SCHRIFTENREIHE ZUR WASSERWIRTSCHAFT

TECHNISCHE UNIVERSITÄT GRAZ

Joerg Koelbl

# Process Benchmarking in Water Supply Sector: Management of Physical Water Losses

56

Herausgeber:
Univ.-Prof. DDipl.-Ing. Dr.techn. Dr.h.c. Harald Kainz

Technische Universität Graz, Stremayrgasse 10, A-8010 Graz
Tel. +43(0)316 / 873-8371, Fax +43(0)316 / 873-8376
Email: office@sww.tugraz.at, Internet: www.sww.tugraz.at

Verlag der Technischen Universität Graz **www.ub.tugraz.at/Verlag**

ISBN 978-3-85125-055-8

Bibliografische Information der Deutschen Bibliothek: Die Deutsche Bibliothek verzeichnet diese Publikation in der Deutschen Nationalbibliografie; detaillierte bibliografische Daten sind im Internet über http://dnb.ddb.de abrufbar.

Printed by TU Graz / Büroservice

# Vorwort des Herausgebers

Wasserverluste aus Trinkwasserversorgungssystemen stellen weltweit eines der größten Probleme hinsichtlich Versorgungssicherheit, aber auch hinsichtlich der hygienischen Qualität des Trinkwassers dar. Auch für Rohrnetze in gutem Zustand ist das Wissen über die Wasserverluste und das Management von Wasserverlusten essentiell. Neben Schadensraten liefert die Kenntnis über die Höhe der Wasserverluste eines Versorgungssystems wichtige Informationen für die Instandhaltungsplanung.

Dipl.-Ing. Dr. techn. Joerg Koelbl hat in seiner Dissertation ein Benchmarkingsystem für den Prozess des Wasserverlustmanagements in Trinkwassernetzen entwickelt. Dieses System ermöglicht die Analyse der verschiedenen Aufgaben des Wasserverlustmanagements in qualitativer und quantitativer Hinsicht und unterstützt im Erkennen von Stärken und Schwächen und in der Ableitung von Verbesserungsmaßnahmen.

Die Arbeit von Dipl.-Ing. Dr. techn. Joerg Koelbl lieferte auch Beiträge zur ÖVGW Richtlinie W 63 (in Druck), welche parallel zu dieser Dissertation überarbeitet wurde. Unter anderem wurde ein neu entwickeltes Klassifikationsschema für Wasserverluste in diese Richtlinie aufgenommen.

Graz, im Juli 2009

Harald Kainz

**Acknowledgement**

This thesis has been developed with the support of several persons to whom I would like to express special thanks.

First of all I would like to thank Professor Kainz for giving me the chance to join the University of Technology in 2002. He encouraged me to write this thesis, supervised it and gave helpful input in this work.

Special thanks also to Professor Haberl for being the 2nd referee of this thesis and for his comments.

Moreover I would like to thank Heimo Theuretzbacher-Fritz for several exciting and informative years of work – especially in the benchmarking projects - and for all his inputs in this thesis.

I would like to express thanks to Roland Liemberger for arousing my interest in water loss management and for inspiring me with his stories about water loss management in several parts of the world. Roland has also supported my participation in the IWA Water Loss Task Force (WLTF) as well as the IWA LAMIC Task Force – thereby creating very valuable contacts for this thesis. Beside Roland I also would like to thank Dewi Rogers for the work in the NRW Management Process Mapping Initiative of the WLTF. Some aspects of this initiative have been used in this thesis.

I would also like to thank Allan Lambert for numerous emails discussing the challenges in calculating the Infrastructure Leakage Index.

Special thanks also to David Main and Peter Stahre for sharing information about benchmarking projects in Canada and in Scandinavia.

Thanks are also expressed to Peter Martinek and Dieter Martinek for their support and for sharing information about multi-parameter measurements.

Also I would like to express thanks to the Austrian Association for Gas and Water (OVGW) and all participating water utilities for enabling and supporting the Austrian benchmarking projects in the water supply sector. Together with my project colleagues from University of Natural Resources and Applied Life Sciences in Vienna several benchmarking projects have been carried out - fruitful years of work, for which I would like to thank Roman Neunteufel, Ernest Mayr and Reinhard Perfler. Also I would like to thank all members of the working group for the OVGW directive W 63 about water losses for their critical comments and the exciting discussions.

Special thanks are expressed to my former employers Christian Kaiser and Thomas Mach who gave me the opportunity to practice planning of water supply and sewerage systems.

I would like to thank all members of our Institute for their colleagueship. I will treasure countless discussions with Professor Kauch, Daniela Fuchs-Hanusch, Gerald Gangl and Franz Friedl and others. Special thanks to Gerryshom Munala from Kenya for proof reading this thesis and for sharing information about the challenges in water management in Africa.

The person who has been mainly responsible for my way back from the private sector to university in 2002 is my uncle Franz Mascher – I would like to thank him for his support.

Last but not least I would like especially thank my parents for their support over all the years.

## Preface of Author

Water losses from drinking water supply systems are one of the greatest problems worldwide not only regarding supply safety (quantity) but also regarding the provision of safe potable drinking water (quality). Many water supply systems are in such a bad condition that only an intermittent supply with water is possible and more than the half of the water is often lost on the way to the customer. Intermittent supply causes an especially high risk of contamination by entering the water distribution system through leaks.

Decision makers often tend to try solving the problem by opening up new resources but this is a fight against the symptoms and not against the real causes. Figure 1 humorously aids understanding of the crucial point of the problem.

But the knowledge about water losses and the management of water losses is also still very important if the supply network is in good condition. Water losses are the only directly measureable indicator for the condition of a pipe network and are, therefore, an important basis for maintenance and rehabilitation planning.

Due to different frame conditions (e.g. the structure of supply network or resources available), but also due to the rapid development of technical equipment for leakage monitoring and leak detection, it is difficult for a single water utility to find the best water loss management strategy and to adopt the own strategy. Therefore, the need for a system that enables a comparison of the process of water loss management regarding effectiveness and efficiency has become apparent.

This is one of the motivations for this work, which has the purpose of developing a process benchmarking system for the process of water loss management. This system should support process analyses and the derivation of optimisation measures to achieve best practices in water loss management for individual utilities.

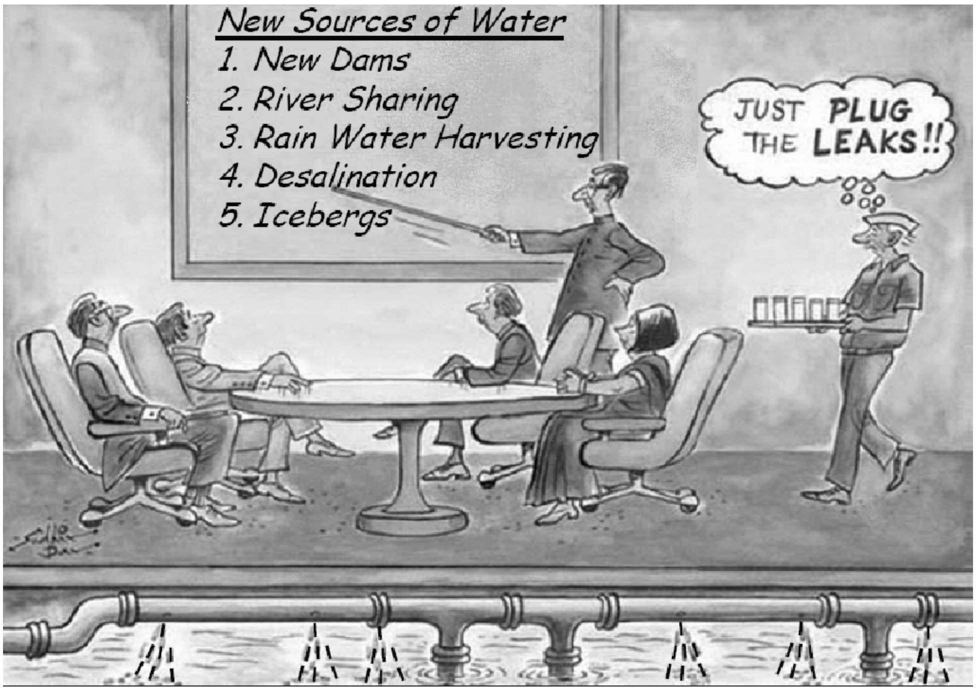


**Figure 1: Understanding the problem of leakage (source: Water and Sanitation Program of the World Bank, in LIEMBERGER 2007)**

**Vorwort des Autors**

Wasserverluste aus Trinkwasserversorgungssystemen stellen weltweit eines der größten Probleme hinsichtlich Versorgungssicherheit (Quantität der Versorgung), aber auch hinsichtlich hygienischer Qualität des Wassers dar. Viele Wasserversorgungssysteme sind in einem derart schlechten Zustand, dass keine kontinuierliche Versorgung mit Trinkwasser möglich ist. Häufig geht in solchen Systemen mehr als die Hälfte des Wassers am Weg zum Kunden verloren. Diskontinuierliche Versorgung bringt auch ein enormes hygienisches Risiko mit sich, da über Leckagen Verunreinigungen ins Rohrnetz gelangen können.

Entscheidungsträger erkennen das wahre Problem der Wasserverluste häufig nicht und tendieren oft dazu, eher die Symptome als die Ursachen zu bekämpfen. Figure 1 bringt das wahre Problem in einer lustigen Art und Weise auf den Punkt.

Aber auch für Rohrnetze in gutem Zustand ist das Wissen über die Wasserverluste und das Management von Wasserverlusten essentiell. Denn Wasserverluste sind der einzig wirklich direkt messbare Indikator für den Zustand der Rohrnetze. Daher stellen Wasserverluste ein wichtiges Entscheidungskriterium für die Instandhaltungs- und Rehabilitationsplanung dar.

Aufgrund unterschiedlicher Rahmenbedingungen (z.B. Struktur des Versorgungssystems oder Verfügbarkeit von Ressourcen) aber auch aufgrund rasant fortschreitender Entwicklungen neuer Technologien für die Überwachung von Wasserverlusten und für die Leckortung, ist es für einzelne Wasserversorgungsunternehmen oft schwierig, die individuell optimale Strategie für das Wasserverlustmanagement abzuleiten. Für einen Vergleich des Prozesses des Wasserverlustmanagements hinsichtlich Effektivität und Effizienz fehlen aber bislang geeignete Systeme.

Das ist eine der Motivationen für diese Arbeit, die das Ziel hat, ein Prozess-Benchmarking System für den Prozess des Wasserverlustmanagements zu entwickeln. Dieses System soll Prozessanalysen und die Ableitung von Optimierungsmaßnahmen unterstützen, um für Wasserversorgungsunternehmen individuell optimale Strategien für das Wasserverlustmanagement zu erreichen.

**Abstract**

In this PhD thesis a benchmarking system for the process of water loss management in drinking water supply systems has been developed. The system is limited to physical (real) water losses. Non-revenue water management is not considered.

The process benchmarking system enables analyses of various tasks of water loss management like leakage monitoring, leak detection, analyses and planning as well as infrastructure management and staff qualification. The comparison of water supply utilities allows the identification of strengths and weaknesses of different water loss management strategies and technologies as well as operational approaches. The analyses are based on technical (qualitative) and economical criteria. Exchange of experience between utilities supports the derivation of measures for improvement.

Beside some general methodological aspects regarding benchmarking, especially process benchmarking, this PhD thesis provides actual information about water loss management. One aspect is a new classification scheme for water losses which was implemented to the OVGW directive W 63 (in press), which has been revised parallel to this PhD thesis.

**Kurzfassung**

In dieser Dissertation wurde ein Benchmarkingsystem für den Prozess des Wasserverlustmanagements in Trinkwassernetzen entwickelt. Das System beschränkt sich auf die tatsächlichen (realen) Wasserverluste. Das Management der nicht in Rechnung gestellten Wassermengen (engl. non-revenue water) wird nicht berücksichtigt.

Das entwickelte Prozess-Benchmarkingsystem ermöglicht die Analyse der verschiedenen Aufgaben des Wasserverlustmanagements. Dazu gehören die Wasserverlustüberwachung, die Leckortung, Analyse- und Planungsaufgaben sowie das Infrastrukturmanagement und die Mitarbeiterqualifikation. Durch den Vergleich von Wasserversorgungsunternehmen können die Stärken und Schwächen der verschiedenen Strategien im Wasserverlustmanagement, der eingesetzten Technologien und der jeweiligen Arbeitsweisen sowohl in wirtschaftlicher Hinsicht, aber auch hinsichtlich der technischen Qualität untersucht werden. Ein Erfahrungsaustausch zwischen den Unternehmen unterstützt das Ableiten von Verbesserungsmaßnahmen.

Neben grundsätzlichen methodischen Aspekten zum Benchmarking, insbesondere dem Prozess-Benchmarking, liefert die gegenständliche Arbeit auch aktuelle Beiträge zum Wasserverlustmanagement. Unter anderem wird ein neu entwickeltes Klassifikationsschema für Wasserverluste auch in die ÖVGW Richtlinie W 63 (in Druck) aufgenommen, welche parallel zu dieser Dissertation überarbeitet wurde.

