring the pipework system has to be installed. Low levels of damage and unavoidable real losses, allow less frequent monitoring regimes. The loss rates usually encountered in Germany are in the medium range.

If there is no continuous monitoring for leaks, the following monitoring frequency rates are recommended, depending upon the level of specific real water losses q_{VR} :

Spec. real water losses q_{VR} (m3/km h) Rough guide as per Fig. 3	Recommended monitoring frequency
High water losses	annually
Medium water losses	every three years
Low water losses	can be dispensed with

Fig.4: Recommended frequency rates for monitoring pipework systems for leaks

7. Failure Statistics

In the context of water loss reduction, a systematic weak point analysis is indispensable for network rehabilitation.
With the DVGW Notice W401 *"Decision Aids for the Rehabilitation of Water Pipework Systems"* and the DVGW Worksheet W395 *"Damage Statistics for Water Pipework Systems"*, water supply companies in Germany have access to basic guidelines on accumulating damage statistics in the field of pipework systems. The DVGW has introduced a nationwide Water Damage Statistics document and has the results from approx. 500 member companies.
The introduction of the DVGW Water Damage Statistics document, which embraces many companies, is one contributory factor in the recording of systematic weak points and the

misdirected development of components for water supply systems, on a sound representative basis. It is also used as a basis for deriving the necessary specifications and requirements within a context of product standardisation.

	Documented length (km)	Documented incidents (number)	Damage rate number per 100 km
Cast iron pipes	21173	5658	27
Ductile cast pipes	13958	375	3
Steel pipes	4799	1602	33
PE pipes	1350	250	18
PVC pipes	4072	183	4
Galv. pipes	2267	503	22
Total	**47619**	**8571**	**18**

Fig. 5 Damage rates to supply pipes

Fig. 5 shows the damage rate for supply pipes, broken down by pipe material and recorded length. Whilst a relatively high damage rate on cast iron, galvanised and steel pipes (corrosion) that are exposed to risk of fracture bears out the experience gained in practice, the relatively high figures for PE pipework are surprising. In this context however, it should not be forgotten that this rate is significantly affected by the high proportion of PE pipework laid some time ago in the new Federal States.

	Documented number	Documented incidents (number)	Damage rate number per 1000 fittings
Slide valves/flaps	384578	5825	15
Drilling fittings	898757	8271	9
Surface hydrant	11053	593	54
Underground hydrant	280674	5470	19
Total	**1575062**	**20159**	**13**

Fig. 6 Damage rates on fittings

Fig. 6 shows the damage rates on fittings. The relatively high damage rates on hydrants and slide valves are primarily explained by the old fittings that are still to be found in the network.

	Documented number	Documented incidents (number)	Damage rate number per 1000 HA
Steel pipes	556468	5744	10.3
PE pipes	577084	2086	3.6
PVC pipes	68848	101	1.5
Lead pipes	124584	2915	23.4
Other	207928	787	3.8
Total	**1534868**	**11633**	**7,5**

Fig. 7 Damage rates on service connection pipes

Fig. 7 shows the damage rates on service connection pipes broken down by pipe material. Amongst the documented total figure of 1.5 million service connection pipes, a total of approx. 11,600 damage incidents were reported, a figure that corresponds to an average damage rate of 7.5 incidents per 1000 service connections. A direct comparison can be made between this average and the damage rates for mains supply pipes.

Assuming an average length of 12 m per service connection, the average then equates to 63 damage incidents per 100km/year compared to an average rate of 18 incidents per 100km/year for mains supply pipes.

8. Active Measures for Monitoring Losses

For the monitoring, reduction and maintenance of a low rate of water loss, a basic strategy is recommended for Germany, which can be achieved with the technical and economic means available today. This strategy should include the following operational stages:

- Detection of water losses
- Technical and economic evaluation of water losses
- Leakage location
- Damage repair
- Documentation of the mains monitoring
- Mains rehabilitation

The requisite cost of the active measures and inspection regime is based on the level of real losses. The cost is approx. DM 300 to 600 km of network/a for inspection and loss control. Key economic data for losses are included in the revised version of W 392.

9. FUTURE AND TRENDS
New procedures for continuous monitoring and repetitive loss reduction procedures

The continuous supply measurement (minimum night-time consumption) and the intermittent district measurement (zero consumption) should not be viewed as contradictory; they are often

combined successfully (Fig. 8). The greatest long-term success is achieved by continuously monitoring small measured districts or pressure zones by supply measurement.
However, certain requirements must be placed on the measuring equipment used for continuous supply monitoring as it is required to cover a large measured range, often has to be retrofitted, and should include a secure data storage or remote transmission facility. District measurement has so far been introduced on only a few mains networks. Pressure management is not normally employed for loss reduction in Germany, as the supply pressure in the mains is specified (on average 3 to 5 bar).

Method	Assessment	General Conditions
Continuous supply measurement (minimum night-time consumption)	Losses can be detected relatively easily. In order to keep losses to a minimum, immediate leakage tracing and repair is essential	- Installation of supply measurement equipment - Measured area: 4 to 30 km network length - Measured period: min. 1-2 h daily - Daily measurement recording - Non-delayed measurements and transmission - Leakproof slide valve - Unambiguous supply measurements - Inclusion of all supply and return flows in the area measured
Area measurement (zero consumption)	Existing losses can be detected immediately; however, as this is the instantaneous measurement of a small section of the network, evaluation of the total loss is not possible	- Measured area: 1 to 10 km network length - Measured period: min. 20 minutes -Transportable supply measurement equipment - Leakproof slide valve - Evaluation of permanent consumers - Residual consumption estimating - Monitoring mains pressure during the period measured

Fig. 8: Leak measurement procedure

In the final analysis, the location i.e. the identification of leaks is crucial to the success of any loss strategy. This is understood to include procedures using equipment that permit leaks to be detected with precision. The most useful approach is first to limit the search to network sections or pipe runs by flow measurement procedures (initial location). The actual leakage location procedure should then, in a second step, permit the individual leaks to be located precisely.

In Germany, the following leakage location procedures are customary:

- Auditory location
- Sound level measurement procedures
- Correlation measurement procedures

10. CONCLUSIONS

In Germany, the IWA recommendations for defining and locating real losses are viewed favourably and are therefore also included in the DVGW standard documentation.

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