**Content**

## Abbreviations

| | |
|---|---|
| ATT | Association of Drinking Water from Reservoirs |
| AWWA | American Water Works Association |
| BDEW | German Association of Energy and Water Industries |
| BGBl. | Federal Law Gazette (Bundesgesetzblatt) |
| BMLFUW | Austrian Ministry of Agriculture, Forestry, Environment and Water Management |
| CARL | Current Annual Real Losses |
| CI | Cast Iron (pipe material) |
| CIS | Commonwealth of Independent States (former USSR) |
| COST | European Cooperation in the field of Scientific and Technical Research |
| DBVW | German Alliance of Water Management Associations |
| DMA | District Metered Area |
| DVGW | German Technical and Scientific Association for Gas and Water |
| DWA | German Association for Water, Wastewater and Waste |
| EC | European Commission |
| EffWB | Investigation of efficiency and quality of communal water supply services in Bavaria (Bavarian benchmarking project in water supply sector) |
| EU | European Union |
| Eurostat | Statistical Office of the European Communities |
| GIS | Geographic Information System |
| GRP | Glass-fibre Reinforced Plastic (pipe material) |
| idgF | in its current version (used for laws) |
| ILI | Infrastructure Leakage Index (water loss performance indicator) |
| ISO | International Organisation for Standardisation |
| IWA | International Water Association |
| LMSVG | Austrian Law on Food Security and Protection of Consumers |
| NEBC | North European Benchmarking Co-Operation |
| NRW | Non-Revenue Water (water loss performance indicator) |
| OECD | Organisation for Economic Co-operation and Development |
| OFWAT | Office of Water Services (Regulatory Body in England and Wales) |
| OVGW | Austrian Association for Gas and Water |
| PCS | Process Control System |
| PE | Polyethylene (pipe material) |

| | |
|---|---|
| PI | Performance Indicator |
| PTKA-WTE | Project Management Agency Forschungszentrum Karlsruhe Water Technology and Waste Management Division |
| PVC | Polyvinyl Chloride (pipe material) |
| SCADA | Supervisory Control and Data Acquisition |
| SGI | Services of General Interest |
| TC | Technical Committee |
| TWV | Austrian Drinking Water Ordinance (Trinkwasserverordnung) |
| UARL | Unavoidable Annual Real Losses |
| ÜBV | Interplant performance comparison of metropolitan utilities |
| VBGW | DVGW regional group “Bavaria” |
| VEWIN | Association of Dutch Water Companies |
| VKU | Association of Local Utilities |
| WLTF | Water Loss Task Force |
| WRG | Austrian Water Law (Wasserrechtsgesetz) |
| WSAA | Water Services Association of Australia |

# 1. Introduction

## 1.1. *Challenge*

As explained in the preface, water losses represent one of the greatest challenges for water utilities worldwide. A possibility to assess water loss management strategies of water utilities and implemented technologies is the methodology of benchmarking, especially of process benchmarking.

In the European Union and worldwide, performance assessment has become one of the most important topics in water supply sector in the past decade. Driven by various frame conditions at a national or international level, e.g. the EU water framework directive 2000/60/EC (EUROPEAN PARLIAMENT 2000), the need for more transparency and modernisation strategies in the monopolistic sector of water supply has become increasingly evident.

To enable performance assessments on a standardised frameset of performance indicators, the International Water Association (IWA) published a performance indicator (PI) system (ALEGRE et al. 2000 and 2006), which is the basis for many performance comparisons and benchmarking projects all over the world.

Many of the existing benchmarking projects use benchmarking systems on utility level, which analyse the entire performance of a water supply company (note: instead of the term “metric benchmarking” the term “corporate benchmarking” should be used for benchmarking systems on utility level).

International experiences have shown that corporate benchmarking is a good detection instrument for hidden optimisation potentials. But it is often difficult to derive measures for improvement on the basis of these data. Therefore it may be necessary to make detailed analyses of various processes. Thus, process benchmarking should display how potentials for improvement can be tapped.

Because many of the first approaches of process benchmarking in European countries have been based on global economic considerations but lack a demonstrative analysis of technical aspects, there is a need to develop process performance indicators for the technical tasks of the water supply sector (e.g. OVERATH & MERKEL 2004).

One process which so far has not been sufficiently considered in process benchmarking projects is the process of “water loss management”. In fact, water losses are an important indicator for the condition of a pipe network, and water loss management is an important process not only for water utilities with high water losses but also for water utilities with small leakage rates as we often find in Austria or other Central European countries.

The IWA “Efficient Operation and Management” Specialists Group is very active in performance assessment and benchmarking but a lot of research in the field of managing water losses has also been done in the past few decades with its Water Loss Task Force (WLTF).

Beside providing definitions of a standardised water balance and different water loss performance indicators within the IWA Blue Pages (LAMBERT & HIRNER 2000), many publications describe modern methods of leakage monitoring and leak detection techniques like active leakage control, pressure management, asset management and many other topics (e.g. LAMBERT 2002, BROTHERS 2002, FARLEY & TROW 2003, PILCHER et al. 2007 or MORRISON et al. 2007).

It is important for water companies to find the right strategy in water loss management. The costs as well as the benefits for each activity and methodology have to be known to enable the right decisions to be made. Therefore each sub process and each single activity in the field of water loss management has to be analysed in detail. Clearly defined sub processes and activities with a measurable input (e.g. costs for personnel and instruments) and a measurable output (e.g. reduction of losses or detection of water losses) are needed. It is necessary to find indicators – technical and economical - for measuring the input and the output of each process.

While water companies have to be effective (this means doing the right things), they also have to be efficient (this means doing the things in the right way with minimal effort). To reach this aim the instrument of process benchmarking can be very helpful. Two existing initiatives on benchmarking the process of water loss management have a strong focus on qualitative comparisons of the process (Canada and the Scandinavian Six-Cities Group project). But, up to now, no systems with systematic quantification of the performance of the process of physical water loss management have been developed. However, such quantification of process performances is absolutely necessary when larger groups of participants are benchmarked. A standardised process performance assessment is also useful for international comparisons.

Therefore a challenge that should be solved within this thesis is to work out a system that enables the comparison of the main process as well as of the sub processes of physical water loss management. The quantification of the process performance should take place on the basis of such measurable indicators as those described above.

The main parts of this thesis were developed within a process benchmarking project of the Austrian Association for Gas and Water (OVGW). The OVGW started their benchmarking initiative with a pilot project on corporate (metric) benchmarking in 2003/2004. This pilot project was followed by a second project on corporate (metric) benchmarking with 72 water supply utilities representing the half of the water supplied in Austria. In 2007 an initiative on process benchmarking was started, and one of the analysed processes was the management of physical water losses.

Beside the OVGW process benchmarking, an initiative of the IWA WLTF deals with mapping the process of non-revenue water (NRW) management. The approach worked out within this initiative is much broader than the OVGW approach, which solely focuses on physical water loss management. The work in the WLTF initiative is still ongoing as this thesis is being written, but has given inspiration for this work, and, further, synergies could be used.

## 1.2. *Aim of this thesis*

The aim of this PhD thesis is to work out a process benchmarking system for the process of water loss management with the focus on the management of physical water losses. The topic of managing non-revenue water (NRW) requires a much broader analyses of many additional activities, but these are not part of this thesis.

The process benchmarking system has to be based on recent developments in performance assessment and should cover all aspects of modern water loss management.

The process benchmarking system should allow the assessment of the performance of water supply utilities from an economic point of view, as well as from technical quality aspects. It should facilitate finding out whether the strategy used in water loss management is effective or not. If not, the system should give support in finding the right strategy.

The system should also show where there is room for improvements within the process operation. This means detecting inefficiencies but also potentials for technical (qualitative) optimisations.

Beside this, the process benchmarking system for water loss management has to fulfil the following criteria:

- *Clear process structure*: The process structure has to be well understandable and all parts of the process (sub processes, supporting processes) have to be well defined.
- *Hierarchical process structure:* The process structure has to be hierarchical, so that both the overall performance and the performance in single parts of the process can be assessed.
- *Practical applicability:* The system of process benchmarking has to be in step with actual practices and therefore it has to be developed closely with water supply utility experts.
- *For all structures:* The system has to be applicable for all structures and all sizes of water supply utilities.
- *Simple data gathering*: The allocation of costs and other data should be simple. The query of context-information should be accomplished with selective lists to keep the effort as low as possible.
- *Transparency*: The system has to be a transparent one; “black-box” solutions have to be avoided.
- *Data quality*: The accuracy and reliability of variables has to be considered.
- *Structural parameters*: The system should consider different frame conditions of water supply systems to allow a performance comparison in “comparable” groups (clusters).
- *Voluntary and anonymous system*: The system should be used for voluntary benchmarking and should allow anonymous evaluations.
- *Field test*: The system has to pass a field test within the Austrian water supply sector. Therefore, a case study with eleven water supply utilities was worked out and the results of this field test are described in this thesis.

## 1.3. *Methodology used*

The first steps within this work were the analyses of common practices in water loss management, which are mainly defined by the IWA Water Loss Task Force, and the analyses of the applicability and benefits of existing (process) benchmarking systems. Two projects which deal with water loss management were analysed in special detail. These are the Canadian benchmarking project and the Scandinavian Six-Cities Group project.

The second step was a process mapping to define the process structure of physical water loss management.

Next, the process benchmarking system was worked out on basis of the process structure. This includes the definition of variables, context information and performance indicators. Quality indices had to be defined and a quality matrix was created for the evaluation of quality in process operation, which helps to identify performance gaps.

Afterwards the process benchmarking system was tested in a field test within the Austrian water supply sector. Eleven utilities participated in the 2007 OVGW process benchmarking. This field test provided useful information about weaknesses within the benchmarking system.

Finally, improvements on the basis of the experiences of the field test were implemented into the process benchmarking system (Figure 2).

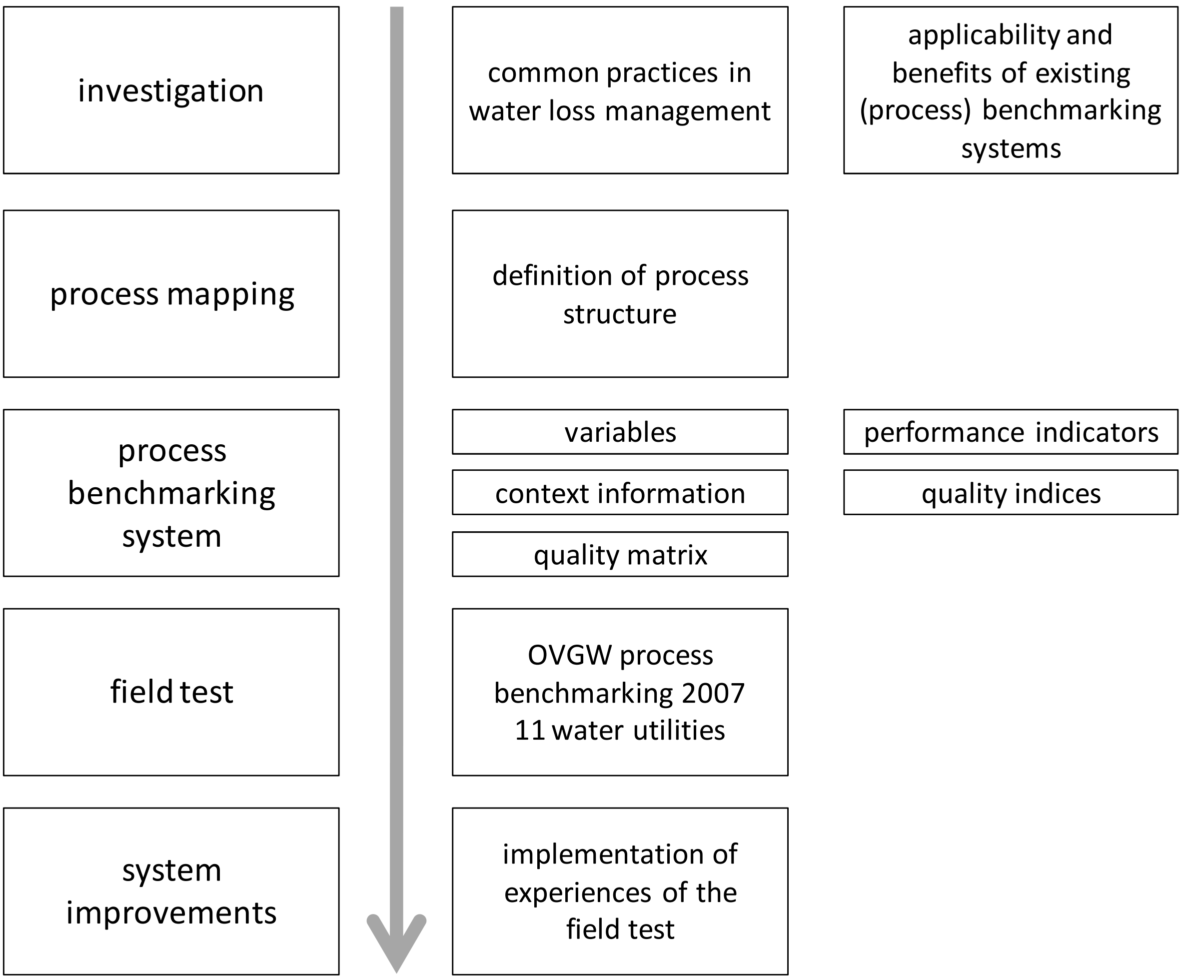


**Figure 2: Course of action**

## 1.4. *Structure of this thesis*

The first part of the work (chapter 2) gives a short overview about the general framework in managing water supply utilities in the European Union with reference to the EU water framework directive (Directive 2000/60/EC, EUROPEAN PARLIAMENT 2000) and to the COST C18 Action (note: COST is the acronym for European **CO**operation in the field of **S**cientific and **T**echnical Research). Parallel to the COST C18 Action, the ISO (International Organisation for Standardisation) has created an international standardisation for service activities relating to drinking water supply systems and wastewater systems by describing the quality criteria of the service and performance indicators.

The second part (chapter 3) focuses on performance assessment in the water supply sector. As well as a short description of the IWA PI-system (ALEGRE et al. 2006) chapter 3 also includes an overview about the basics of benchmarking. The differences between corporate (metric) benchmarking and process benchmarking are explained and existing process benchmarking systems are described. Methodical differences and advantages and disadvantages of various approaches in process benchmarking are worked out (holistic strategy vs. selective strategy). This chapter also includes a description of the Austrian benchmarking activities in the water supply sector.

The last theoretical chapter (chapter 4) gives an overview of the state of the art in water loss management. Beside a short description of the IWA Water Loss Task Force standards there are also references to the German standard DVGW W 392 (2003) and to various Austrian standards like OeNorm B 2539 – OVGW W 59 (2005), OVGW W 63 (1993), OVGW W 100 (2007), etc.

Chapter 5 is the central part of this thesis, where the developed process benchmarking system for the management of physical water losses is described in detail. The first part of this chapter describes the process structure with definitions of the sub- and supporting-processes. The input- and output-factors and quality criteria of all sub processes are also described. Afterwards, the process benchmarking system with its variables, context information and performance indicators are described in detail (note a detailed description of all variables and context information is shown in the appendix). An essential part of the system is the assessment of the quality of process operation. Therefore all the context information is summarised in a structured quality matrix which allows orientation on where there are potentials for improvement and what measures can be derived.

Chapter 6 describes a field test of the new system within the Austrian water supply sector and details the lessons learned in this first project run.

Finally, (chapter 7) some conclusions about the new system and the first project run in Austria are made and an outlook (chapter 8) on future research like the extension of this process benchmarking system on the diversified topic of non-revenue water management is given.

The appendix includes a detailed description of the data collection system.

# 2. General framework

After some decades of building public water supply systems in compliance with high quality standards regarding accessibility, water quality and supply safety, a new aspect has become more important: the performance and the standards of water supply should be attained with less use of resources, which means as efficiently as possible (NEUNTEUFEL et al. 2004).

The economic optimisation of the water supply sector under guarantee or optimisation of high quality standards and in compliance with ecological targets can give support in (NEUNTEUFEL et al. 2004):

- easing the burden on public households
- increasing the customer satisfaction regarding water quality, supply safety and customer service.

Therefore increasing pressure from various interest groups in the water supply sector (as a part of services of general interest) was seen during the last decade of the 20th century. The European Commission with its intentions and discussions about liberalisation, modernisation and performance of services of general interests was an especially strong driving force for the development of performance evaluation systems for the water supply sector.

The understanding of quality, efficiency, standards and demands for the water supply sector strongly depends on the point of view of different observers. Table 1 gives an example:

**Table 1: Standards and demands for water supply utilities (according to GIRSBERGER 2003 in THEURETZBACHER-FRITZ et al. 2006)**

<table>
<tr><th>who</th><th>understanding for quality</th><th>frame of reference</th></tr>
<tr><td rowspan="3">politicians</td><td>low water price</td><td rowspan="3">public interest</td></tr>
<tr><td>sustainable use of water</td></tr>
<tr><td>effective administration</td></tr>
<tr><td rowspan="4">managing director</td><td>satisfied customers and authorities</td><td rowspan="4">performance assignment</td></tr>
<tr><td>less complaints</td></tr>
<tr><td>good staff</td></tr>
<tr><td>enough budget</td></tr>
<tr><td rowspan="3">technical director</td><td>ensured water quality</td><td rowspan="3">efficient and unproblematic operation</td></tr>
<tr><td>sufficient pressure and volume of water</td></tr>
<tr><td>no interruptions of supply</td></tr>
<tr><td rowspan="2">quality manager</td><td>fulfilment of quality standards</td><td rowspan="2">all business objectives</td></tr>
<tr><td>measures for improvement</td></tr>
<tr><td>chemistry</td><td>compliance with parameter and indicator parameter values</td><td>food law</td></tr>
</table>

Whereas the European Commission is still thinking about the possibilities for liberalisation, the European Parliament refused the liberalisation of the drinking water supply sector with its decision from December 2003 (EUROPEAN PARLIAMENT 2003, COM(2003) 270 – (2003/2152(INI), A5 0484/2003, Pte. 48-49) to the Green Paper on services of general interests (EUROPEAN COMMISSION 2003). Beside other measures, chiefly performance comparisons, like benchmarking, should be implemented to ensure modernisation and to increase the efficiency of the drinking water supply sector (EUROPEAN PARLIAMENT 2003):

> *A5 0484/2003: The European Parliament…*
>
> *48)…considers that* ***liberalisation*** *of water supply (including wastewater disposal) should not be carried out in view of the distinctive regional characteristics of the sector and local responsibility for provision of drinking water as well as various other conditions relating to drinking water; calls, however, without going as far as liberalisation, for water supply to be 'modernised' and for the principle of equal treatment of public and private companies to be enforced by means of a variety of individual measures involving limited market opening and the removal of restrictions on competition.*
>
> *49)…takes the view that* ***benchmarking****, economic-efficiency testing, cooperation and efficiently structured undertakings should also be sought in water management, and that a good many specific measures providing limited openings to the market short of full liberalisation will impact favourably on security of supply, price structures and the protection of ground water and the environment.*

It is necessary to implement measuring systems with a feedback function in order to evaluate the fulfilment of various demands on the water supply sector in an understandable way and to enable learning from better performing utilities. Benchmarking is such a measuring system with a feedback function (THEURETZBACHER-FRITZ et al. 2006).

Several European countries, e.g. Germany, consider benchmarking to be an efficient instrument for identifying, getting acquainted with, and adopting successful methods and processes from benchmarking partners. Therefore, the benchmarking concept of the German water sector is part of the modernisation strategy for the regulatory framework of the German federal government. In 2005 several German Associations of the water sector signed the extended "Statement of the Associations of the Water Industry on Benchmarking in the Water Sector" and thus defined for themselves the support of benchmarking to be an integral part of their self-administration (PROFILE OF THE GERMAN WATER INDUSTRY 2008).

The Austrian water supply utilities and their umbrella organisation OVGW also decided to implement the methodology benchmarking as a suitable instrument for performance evaluation, performance presentation and for improving quality and efficiency.

## 2.1. *EU - Water Framework Directive 2000/60/EC*

In October 2000 the European Parliament and the Council of the European Union enacted the most important law for the European water sector – directive 2000/60/EC (water framework directive) establishing a framework for Community action in the field of water policy.

The purpose of the water framework directive is to establish a framework for the protection of inland surface waters, transitional waters, coastal waters and groundwater which (EUROPEAN PARLIAMENT 2000):

*(a) prevents further deterioration and protects and enhances the status of aquatic ecosystems and, with regard to their water needs, terrestrial ecosystems and wetlands directly depending on the aquatic ecosystems;*

*(b) promotes sustainable water use based on a long-term protection of available water resources…*

*and thereby contributes to:*

- *the provision of the sufficient supply of good quality surface water and groundwater as needed for sustainable, balanced and equitable water use,*
- *a significant reduction in pollution of groundwater…*

The article 4 of the water framework directive deals with environmental objectives and explains how to handle the river basin management plans. Concerning ground water one of the objectives is:

…*member states shall protect, enhance and restore all bodies of groundwater, ensure a balance between abstraction and recharge of groundwater, with the aim of achieving good groundwater status at the latest 15 years after the date of entry into force of this directive…*

In article 5 the member states are called on to ensure that for each river basin district within its territory:

- *an analysis of its characteristics,*
- *a review of the impact of human activity on the status of surface waters and on groundwater, and*
- *an economic analysis of water use*

is undertaken according to the technical specifications set out in Annexes II and III and that it is completed at the latest four years after the date of entry into force of this directive.

Annex III of the water framework directive describes the economic analysis:

*The economic analysis shall contain enough information in sufficient detail (taking account of the costs associated with collection of the relevant data) in order to:*

*(a) make the relevant calculations necessary for taking into account under Article 9 the principle of recovery of the costs of water services, taking account of long term forecasts of supply and demand for water in the river basin district and, where necessary:*

- *estimates of the volume, prices and costs associated with water services, and*
- *estimates of relevant investment including forecasts of such investments;*

*(b) make judgements about the most cost-effective combination of measures in respect of water uses to be included in the programme of measures under article 11 based on estimates of the potential costs of such measures.*

Article 9 of the water framework directive is very important for the water supply sector, as it claims cost recovery for water services:

> *… member states shall take account of the principle of recovery of the costs of water services, including environmental and resource costs, having regard to the economic analysis conducted according to Annex III, and in accordance in particular with the polluter pays principle.*
>
> *Member states shall ensure by 2010:*
>
> - *that water-pricing policies provide adequate incentives for users to use water resources efficiently, and thereby contribute to the environmental objectives of this directive,*
> - *an adequate contribution of the different water uses, disaggregated into at least industry, households and agriculture, to the recovery of the costs of water services, based on the economic analysis conducted according to annex III and taking account of the polluter pays principle.*
>
> *Member states may in so doing have regard to the social, environmental and economic effects of the recovery as well as the geographic and climatic conditions of the region or regions affected…*

On the basis of the results of analysis specified in article 5 of the directive, the member states have to ensure the establishment of programmes of measures in order to achieve the objectives established under article 4.

According to article 11, each programme of measures shall include the "basic" measures and, where necessary, "supplementary" measures. "Basic measures" are the minimum requirements to be complied with and shall consist of:

> *(a) those measures required to implement Community legislation for the protection of water, including measures required under the legislation specified in article 10 and in part A of annex VI;*
>
> *(b) measures deemed appropriate for the purposes of article 9 (cost recovery);*
>
> *(c) measures to promote an efficient and sustainable water use in order to avoid compromising the achievement of the objectives specified in article 4;*
>
> *(d) measures to meet the requirements of Article 7 (waters used for the abstraction of drinking water), including measures to safeguard water quality in order to reduce the level of purification treatment required for the production of drinking water…*

To sum up, the water framework directive represents the legislative basis for a sustainable management of water resources within the European Union. Beside various aspects of protection of water resources, economic aspects are also considered within the directive. Member states are instructed to analyse the economic situation of the water sector and to set measures for cost recovery.

The objectives of the water framework directive correspond with the content of this thesis: the minimisation of water losses supports the aim of a sustainable use of resources and the methodology of benchmarking is seen as a key instrument for economic analyses in many member states.

## 2.2. *IWA*

The International Water Association is a global network of water specialists, spanning the continuum between research and practice and covering all facets of the water cycle. The Vision of IWA is to connect water professionals worldwide to lead the development of effective and sustainable approaches to water management (IWA 2008).

Concerning the focus of this thesis (water loss management, benchmarking) two of the 60 IWA Specialist Groups are of special importance:

- Efficient Operation and Maintenance Specialist Group
- Statistics and Economics Specialist Group

The *Efficient Operation and Maintenance Specialist Group* focuses on the operation, maintenance and rehabilitation of water supply systems. It considers performance indicators for distribution systems, non-revenue water and leakage control and methods for the renovation and replacement of pipelines (IWA 2008). Within the Specialist Group six Task Forces are active:

- Benchmarking
- Efficient Water Management
- International Demand Management Framework
- Operation and Maintenance Network
- Performance Indicators for Water Supply
- Water Loss

One of the most active Task Forces within this Specialist Group is the Water Loss Task Force (WLTF). Therefore thought has been given to promoting the WLTF to the status of Specialist Group.

Beside various basic publications like Manuals of Best Practices, e.g., ALEGRE et al. (2000 and 2006) about performance indicators or Guidance Notes in water loss management (e.g. PILCHER et al. 2007 or MORRISON et al. 2007), the Specialist Group (or its Task Forces) organises International Specialist Conferences (e.g. Efficient 2007, Water loss 2005, 2007 or PI08).

The scope of the *Statistics and Economics Specialist Group* is to provide a forum to debate how utilities are financed, their various water tariff structures and the measurement of performance. The Group provides water sector statistics on countries water facts updating abstraction, consumption and water charging figures through periodical worldwide surveys. In 2005, this Specialist Group organised a Specialist Conference on Statistics and Economics in Crete. Another one will follow in 2009. LARSSON et al. (2002) published a manual on process benchmarking in the series of Manuals of Best Practices.

Within a **Joint Task Group on Benchmarking** the two Specialist Groups are engaged to publish a Benchmarking Manual (in progress). At the World Water Congress 2008 in Vienna the joint Task Group, under the leadership of Heimo Theuretzbacher-Fritz (Graz University of Technology) and Enrique Cabrera (Instituto Technologico del Agua, Spain), organised a workshop on benchmarking. In March 2009 the “PI09” Specialist Conference was held.

## 2.3. *COST Action C18*

COST is an intergovernmental framework for European Cooperation in the field of Scientific and Technical Research, allowing the co-ordination of nationally funded research on a European level. COST Actions cover basic and pre-competitive research as well as activities of public utility. The goal of COST is to ensure that Europe holds a strong position in the field of scientific and technical research for peaceful purposes, by increasing European cooperation and interaction in this field (COST 2008).

The COST Action C18 “Performance assessment of urban infrastructure services: the case of water supply, wastewater and solid waste” had the objective from 2004 to 2008 to increase the knowledge and to promote the use of effective, scientifically robust and well devised methodologies for decision-making based on the use of performance indicators for urban infrastructure services, able to attract utilities to use them as routine management tools (COST C18 2008).

The final stage of the COST Action C18 was the International Conference on Performance Assessment of Urban Infrastructure Services (PI08) in Valencia 2008, which was organised together with the IWA Efficient Operation and Maintenance Specialist Group.

## 2.4. *ISO TC 224*

The International Organisation for Standardisation (ISO) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing international standards is normally carried out through ISO technical committees (TC). In 2007 the ISO TC 224 published the international standard series ISO 24512 (2007).

ISO 24512 is one of a series of standards addressing water services. The full series consists of the following international standards:

- ISO 24510 (2007): Activities relating to drinking water and wastewater services — Guidelines for the assessment and for the improvement of the service to users
- ISO 24511 (2007): Activities relating to drinking water and wastewater services — Guidelines for the management of wastewater utilities and for the assessment of wastewater services (note: no relevance for this thesis)
- ISO 24512 (2007): Activities relating to drinking water and wastewater services — Guidelines for the management of drinking water utilities and for the assessment of drinking water services

The objective of these international standards series is to provide the relevant stakeholders with guidelines for assessing and improving the service to users, and with guidance for managing water utilities, consistent with the overarching goals set by the relevant authorities and by international intergovernmental organisations.

ISO 24510 (2007) addresses the following topics:

- a brief description of the components of the service relating to the users
- core objectives for the service, with respect to users’ needs and expectations
- guidelines for satisfying users’ needs and expectations

- assessment criteria for service to users in accordance with the provided guidelines
- examples of performance indicators linked to the assessment criteria that can be used for assessing the performance of the service

ISO 24512 (2007) addresses the following topics:

- a brief description of the physical/infrastructural and managerial/institutional components of water supply utilities
- core objectives for water supply utilities, considered to be globally relevant at the broadest level
- guidelines for the management of the water supply utilities
- guidelines for the assessment of the water services with service assessment criteria related to the objectives, and performance indicators linked to these criteria

The relevance of the ISO 24512 series for this work can be seen in its approach of defining standards for water supply and giving guidelines for the management and for the assessment of water services on an international level. The central aim of these standards is to provide safe drinking water for customers. In the context of operation and maintenance of water transportation and distribution systems, ISO 24512 (2007) states:

> *Leak detection and repair programmes should be implemented in order to protect the drinking water against any possible hygienic risks and to prevent any deterioration in the hydraulic efficiency of the network, taking into account the utility's economic and environmental constraints.*

Benchmarking the process of water loss management can support the objectives of ISO 24512.

## 2.5. *Global water loss situation*

A recent study of the World Bank published by KINGDOM et al. (2006) estimates the worldwide volumes of physical water losses at about 33 billion m³ per year. About half of this volume occurs in developing countries (16 billion m³/a). About 10 billion m³/a is lost in developed countries and about 7 billion m³/a in Eurasia (CIS).

The costs of these physical water losses are estimated (on basis of marginal costs of 0.20 US$/m³ in developing countries and 0.30 US$ in developed countries and CIS) at about 8 billion US$ worldwide, with about 3 billion US$ in developing countries, 3 billion US$ in developed countries and 2 billion US$ in Eurasia (CIS). KINGDOM et al. (2006) mention that these estimations are conservative.

Faced with a tremendous increasing rate of the world’s population and decreasing available water resources due to contamination, overuse and climate change the water lost through leakage is aggravating the global water crisis. Beside these aspects of water stress, CHARALAMBOUS (2008) mentions the importance of an effective and efficient water loss management for solving this water crisis.

## 2.6. *Instruments for performance assurance*

To reach the objective of modernisation of the water supply sector it is necessary to ensure performance standards. Therefore different methodologies with different aims and different interests (e.g. regulators, stakeholders, customers) are common. The following sub-chapters give a brief description of some common measures for performance assurance, especially in water loss management.

### 2.6.1. Training programmes

Training programmes are often organised by national organisations and associations like, e.g., the OVGW, which offers educational programmes (water master) and special training programmes, e.g., for water loss management. But on the international level training programmes are also becoming more and more important especially for countries with weak structured water supply sectors. Therefore, e.g., the IWA Water Loss Task Force has an initiative on training programmes (compare DICKINSON 2008).

In general, training programmes are voluntary, even if there is some (weak) pressure in the form of public, stakeholder or funders interests.

### 2.6.2. Laws, standards, directives and guidelines

Laws are binding on national and international level. In Austria there is no law directly referring to water losses. However, the Austrian LMSVG (BGBl. 13/2006), the Austrian Law on Food Security and Protection of Consumers, the TWV (BGBl. II Nr. 304/2001 idgF), the Austrian Drinking Water Ordinance, and the WRG 1959 (BGBl. Nr. 215/1959 idgF), the Austrian Water Law, indirectly influence the water loss management in the way that drinking water must fulfil the high quality standards of these laws (e.g., parameter and indicator parameter values). §50 of WRG 1959 (BGBl. Nr. 215/1959 idgF) deals with maintenance and states that systems have to be kept in conditions that correspond to their function. Therefore high water losses can be seen as a risk for the function of a water supply system.

The codex chapter B1 of the LMSVG (BGBl. 13/2006) and the WRG 1959 (BGBl. Nr. 215/1959 idgF) regulate the drinking water in Austria concerning the quality of the product water and the allowed use of water. Detailed requirements on the quality of water are defined in the TWV (BGBl. II Nr. 304/2001 idgF). The TWV represents the implementation of the directive 98/83/EC (EUROPEAN COUNCIL 1998), which concerns the quality of water intended for human consumption.

In general, standards and directives represent the state of the art and are binding for planners and operators. Guidelines provide additional and/or innovative information about specific topics. International standards e.g. ISO 24510-24512 (2007) need to be ratified into national standards before they are binding at national level.

In Austria there are several national standards and directives concerning or just referring to water losses: e.g., OeNorm B 2539 – OVGW W 59 (2005), OVGW W 63 (1993 and in press), OVGW W 100 (2007) or OVGW W 85 (2007).

It is usually necessary to generate comparable data for different structures of water supply utilities to enable the definition of standard values within standards, directives and guidelines. Often voluntary performance comparisons are used for that purpose. As an example, the OVGW used benchmarking data to define standard values for failure rates within the OVGW W 100 (2007).

### 2.6.3. Regulation

According to Wikipedia (2008) regulation can be considered as:

> *…legal restrictions promulgated by government authority. One can consider regulation as actions of conduct imposing sanctions (such as a fine). This action of administrative law, or implementing regulatory law, may be contrasted with statutory or case law.*
>
> *Regulation mandated by a state attempts to produce outcomes which might not otherwise occur, produce or prevent outcomes in different places to what might otherwise occur, or produce or prevent outcomes in different timescales than would otherwise occur. Common examples of regulation include attempts to control market entries, prices, wages, pollution effects, employment for certain people in certain industries, standards of production for certain goods, the military forces and services. The economics of imposing or removing regulations relating to markets is analysed in regulatory economics.*

Different forms of regulation are common in the water supply sector. England and Wales, for example, are strictly regulated by OFWAT (Office of Water Services) which uses the methodology of yardstick competition. The regulation concentrates on aspects of price setting in private monopoly organisations. The price regulation is based on Price Cap-Regulation (RPI-X). Clausen & Scheele (2001) describe this approach in detail.

But “weaker” regulation forms are also used within the water supply sector, e.g. in the Netherlands. The Dutch approach follows the principle of “naming and shaming” what is also called “sunshine regulation”. The state is not willing to impose sanctions on water supply utilities but with the publication of performance comparisons the utilities are exposed to public pressure, which should be an incentive for improvements (compare Clausen & Scheele 2001).

In any case performance indicators also play an important role for regulation purposes.

### 2.6.4. Performance comparisons and benchmarking

Performance comparisons and benchmarking projects can be organised on a voluntary basis but can also be obligatory. Depending on the purpose, these projects are initiated by different organisations, e.g. associations, consultants or government agencies.

Performance comparisons provide useful information about the water supply sector and are, therefore, of the highest interest for deducing standard values for the sector.

The following chapters describe the methodologies of performance comparisons and benchmarking in detail.

# 3. Performance assessment in water supply sector

Performance indicator systems (short: PI systems) and benchmarking are instruments for internal corporate management but also for comparisons of utilities on a regional, national and international scale (MERKEL 2001).

The basis for corporate benchmarking are standardised performance indicator systems, which evaluate all the tasks of a sustainable water supply sector holistically, considering supply safety, supply quality, customer service, sustainability and efficiency. Such a “quasi-competition” on a voluntary basis can display the performance, but also enables the derivation of measures for improvement (HIRNER & MERKEL 2002).

According to these principles a large number of benchmarking projects have been carried out all over the world in the water supply sector over the last few years.

## 3.1. *IWA Performance Indicator System*

At the end of the 1990`s a committee of the International Water Association developed a system of performance indicators for the water supply services (ALEGRE et al. 2000) and carried out several national field tests in order to adapt the system to practical applications. Six years later, after a field test with more than 70 undertakings worldwide, an updated, improved version of the manual of best practise was published by ALEGRE et al. (2006).

Undoubtedly, the IWA PI system is the state of the art for performance indicator systems in the water supply sector and is the basis for many projects worldwide, although individual adaptations (e.g. additional PIs) for the frame conditions of single countries may be useful.

The main objective of the manual is to provide guidelines for the establishment of a management tool for water supply utilities based on the use of performance indicators. Further objectives are to provide a coherent framework of indicators for benchmarking initiatives but also for regulatory agencies and international statistics collected by the IWA (ALEGRE et al. 2006).

This chapter gives an overview of the IWA performance indicator system for water supply services described by ALEGRE et al. (2006).

### 3.1.1. Elements of the PI system

The PI system consists of four types of data elements, each of them with different rules within the system:

- variables
- performance indicators
- context information
- explanatory factors

#### 3.1.1.1. Variables

Variables are the data elements of which the performance indicators are calculated from. The variables are values (resulting from a measurement or record) expressed in a specific unit (e.g. “length of mains”, unit: km; “average service pressure head”, unit: m; “total sub process costs”, unit: €/a). Confidence grades indicate the data quality for each variable.

Variables should fulfil the following requirements:

- univocal definitions
- reasonably achievable
- refer to the same geographical area and the same assessment period as the PI they are used for
- be as reliable and accurate as the decision made based on them requires

#### 3.1.1.2. Performance indicators

PIs are measures of the efficiency and effectiveness that result from the combination of several variables. Each PI should express the level of performance achieved in a certain area and during a given assessment period (e.g. one year). A clear processing rule should be defined for each performance indicator to specify all the variables required and their algebraic combination.

As with variables, the performance indicators also consist of values expressed in specific units and confidence grades indicate the quality of data represented by the indicator. Performance indicators are typically expressed as ratios between variables. These ratios may be commensurate (e.g., “non-revenue water”, unit: %) or non-commensurate (e.g. “total process costs”, unit: €/km or €/100 service connections; “real losses per connection per day”, unit: l/conn·d).

In general, the latter case allows a better performance comparison due to the fact the denominators represent the dimension of the water supply system (e.g. number of service connections or total mains length). THEURETZBACHER-FRITZ et al. (2008) discuss aspects of the right choice of denominators and the influence of different denominators on the comparability of performance indicators.

Performance indicators should fulfil the following requirements. They should be:

- clearly defined with a concise meaning
- reasonably achievable (depends on the related variables)
- auditable
- as universal as possible and provide a measure which is independent from the particular condition of the utility
- simple and easy to understand
- quantifiable so as to provide an objective measurement of the service, avoiding any personal or subjective appraisal
- every PI should provide information significantly different from other PIs
- only PIs which are deemed essential for effective performance evaluation should be established

#### 3.1.1.3. Context information

These data elements provide information on the characteristics of an undertaking and account for differences between water supply systems. There are two possible types of context information:

- External factors that can not be changed by management decisions. These information describes the frame conditions of a system (e.g. geographics, demographics), which are relatively constant through time.
- Data elements that are not modifiable by management decisions in a short or medium term, but the management policies can influence them in the long term (e.g. the condition of the infrastructure of a supply system, pipe material).

Context information is necessary when comparing different structured systems and gives support in cause analyses.

The requirements for context information are, in general, the same as for performance indicators and variables. If the level of detail and confidence grading is not the same, they should be:

- univocal definitions
- reasonably achievable
- if external, be collected whenever possible from official survey departments
- fundamental for the interpretation of PIs
- as few as possible

#### 3.1.1.4. Explanatory factors

Explanatory factors are key elements of PI systems that are used to explain PI values but they are also used for the grouping of comparable water supply systems. Explanatory factors may be context information, variables or PIs (e.g. average age of network, service connection density or network delivery rate).

#### 3.1.1.5. Data reliability and accuracy

To fulfil high quality standards in performance comparison, knowledge about data reliability and accuracy is absolutely necessary. Data of insufficient accuracy could be misleading and may result in wrong decisions by the utility management.

The reliability expresses how trustworthy the source of the data is. The IWA system recommends following bands for the reliability of a data source (Table 2):

**Table 2: Recommended bands for the reliability of the data source (ALEGRE et al. 2006)**

| reliability band | Definition |
|---|---|
| + + + | **highly reliable data source:** data based on sound records, procedures, investigations or analyses that are properly documented and recognised as the best available assessment methods |
| + + | **fairly reliable data source:** worse than + + + but better than + |
| + | **unreliable data source:** data based on extrapolation from limited reliable samples or on informed guess |

The accuracy accounts for measurement errors and expresses possible error margins for input data (e.g. possible metering errors of system input volume). Further, the accuracy has to be considered in the calculation of performance indicators. The IWA system recommends the following accuracy bands (Table 3):

**Table 3: Recommended accuracy bands (ALEGRE et al. 2006)**

| data accuracy | accuracy band | associated uncertainty |
|---|---|---|
| A | 0 – 5 % | better than or equal to ± 5% |
| B | 5 – 20 % | worse than ± 5%, but better than or equal to ± 20% |
| C | 20 – 50 % | worse than ± 20%, but better than or equal to ± 50% |
| D | > 50 % | worse than ± 50% |

For single input data, especially for water balance data, a more detailed consideration of data accuracy seems to be useful. Therefore the data accuracy of water balance data is considered by direct error margins (e.g. ±0,5% or ±1,5% for the system input volume) within the process benchmarking system described in this thesis (see chapter 5.3.5).

### 3.1.2. Structure of the PI system

Within the IWA PI system the performance indicators are structured into six main groups (Table 4): water resources (WR), personnel (Pe), physical (Ph), operational (Op), quality of service (QS) and economic and financial (Fi). These main groups are divided into subgroups and some of the indicators are broken down into sub-indicators.

**Table 4: IWA PI system structure**

| group code | main PI group | subgroup | number of PIs subgroup (sub-indicators) | number of PIs main group (sub-indicators) |
|---|---|---|---|---|
| WR | water resources | no subgroup | - | 3 (+1) |
| Pe | personnel | total personnel | 2 | 20 (+6) |
| | | personnel per main function | 5 (+2) | |
| | | technical services personnel per activity | 6 | |
| | | personnel qualification | 3 | |
| | | personnel training | 1 (+2) | |
| | | personnel health and safety | 2 (+2) | |
| | | overtime work | 1 | |
| Ph | physical | water treatment | 1 | 11 (+4) |
| | | water storage | 2 | |
| | | pumping | 4 | |
| | | valve, hydrant and meter availability | 2 (+4) | |
| | | automation and control | 2 | |
| Op | operational | inspection and maintenance | 6 | 31 (+13) |
| | | instrumentation and calibration | 5 | |
| | | electrical and signal transmission equipment inspection | 3 | |
| | | vehicle availability | 1 | |
| | | rehabilitation | 2 (+5) | |
| | | operational water losses | 3 (+4) | |
| | | failure | 6 | |
| | | water metering | 4 | |
| | | water quality monitoring | 1 (+4) | |
| QS | quality of service | service coverage | 3 (+2) | 24 (+10) |
| | | public taps and standpipes | 4 | |
| | | pressure and continuity of supply | 8 | |
| | | quality of supplied water | 1 (+4) | |
| | | service connection and meter installation and repair | 3 | |
| | | customer complaints | 5 (+4) | |
| Fi | economic and financial | revenue | 1 (+2) | 23 (+24) |
| | | cost | 1 (+2) | |
| | | composition of running costs per type of costs | (+5) | |
| | | composition of running costs per main function of the water undertaking | (+5) | |
| | | composition of running costs per technical function activity | (+6) | |
| | | composition of capital costs | (+2) | |
| | | investment | 1 (+2) | |
| | | average water charges | 2 | |
| | | efficiency | 9 | |
| | | leverage | 2 | |
| | | liquidity | 1 | |
| | | profitability | 4 | |
| | | economic water losses | 2 | |
| | | | **total number of PIs (sub-indicators)** | **112 (+58)** |

### 3.1.3. Relevance for process benchmarking of water loss management

The IWA PI system (ALEGRE et al. 2006) describes a PI system for corporate (metric) benchmarking purposes. Therefore the indicators described within this system are often too general to be used for process benchmarking.

There are, however, some aspects which are relevant for benchmarking the process of physical water loss management:

- general valid requirements for performance indicators, variables, context information and explanatory factors
- the IWA water balance
- various relevant PIs especially of the group of operational indicators
    - water losses
    - inspection and maintenance of physical assets
    - rehabilitation
    - failures
    - water metering
    - instrumentation calibration

In fact the process of physical water loss management is an integrative process which is influenced by many different tasks of a water utility (compare chapter 5.2) aspects of almost all other PI groups are also relevant.

Of more relevance for process benchmarking than the manual of ALEGRE et al. (2006) is the IWA manual of best practice about process benchmarking by LARSSON et al. (2002), which is described in chapter 3.2.2.4.

## 3.2. *Benchmarking in the water supply sector*

According to KOUZMIN et al. (1999), benchmarking can be seen as an important management tool of total quality management (TQM). The methodology was first developed by Xerox Corporation in 1979, when severe quality and costs problems became visible in the face of the extremely low price of Canon copier machines (HORVATH & HERTER 1992). Today, this instrument is used by a large number of companies of various industry sectors worldwide.

The term “benchmarking” was originally used by land surveyors to compare elevations. Today benchmarking has a narrower meaning in the management lexicon since the benchmark is industry best-practice and is not in any sense a standard. CAMP (1989) defines benchmarking as:

> *…the continuous process of measuring products, services and practices against the toughest competitors or those companies recognised as industry leaders, (that is) ... the search for industry best practices that will lead to superior performance.*

The aim of benchmarking is to identify competitive targets which render the weak points of the benchmarking organisation visible and to establish measures of improvement. This means, the basic idea behind benchmarking is not to find out “by how much others are doing better but, rather, how they make it to do better in certain areas” (HORVATH & HERTER 1992).

Depending on the benchmarking object, there are two different types of benchmarking methodologies:

- corporate benchmarking (utility level)
- process benchmarking (process level).

Whereas the corporate benchmarking focuses on an evaluation of utilities overall performance, process benchmarking goes more into detail by analysing single working flows (e.g. customer meter reading, customer meter replacement, water treatment, construction of pipes, network inspection, physical water loss management).

### 3.2.1. Corporate benchmarking

#### 3.2.1.1. Objectives of corporate benchmarking

Corporate benchmarking analyses a broad spectrum of a utility's success factors and gives an overview about the utility's overall performance (benchmarking on utility level). Quantitative comparisons of utilities performances are possible on the basis of performance indicators. For groups with comparable frame conditions it is possible to evaluate benchmarks (best values) for each performance indicator. Deviations from benchmarks represent optimisation potentials which have to be analysed regarding possible measures under the existing frame conditions. The aim of corporate benchmarking is the identification of areas for optimisation within the whole field of activities of a water supply utility.

Depending on the detailedness, benchmarking projects are organised as single performance comparisons (note: and therefore these projects should not be called "benchmarking projects"), which may represent just a part of the whole field of tasks of a benchmarking cycle, up to systematic, holistic (considering supply safety, supply quality, customer service, sustainability and efficiency) and periodical, "real" benchmarking activities.

Corporate benchmarking does not go into as much detail as process benchmarking, but with a holistic approach a good overview about strengths and weaknesses of utilities can be found out. Therefore the results of corporate benchmarking projects are often the basis for more detailed analyses such as process benchmarking.

#### 3.2.1.2. Methodology in corporate benchmarking

By definition, benchmarking is a continuous und systematic measuring process which compares the performance of an utility with the "best in class" in order to derive measures for improvements (CAMP 1989).

Performance indicator systems and benchmarking are management instruments for internal purposes as well as for company comparisons on a regional, national and an international level (MERKEL 2001). The aim is to arrange a quasi competition. In Austria benchmarking is based upon the principles of voluntary and anonymous participation.

Figure 3 shows the workflow of a benchmarking process. The first step is a comparison of performance indicators of different water utilities. The variation of the individual value from the optimum value represents a theoretical potential for improvement. However, the best possible homogeneous data collection and largest possible sampling of similar participants are crucial criteria for achieving good comparability.

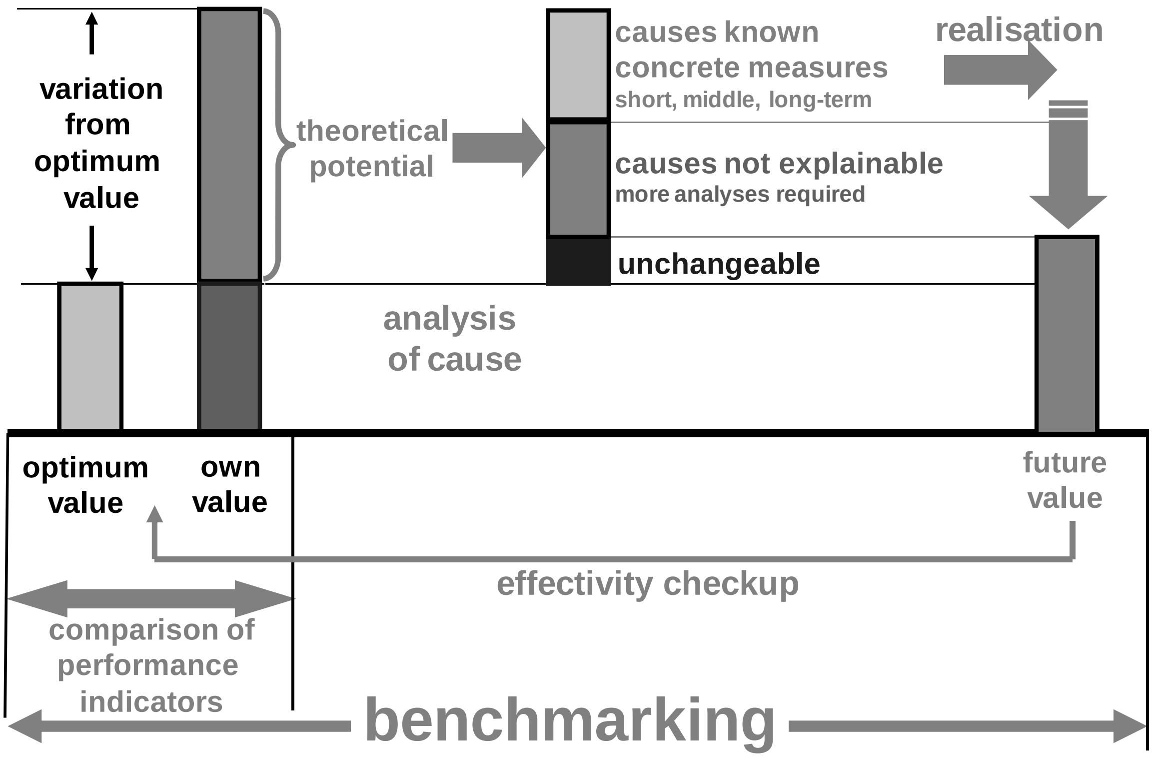


**Figure 3: Benchmarking process (SCHULZ in HIRNER & MERKEL 2002, amended)**

Causes for variations from the optimum value, which are related to local characteristics, stay unchangeable. Some causes are not explainable at the moment and thus have to be analysed. Concrete measures can be defined for those causes which are known. In a next step, these measures are realised in order to gain a future value of the amount of the optimum level plus unchangeable elements. To complete the benchmarking process, an effectivity check-up in the form of a new comparison of performance indicators is necessary (KOELBL et al. 2006).

### 3.2.2. Process benchmarking

Process benchmarking goes into more detail than corporate benchmarking by analysing single working flows (e.g. customer meter reading, customer meter replacement or water loss management). Due to the more detailed analyses compared to corporate benchmarking it is (rather) possible to identify concrete optimisation potentials and to set measures for improvement.

Various international experiences (compare PICCININ 2006 or OTTILINGER 2004) as well as also experiences within the Austrian OVGW Benchmarking project (KOELBL et al. 2008b) show that:

- Corporate benchmarking is a good instrument for detecting where optimisation potentials are hidden.
- Process benchmarking displays how these potentials can be tapped.

Figure 4 gives an overview of the characteristics of corporate and process benchmarking.

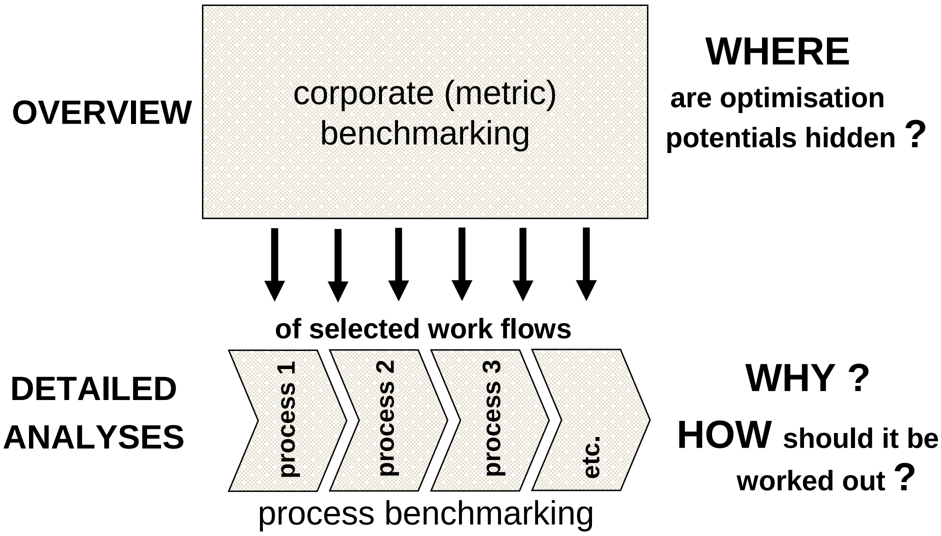


**Figure 4: From corporate to process benchmarking (KOELBL et al. 2007a, amended)**

### 3.2.2.1. What is process benchmarking?

According to SIEBERT & KEMPF (1998), process benchmarking is the comparison of similar processes with the aim of process optimisation.

Although when there are many water supply process benchmarking projects in different countries all over the world, clear definitions of process benchmarking and its steps are often missing. This has already led to some misunderstandings in the "process benchmarking community".

A central question in this discussion is whether the performance comparison of single processes should be done in a more qualitative or a more quantitative way. Some "benchmarkers" are of the opinion that the calculation of PIs is part of metric (corporate) benchmarking and not of process benchmarking (note: this is one of the reasons why the term "metric" should be displaced by the term "corporate"). Thus in this case the process analysis has to be done in a solely qualitative way. Other approaches focus on the calculation of financial PIs without considering the qualitative criteria of process operations.

Chapter 3.2.3 describes international experiences in process benchmarking. After reviewing all these approaches, the following definition of process benchmarking seems to be practicable:

> *Process benchmarking is a management methodology to compare and to optimise the performance in process operation. The basis of such a performance comparison is a well defined and clear process structure with a division of a process into sub processes and single tasks. Process performance indicators should be calculated for the overall process as well as for several sub processes and tasks to enable a comparison on a quantitative basis. In addition to the calculation of process performance indicators it is useful to describe the process operation in a written form. Beside economic aspects, the quality of process operation also has to be analysed. A central part in process benchmarking is the exchange of experiences, preferably in workshops. After cause analyses and implementation of measures the success in optimisation is verified within a new performance comparison.*

#### 3.2.2.2. Objectives of process benchmarking

As mentioned above, the objective of process benchmarking has a stronger focus on concrete optimisation potentials than corporate benchmarking. A precondition for the derivation of concrete measures for improvement of operating procedures is the knowledge about the performance in process operation. Therefore process analyses have to give answers to the following:

- How are the processes, the single sub processes or tasks operated?
- What are the main process and sub process costs?
- What is the working time for the main process and for the sub processes?
- Are the defined quality criteria fulfilled?
- How do the other utilities perform and why are they better or worse?

Hence the operational benefits of process benchmarking for water utilities are lower costs for the same quality in process operation or a higher quality in process operation for the same costs.

The macroeconomic benefit of process benchmarking within this sector can be seen in increasing efficiency and quality of the water supply sector and pushing modernisation.

In combination with corporate benchmarking, the objectives of a modern water supply (supply safety, supply quality, customer service, sustainability and efficiency) should be assured for the future.

#### 3.2.2.3. Methodologies in process benchmarking

A precondition for high-quality process benchmarking is a diligent and clear hierarchical process structure. Hence, the input and output factors need to be specified for each process and the sub processes to clearly confine the whole process as well as the sub processes. This step is called process mapping.

In order to benchmark both technical and economical aspects, quality criteria for each process step have to be determined. Also a lot of background information about the individual frame conditions (e.g. structure of the water supply system) and about the differences in operation is necessary.

Because existing cost accounting systems of utilities often do not reflect the requirements of collecting costs for process benchmarking, an applicable cost allocation system has to be formulated. It makes sense to use a bottom-up approach for data collection and a top-down approach to control the sum of collected data. This means collecting data on the level of sub processes or for single tasks and controlling the sum of costs for the whole process. The overall process costs have to be plausible within the whole operational and capital costs of the utility.

After creating a process performance indicator system, the second step is the process comparison within a group of participating utilities. The results of the performance comparison should be analysed internally within the utilities before coming to the most important step within process benchmarking: the exchange of experiences and learning from each other.

Experience has shown that this exchange can be done preferably in “best practices” workshops where the results of the performance comparison can be discussed and analysed and best practices can be worked out. Of course, further actions like bi-lateral analyses of two utilities or workshops in small groups can (and should!) follow.

To reach the aim of becoming “best in class” it is necessary to work out best practices of process operation and to implement these best practices into the process operation and water loss management policies of the participating utilities.

The procedure of process benchmarking as described above is shown graphically in Figure 5.

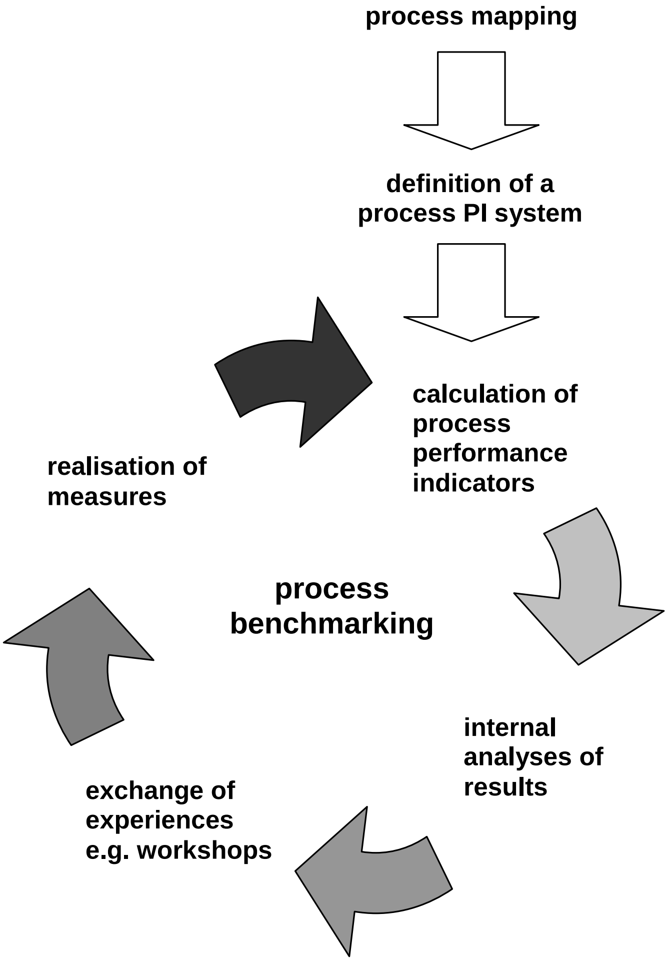


**Figure 5: Procedure of process benchmarking**

3.2.2.4. Different process benchmarking concepts

In the IWA manual of best practise about process benchmarking in the water sector LARSSON et al. (2002) describe a holistic approach to process benchmarking as practised, e.g., in the Netherlands or Scandinavia. The idea of that system is to analyse all the duties of a water supply utility, beginning with the extraction and ending at the sales to customers. The so-called processes are highly aggregated sequences of single tasks dealing with, e.g., the process of water treatment. However this holistic IWA approach only results in a very coarse division (Table 5).

Another approach can be seen in the selective strategies of process benchmarking which are used in various countries, e.g. Australia (PICCININ 2006) or Bavaria in Germany (KIESL & SCHIELEIN 2005). The selective strategy seems to be more practicable for Austrian requirements as Austrian process benchmarking is seen as a complement to the metric benchmarking activities.

**Table 5: Holistic approach vs. selective process benchmarking approach**

| holistic approach | selective approach |
|---|---|
| • IWA manual of practice:<br>Process Benchmarking in the Water Industry (LARSSON et al. 2002)<br>• practised e.g. in the Netherlands and Scandinavia<br>• analyses of all duties from water extraction to the sales process<br><br>+ closed cost allocation system<br>- highly aggregated sequences of single tasks<br>- very coarse division | • practised e.g. in Australia, Germany and Austria<br>• analyses of selected processes out of the whole field of duties<br>• seen as a complement to corporate benchmarking activities<br><br>+ simple cost allocation system<br>- no closed cost allocation system<br>+ more detailed analyses possible than in the holistic approach |

### 3.2.3. International experiences in benchmarking

This chapter includes descriptions of selected international benchmarking projects. Beside some important examples of corporate benchmarking projects the focus is on process benchmarking projects. The list does not claim to be complete.

#### 3.2.3.1. Australia (IWA/WSAA)

Until the year 2000 the Water Services Association of Australia (WSAA) organised several cycles of corporate benchmarking. Due to the fact that the process of exchanging experiences and derivating optimisation measures on basis of corporate benchmarking results was exhausted, the participants wished to go more into detail and to start process benchmarking (compare PICCININ 2006).

Since May 2000 a number of process benchmarking projects have been carried out in Australia with participation of Australian utilities but also with international participation. In a rolling programme of process benchmarking exercises, one process is analysed each year. The programme has consisted of civil, mechanical and electrical maintenance practices, customer service, shared services and asset management (IWA/WSAA 2006):

2000 – Civil Maintenance Practices (13 WSAA Members)

2001 – Mechanical and Electrical Maintenance Practices (14 WSAA Members)

2002 – Customer Service (12 WSAA Members, plus international comparisons)

2003 – Shared Services (10 WSAA Members, plus limited UK data)

2004 – Asset Management (19 WSAA Members, plus 2 USA)

2005 – Civil Maintenance Practices (17 WSAA Members, 1 USA, 1 Canada)

2006 – Mechanical and Electrical

2007 – Customer Service

2008 – Asset Management

2009 – Civil Maintenance

Since 2008 the International Water Association has supported the WSAA process benchmarking activities and a worldwide IWA/WSAA process benchmarking is now initiated.

The IWA/WSAA process benchmarking approach not only uses a quantitative assessment of data, but also links the metric results to the observed qualitative practices of a utility to provide a meaningful improvement plan and discussion of relative performance. The quantitative assessment is considered from three perspectives (IWA/WSAA 2006):

- What are the costs of undertaking the activity?
- What is the service level at which the activity is delivered?
- What cost and service level tradeoffs are being made by the utility?

The qualitative assessment includes interviewing each of the participants to understand how the activities are undertaken. When the two assessments are drawn together the utilities should be provided with an understanding of their relative performance with respect to service levels and costs against their peers, and with a detailed roadmap that provides improvement opportunities (IWA/WSAA 2006).

From the methodical point of view, the OVGW process approach is similar to the Australian approach. Both systems use a selective approach, focusing on different topics drawn from the whole value chain of a water supply utility. And both systems use metric elements for a quantitative assessment of process economics and use qualitative methodologies (interviews, context information) to assess the quality in process operation.

The differences between the Australian and the Austrian benchmarking project are the intensity of analysing the single processes, which is proably higher in the Australian project, but also in project costs, which are more than 10 times higher in the Australian project. The processes analysed are also different and the IWA/WSAA does not benchmark the process of water loss management.

#### 3.2.3.2. Canada

The Canadian National Water and Wastewater Benchmarking Initiative started a pilot project in 1997 for four participating cities on corporate benchmarking for the waste water sector. In 2001 the project was extended to the water supply sector. The current project has been joined by 42 utilities from the water supply and waste water sector. The Canadian benchmarking project is considered to be one of the leading public sector benchmarking projects of its kind in the world (McCormack 2005, Main et al. 2008).

Process benchmarking activities have been carried out together with corporate benchmarking activities since 2001 because process benchmarking is seen as a tool to bridge the gap between corporate benchmarking and utility goal attainment. Process benchmarking activities are worked out by various Process Benchmarking Task Forces which consist of members of participating utilities. These task forces identify process related issues that are common to many utilities and refine process-specific performance measures. The aim is to identify related “Best Practice“ sources (e.g. methodologies of participating utilities, AWWA, IWA etc.) and to set a specific “Action Plan” for participating utilities according to adopted Best Practices. Other functions of these Task Forces are building up networks with experts and peers, piloting the implementation of the processes in a few utilities and refining for the Best Practices for general use (MAIN 2008a).

Currently process benchmarking activities are being undertaken on the following topics (MAIN 2008a):

- Water Loss Management
- Maintenance Planning (Collection, Distribution, Drainage)
- Complex Facilities Maintenance Planning
- Sustainable Funding Through Asset Management
- Wastewater Treatment Plant Optimisation
- Energy Management
- Inflow and Infiltration
- Succession Planning
- Attendance Management
- Stormwater Management

*3.2.3.2.1. Canadian process benchmarking on Water Loss Management*

According to MAIN (2008b), following objectives are pursued within the Canadian process benchmarking on Water Loss Management (compare to Figure 6):

- Calculation of the international best practice performance indicator for water losses, the Infrastructure Leakage Index (ILI)
- Comparison of estimates for unmetered water consumption volumes and development of standard methods for these estimates (e.g. main flushing)
- Investigation of water loss management policies, measures, tools and approaches of the benchmarking participants and leveraging this practical experience and knowledge for the benefit of all participants
- Investigation of costs and benefits of water loss management measures, and determination of which initiatives provide the best results

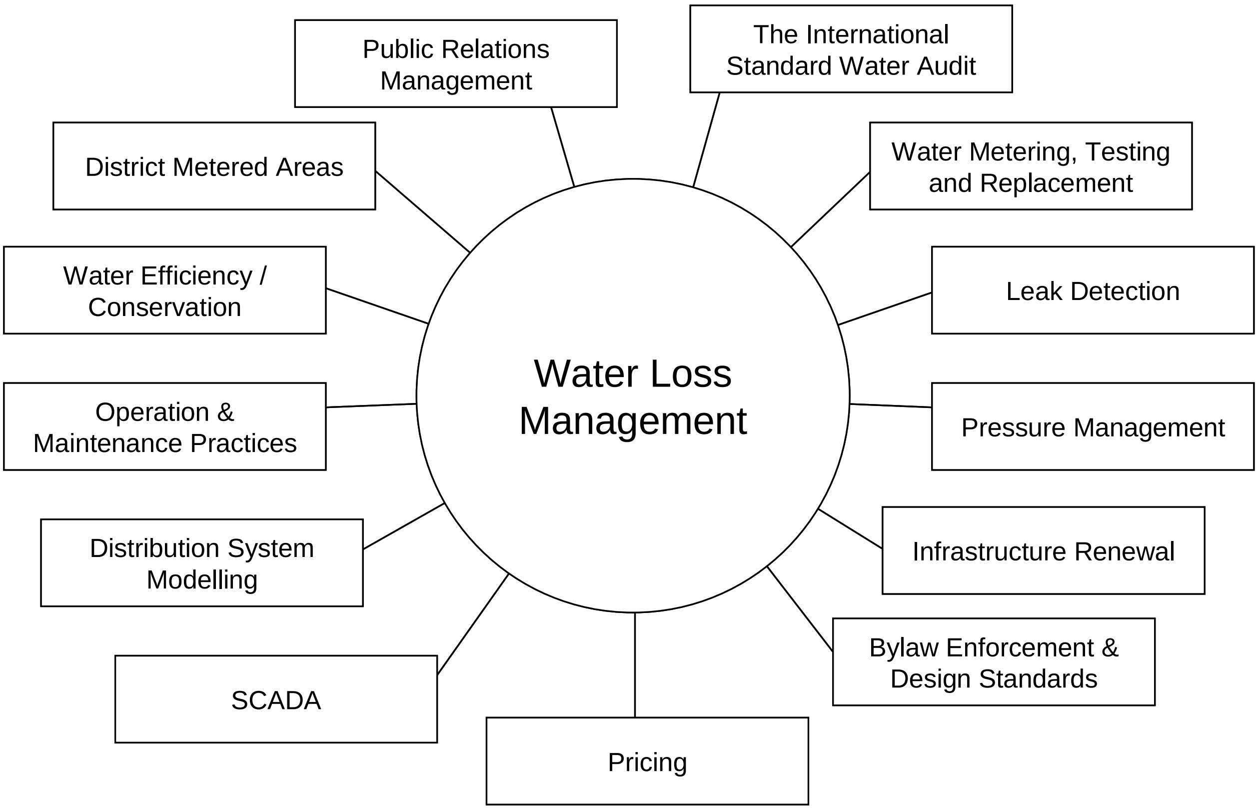


**Figure 6: Canadian water loss management strategies (McCormack 2005, amended)**

The idea of the Canadian process benchmarking on Water Loss Management is to calculate only a few performance indicators. The focus is laid on the calculation of the IWA water balance, water loss PIs and the estimation of Non-Revenue-Water (NRW), especially unbilled consumption.

According to water losses, the following PIs were calculated in the Canadian 2005 project (data from 2005):

*Non-Revenue Water*

- % of supply
- litres per connection per day
- costs of NRW

*Real Losses*

- ILI

To estimate the costs of NRW for apparent losses and for the unbilled authorised consumption the typical water rate per m³ (Canadian $/m³) was taken into account. The variable production unit costs were considered for real losses. These were calculated by unit cost of bulk water purchased plus unit cost of treatment chemicals plus unit pumping costs and unit cost of distribution.

Other aspects were the costs and amount of leak detection but also the influence of the average mains' age and the pipe material on water losses were analysed.

Within a workshop, and as central part of the project, the results were presented and analysed by the participants. Utilities that are more advanced could share the benefit of their lesson learned, and mostly, the errors they made along the way (MAIN 2008b).

To sum up the aspects of the Canadian benchmarking described in this work, it has to be mentioned that the Canadian benchmarking initiative is one of the first in the water supply sector worldwide. With an annual benchmarking workshop and a quite stable number of more than 40 utilities participating in this benchmarking project a central objective of benchmarking has been fulfilled: continuity! The Canadian benchmarking initiative can look back at more than 10 successful years in this business. The crucial factors of success seem to be the focus on exchange of experiences (workshops) and to make the benchmarking systems not too complex (low effort in data collection).

All in all, the Canadian process benchmarking approach is similar to the approach of the Six-Cities Group (Scandinavia), which is described in chapter 3.2.3.4. Contrary to process benchmarking systems with detailed process performance indicator systems the Canadian approach focuses on working out best practices on basis of qualitative analyses of the process operation and comparable international examples. With the calculation of only a few performance indicators regarding the amount of water losses and some cost indicators, this approach is quite different than, e.g., the Austrian process benchmarking approach. The main part of the project is the annual workshop where an intensive exchange of experiences is enabled and new aims for further benchmarking activities are defined.

#### 3.2.3.3. Germany

A very good overview about benchmarking activities in Germany is given in the PROFILE OF THE GERMAN WATER INDUSTRY (2008). The following descriptions derive from this publication of the German Associations of the water sector (ATT - Association of Drinking Water from Reservoirs, BDEW - German Association of Energy and Water Industries, DBVW - German Alliance of Water Management Associations, DVGW - German Technical and Scientific Association for Gas and Water, DWA - German Association for Water, Wastewater and Waste, VKU - Association of Local Utilities).

The German water sector considers benchmarking to be an efficient instrument for identifying, getting acquainted with, and adopting successful methods and processes from benchmarking partners. As in many other countries, in Germany the principle of benchmarking is also based upon two prerequisites which make an essential contribution to success: voluntary participation and confidential treatment of information.

In 2005 the German Associations of the water sector signed the extended “Statement of the Associations of the Water Industry on Benchmarking in the Water Sector” and thus defined for themselves the support of benchmarking to be an integral part of their self-administration.

The benchmarking concept of the German water industry is part of the modernisation strategy for the regulatory framework of the German federal government. This concept was developed and promoted by the water sector itself in consultation with the political partners. The aim of the concept is to optimise processes and open potentials for improvement. It is mentioned that these aims can not be realised by compulsory benchmarking based on statutory provisions.

The different German benchmarking projects are carried out by independent private providers which, on the one hand, should ensure a high quality standard of the projects through free market and, on the other hand, the competition and free selection of providers should lead to projects optimally adjusted to the particular issues to be addressed.

Germany-wide, more than 27 different benchmarking projects are being currently carried out (Table 6). These projects range from mere comparisons of performance indicators and the examination of entire companies (corporate benchmarking) to individual process analyses (e.g. construction of service connections). In all these benchmarking activities the aspects of supply safety, quality, customer service, sustainability and efficiency are considered.

Up to the end of 2007, more than 750 German companies, representing about 60 % of the water output of the public water supply, participated in benchmarking. Beside optimisation measures carried out within the companies, methodical developments within the different benchmarking projects are also described within the PROFILE OF THE GERMAN WATER INDUSTRY (2008), e.g. the development of hierarchical and compatible performance indicator systems (note: many of them based on the IWA PI-System), criteria for building peer groups for the comparison or methods for the quantification of external influences like the degree of outsourcing.

Currently 11 process benchmarking projects are realised in the drinking water sector of Germany. These projects focus particularly on human resources management, the operation of the pipeline network, construction of mains and service connections, the billing of consumption and metering, water abstraction and water treatment, customer service and operation of impounding reservoirs (PROFILE OF THE GERMAN WATER INDUSTRY 2008).

Additional to the projects in Table 6, HEIN et al. (2008) describe a process benchmarking for drinking water production which is executed by the IWW Water Centre.

Even though are many process benchmarking projects organised in Germany none of them analyses the process of water loss management.

**Table 6: Performance comparisons and benchmarking projects in Germany (PROFILE OF THE GERMAN WATER INDUSTRY 2008, amended) part 1**

| No. | Project name | Project organising/ executing organisation | Project type | Period | Partici-pants | System input volume (mill. $m^3/a$) |
|---|---|---|---|---|---|---|
| 1 | Process indicators for water management, abstraction and treatment | German Federal Ministry of Education and Research; project management: PTKA-WTE* | • research project<br>• process benchmarking | 2005 to 2008 2nd cycle | 12 | |
| 2 | Comparison of indicators in Mecklenburg-Western Pomerania | different utilities at initiative of the association of water supply and waste water disposal utilities of Mecklenburg-Western Pomerania within BDEW and the BDEW “Northern Germany regional section” | • indicator comparison | since 2003 3rd cycle | 36 | 143 |
| 3 | Indicator comparison project | The different utilities; for participants of Lower Saxony, the project initiator is the Wasserverbandstag e.V. Bremen, Lower Saxony, Saxony-Anhalt (WVT) | • indicator comparison | since 2000 5th cycle | 57 | 344 |
| 4 | Indicator comparison of the Wasserverbandstag e.V. of Lower Saxony | Wasserverbandstag e.V. Bremen, Lower Saxony, Saxony-Anhalt (WVT) | • indicator comparison | since 2001 3rd cycle | 22 | 171 |
| 5 | Benchmarking initiative of the Land Rhineland-Palatinate | Ministry for Environment, Forestry and Consumer Protection; Cooperation partners: Association of municipalities and cities in Rhineland-Palatinate, Federation of towns in Rhineland-Palatinate, VKU, DWA, DVGW, LGW | • corporate benchmarking | since 2004 | 96 | 162 |
| 6 | Benchmarking on water supply in Hessen | BDEW and DVGW regional section of Hesse, in cooperation with the association of cities and municipalities in Hesse and the federation of towns in Hesse | • corporate benchmarking | since 2005 | 34 | 223 |
| 7 | Associations’ model of performance indicators comparison in Baden-Wuertemberg | Federation of towns in Baden-Württemberg, Association of municipalities in Baden-Württemberg, DVGW B.-W., VGW B.-W., VKU B.-W. | • corporate benchmarking | since 2005 2nd cycle | 75 / 102 | 150 / 373 |
| 8 | Inter-utility performance benchmarking of metropolitan supply utilities | ÜBV** (represented by the ÜBV office – Stadtwerke Münster) | • corporate benchmarking | since 1949 | 24 | 785 |
| 9 | Corporate benchmarking on drinking water supply | | • corporate benchmarking | since 2000 7th cycle | 10 | 1.444 |
| 10 | *EffWB* (Bavaria) | Bavarian State Ministry for the Environment, Health and Consumer Protection, VBGW (DVGW regional group “Bavaria”), Bavarian Association of municipalities, Bavarian Federation of towns | • corporate benchmarking | since 2000 3rd cycle started | 95 / 84 | 324 / 196 |

**Table 6 continued: Performance comparisons and benchmarking projects in Germany (PROFILE OF THE GERMAN WATER INDUSTRY 2008, amended) part 2**

| | | | | | | |
|---|---|---|---|---|---|---|
| 11 | Project of the Land NRW | Ministry of economics, medium-sized businesses and energy of the Land North-Rhine-Westphalia (NRW), Ministry of the Interior of NRW, Ministry for the Environment and Nature Conservation, Agriculture and Consumer Protection of NRW, VKU, BDEW regional section of NRW | • corporate benchmarking | on the point of starting | | |
| 12 | Benchmarking on water supply in Saarland (fed.state) | Association of the Saarland gas and water industry | • corporate benchmarking<br>• process benchmarking | from 2007 | 29 | 63 |
| 13 | BkV*** / benchmarking of VKU – Water | Association of municipal utilities | • corporate benchmarking<br>• process benchmarking | since 1953 54th cycle | 179 | 693 |
| 14 | BkV*** / benchmarking of VKU – special purpose associations | Association of municipal utilities | • corporate benchmarking<br>• process benchmarking | 11th cycle | 8 | 293 |
| 15 | Benchmarking on the water supply in Thuringia | | • corporate benchmarking<br>• process benchmarking | since 2003 2nd cycle | 21 /16 | 64 / 40 |
| 16 | BKWasser | | • corporate benchmarking<br>• process benchmarking | since 2000 6th cycle | 50 | 45 |
| 17 | Benchmarking | Aggerverband and Wupperverband | • corporate benchmarking<br>• process benchmarking | since 2004 | 2 | 155 |
| 18 | Benchmarking on operation of impounding reservoirs | Association of Drinking Water from Reservoirs | • corporate benchmarking<br>• process benchmarking | since 2005 | 4 | 578 |
| 19 | Process benchmarking on water supply in Rhineland-Palatine | Federation of towns in Rhineland-Palatinate, Association of municipalities and cities in Rhineland-Palatinate, Ministry for Environment, and Forestry in R.-P., DVGW,VKU, DWA, LGW | • process benchmarking | on the point of starting | | |
| 20 | Benchmarking on implementation of consumption billing | the different utilities (the project executing organisation was “KOWAB – Kooperation Wasser und Abwasser Brandenburg-Ost”) | • process benchmarking | since 2001 4th cycle | 38 | 263 |
| 21 | Benchmarking on customer surveys | the different utilities (the project executing organisation was KOWAB) | • process benchmarking | since 2002 7th cycle | 26 | 212 |
| 22 | Benchmarking on house connection provision | the different utilities | • process benchmarking | since 2001 3rd cycle | 32 | 235 |
| 23 | Benchmarking on support processes | the different utilities | • process benchmarking | since 2006 | 12 | 60 |
| 24 | Benchmarking on pipeline network operation | the different utilities | • process benchmarking | since 2001 3rd cycle | 38 | 186 |
| 25 | Benchmarking on human resources management | | • process benchmarking | since 2005 2nd cycle | 2 | |
| 26 | Competitive water supply | | • process benchmarking | | 50 | 270 |
| 27 | Benchmarking on drinking water laboratories | six major water laboratories belonging to or working on behalf of drinking water suppliers **** | • process benchmarking | since 2006 | 6 | 855 |

| | |
|---|---|
| * | Project Management Agency Forschungszentrum Karlsruhe Water Technology and Waste Management Division |
| ** | Interplant performance comparison of metropolitan utilities |
| *** | Operational cost comparison |
| **** | According to KLEIN et al. (2008) |

In the following one project out of this large range of German benchmarking project is described more in detail. It is the *EffWB* Bavarian benchmarking project which has been very important for the Austrian benchmarking activities because of the cooperation between OVGW and the Bavarian project organisers. THEURETZBACHER-FRITZ et al. (2005) describe a first cross-border comparison of Austria and Bavaria.

*3.2.3.3.1. Bavarian benchmarking project EffWB*

The Bavarian State Ministry for the Environment, Health and Consumer Protection, the VBGW (DVGW regional group "Bavaria"), the Bavarian Association of municipalities and the Bavarian Federation of towns together with water suppliers initiated the *EffWB* Bavarian benchmarking in 2001.

The purpose of the *EffWB* project is to enhance efficiency and ensure the quality of the municipal water suppliers in Bavaria. The Bavarian water sector is similarly structured to the Austrian water sector, around 2500 water utilities supplying 12 million inhabitants in rural, urban and metropolitan areas. 95 utilities from the 1350 utilities with more than 100,000 m³ supplied water per year took part in the first round of the benchmarking exercise from 2001 to 2002 (KIESL & SCHIELEIN 2002). The size of participating utilities in terms of water supplied was between 0.1 and 116 million m³/a. The Free State of Bavaria sponsored the project, which is part of a number of measures aimed at stabilising fees and charges relating to drinking water supplies, while at the same time the requirements and services are also increasing (THEURETZ-BACHER-FRITZ et al. 2005). The project was repeated in 2004 with 84 participants (KIESL & SCHIELEIN 2005) and also in 2007 with 89 participants (KIESL 2008). The project objectives for participating utilities are (THEURETZBACHER-FRITZ et al. 2005):

- to analyse the efficiency and quality of the services
- to clearly define the position compared to other companies
- to detect their own deficiencies
- to identify the reason for such deficiencies and possible alternatives for improvement
- to initiate – if necessary – targeted measures for optimisation

The Bavarian benchmarking system represents a corporate benchmarking, but, in addition, some processes are also analysed. The structure of the benchmarking system corresponds with the IWA system (ALEGRE et al. 2000 and 2006). The tasks and operating processes are analysed in detail and made comparable for various types of companies. This ensures that the position of the individual water suppliers in the whole sector and within a comparable group of companies can be assessed. Furthermore, the reasons for any deviation and the alternatives for improvement are determined. According to the IWA approach, the analysis focuses on the following aspects: efficiency of the supplier, reliability of the supplying system, quality of the supplies, sustained activities of the supplier and customer support provided by the supplier (THEURETZBACHER-FRITZ et al. 2005).

A third aspect of the analysis focuses on some core processes of the whole value chain of the water supplier. Six processes are analysed within the *EffWB* project together with the corporate benchmarking activities. The six processes selected are processes which occur in every utility and are representative. The process analyses focus on the topics construction of new pipelines, the installation of private service connections, replacement of meters and the accounting and invoicing of the water consumed (Table 7). Two of the six processes are obligatory for all participants and four processes are facultative (KIESL & SCHIELEIN 2002).

**Table 7: Bavarian *EffWB* processes (KIESL & SCHIELEIN 2002)**

| | |
|---|---|
| Process 1 (obligatory) | Construction of new mains in development areas |
| Process 2 (obligatory) | Planable maintenance of the supply network<br>Part 1: Renovation and renewal of mains and service connections |
| Process 3 (facultative) | Planable maintenance of the supply network<br>Part 2: Inspection and maintenance of mains and service connections |
| Process 4 (facultative) | Construction of new service connections |
| Process 5 (facultative) | Customer meter replacement |
| Process 6 (facultative) | Customer meter reading and accounting |

The process analysis is mainly focused on a cost analysis of each process and the sub processes. Qualitative aspects of process operation are generally not considered. KIESL & SCHIELEIN (2005) mention that the result of these process analyses enable only a first orientation of the process performance and that the results are only the basis for discussions and detailed individual analyses within the participating companies.

The topics of the *EffWB* processes formed the starting point for the OVGW process benchmarking, which is described in detail in Chapter 3.2.4.2.

#### 3.2.3.4. The Six-Cities Group Benchmarking (Scandinavia)

In 1995 six Scandinavian cities - Copenhagen, Oslo, Helsinki, Stockholm, Gothenburg and Malmo - decided to start a benchmarking co-operation project. Beside yearly corporate benchmarking projects since 1996, a number of process benchmarking projects have also been carried out. The first trial for process benchmarking in selected topics was started in 1998.

STAHRE & ADAMSON (2002) give the following definition for process benchmarking:

> *Process benchmarking focuses on selected processes in the business and not on the business as a whole. The aim of process benchmarking is to improve the processes and to increase the efficiency by "learning from others". By comparing performance indicators and work processes in different cities the best practices are identified. The benchmarking includes comparisons and evaluations of goals, best practices, routines, basic data, performance indicators etc. for the processes studied. As a base for the process benchmarking one has to go into more detail in the work processes. The use of process charts can be of great help here.*

Figure 7 gives an overview of the different stages in benchmarking and performance assessment in the Six-Cities Group. According to STAHRE & ADAMSON (2002), the corporate benchmarking activities were supplemented by joint projects, including inventories of some practices that had already been applied in the six cities in the first years of the work. The aim of some of these projects was to explain differences observed in the corporate benchmarking and to suggest new routines. Some examples of such joint projects are:

- Construction of tariffs for water supply services
- Development of a model for assessing the urban water balance in order to increase the accuracy in calculation of water losses

So the first step in the direction of process benchmarking was done from the very beginning.

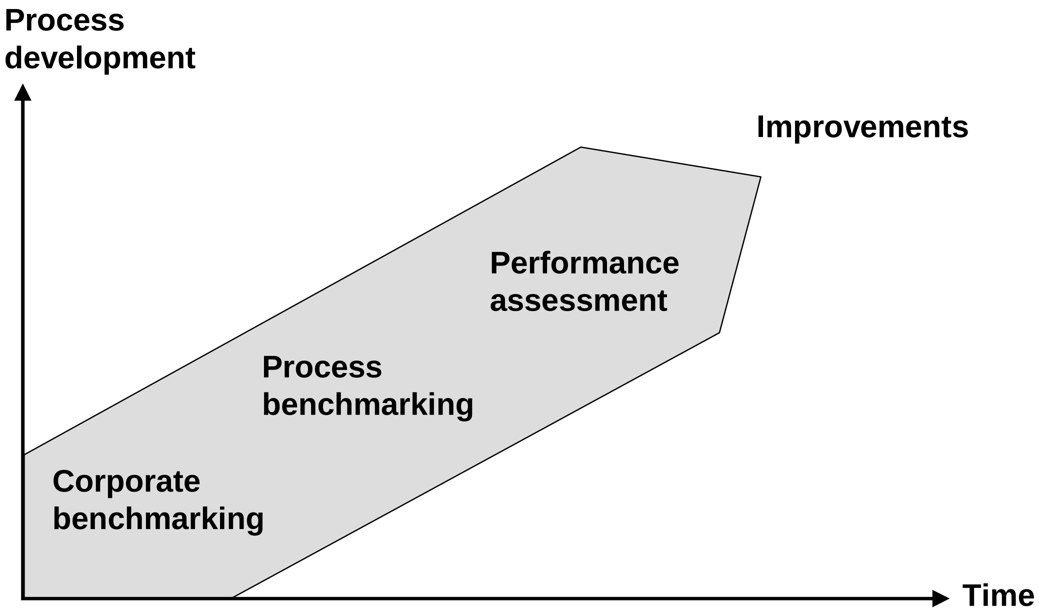


**Figure 7: Overview of benchmarking and performance assessment in the Scandinavian Six-Cities Group (STAHRE & ADAMSON 2002, amended)**

After some cycles of process benchmarking with additional analyses of single working routines, a new type of process benchmarking project was initiated in 2001, focusing on network operation and maintenance processes. The aim was to clarify in depth how performance indicators should be interpreted when comparing the different cities and how to identify the significance of relevant explanation factors. Therefore in the sector of water supply the following three process benchmarking projects were initiated (STAHRE & ADAMSON 2002):

- Water losses
- Interruption in delivery of drinking water to the customer
- Rehabilitation of networks

The single projects are organised in such a way that each of these benchmarking projects is performed by two participating cities, which in general are the best and worst in class (Figure 8). The results are documented in a report and a third city visits the two benchmarking utilities and carries out an audit of the project. The project is discussed and evaluated within a workshop together with the people working in the areas studied from all the utilities. Further outcomes of the projects, besides getting a better understanding of relevant explanation factors, are also the highlighting of examples of good performance and examples of objectives, strategies, criteria, routines, organisation, equipment etc. (STAHRE & ADAMSON 2002).

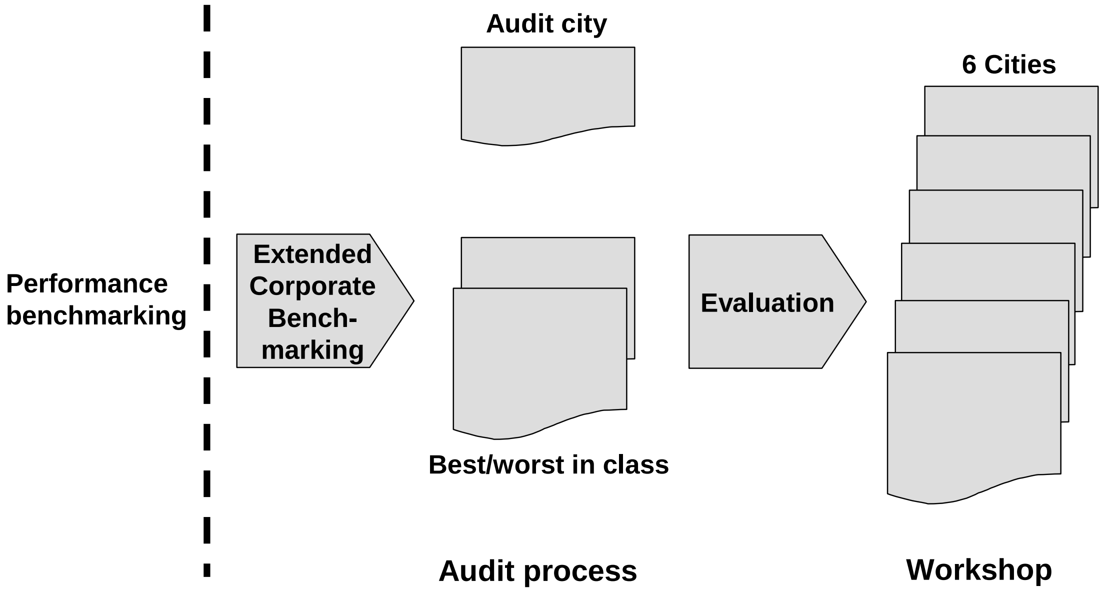


**Figure 8: Working model for process benchmarking in the Six-Cities Group (STAHRE & ADAMSON 2005, amended)**

*3.2.3.4.1. The Six-Cities Group process benchmarking on water losses*

Leakage from the water distribution network was one of the topics that attracted interest at an early stage of the Six-Cities Group Benchmarking. The basis for the process analysis was the calculation of the amount of water losses. Instead of the misleading "water loss ratio" performance indicator expressed in percentages, the group decided to use the PI "real losses per mains length" expressed in $m^3$ per km of water main per day. For further analyses, the ILI (Infrastructure Leakage Index) was also calculated. As a first outcome, the necessity for improving accuracy of water balance data was realised. Therefore a new model for the collection of basic data regarding water balance was introduced (STAHRE & ADAMSON 2002).

In 2001, two of the six cities started a process benchmarking project on leakage in the water distribution system with the objective of clarifying the relevant explanatory factors for leakage and also illustrating good practice for reducing leakage. Those two cities have about the same leakage level per km of water main. One city has severe geological conditions and has to work hard to keep the leakage under control. In the other city the network leakage is not seen as a problem. Beside the performance in leakage, additional performance indicators and background information (e.g. pipe material and average age of pipes, geological conditions) were also analysed. The following PIs were calculated for each of the years from 1996 to 2000 (STAHRE & ADAMSON 2002):

- Water leakage in $m^3$ per kilometre of water mains per day
- Number of bursts on water mains per 10 kilometre and year
- Number of bursts per 1000 service connections
- Interruptions of water service in minutes per customer and year
- Net cost for operation and maintenance in Euro per meter water mains

- Pipe renewal rate in ‰ of the total length of water mains

On basis of the calculated PIs the following most important explanatory factors were found out (STAHRE & ADAMSON 2002):

- Geologic and topographic conditions
- Population density
- Pressure in the network
- Long term planning for maintenance and renewal
- Design and construction aspects
- Level of resource allocation for leakage control

Recommendations based on the conducted benchmarking study and mainly on the experiences from one of the participating cities can be summarised as follows (STAHRE & ADAMSON 2002):

- Clear objectives need to be defined and a strategy to keep leakage under control has to be formulated.
- Realistic and measurable targets need to be defined.
- If the geological conditions are severe it is necessary to have a special group for systematic leakage control.
- The leakage control must cover the whole system from water abstraction (or water treatment plant) to consumer.
- Accuracy in water metering is crucial.
- District metering gives the base for prioritising the leak detection efforts.
- Methods and routines for systematic leakage control and leak detection need to be implemented.
- To highlight the results from leakage control in the whole organisation helps to make the leakage problem understandable for the whole staff.

To summarise the Six-Cities Group approach in process benchmarking on water losses from the methodical point of view, it becomes clear that the main focus of the project is not on the calculation of a lot of performance indicators on basis of a rigid process structure but on a more or less qualitative analyses of good practises in process operation. This approach is much different to, e.g., the Austrian approach with a detailed process performance indicator system.

An advantage of the Six-Cities Group approach is that the individual possibilities of process operation can be better displayed than by a given process structure. This is accomplished through the use of process charts and oral or written descriptions of the process operation.

The Six-Cities Group approach may be more suitable for the comparison of only a very few participants (in the case described two cities took part in the 2001 project). For larger groups of participants it may become difficult to quantify the effort or the quality in process operation and maybe a lot of additional questions will have to be answered at a later stage of the project. Another aspect (which may also occur in projects with more participants) is the risk that the “real” best-practice-utility does not participate in the process benchmarking project. So it has to be assumed that the outcome of a process benchmarking between utilities with a poor or medium performance can not lead to “real” best practices. However, the aspect of choosing the right benchmarking partners is another topic that often can not be solved because the partner of choice is not known before the start of a project or a potentially good partner is not interested in a benchmarking project.

All in all, the Six -Cities-Group process benchmarking approach is a very interesting one and was one of the first projects in the world using this methodology in water supply sector. The approach is similar to the Canadian approach which is described in chapter 3.2.3.2.

#### 3.2.3.5. Netherlands

Until the1970s more than 110 communal water utilities existed in the Netherlands. Increasing problems with water quality and supply safety lead to a reorganisation of the Dutch water supply sector (ACHTIENRIBBE 1997 in CLAUSEN & SCHEELE 2001). At the end of the 1990s the number of water supply utilities in the Netherlands was reduced to about 20 after a consolidation process.

In 1997 the Dutch Ministry for Economic Affairs ordered a study about the performance of the Dutch water supply sector, which stated the high technical standards but also mentioned cost inefficiencies. The implementation of benchmarking was suggested to decrease these inefficiencies and to gain further information about the sector (DIJKGRAAF et al. 1997 in CLAUSEN & SCHEELE 2001).

In the same year the roof organisation of the Dutch water supply utilities (VEWIN) started a voluntary nationwide benchmarking project which covered 85 % of the supplied water in the Netherlands. The project was repeated in the year 2000 (VEWIN 2001) with 15 participating utilities, in the year 2003 (VEWIN 2004) and also in 2006 (VEWIN 2007).

The VEWIN approach represents a corporate benchmarking system which focuses on the analyses of

- finances and efficiency
- supply quality
- product quality and
- environmental quality.

To make the operational costs transparent at a detailed level, a process model is used in which five processes are distinguished:

- production
- distribution
- process-support
- sales and
- general.

At the beginning the VEWIN benchmarking approach was a form of “sunshine-regulation” because the results of the studies were openly published and available to all. Therefore the participating utilities were, of course under public pressure (including their customers) to optimise their performance. This approach has proved to be counterproductive and meanwhile the Dutch benchmarking has been changed to an anonymous system.

Process benchmarking is not implemented in the VEWIN benchmarking, but the Dutch benchmarking project was one of the first benchmarking projects in the water sector in Europe and was also the basis for the North European Benchmarking Co-Operation (NEBC).

#### 3.2.3.6. North European Benchmarking Co-Operation (NEBC)

The NEBC benchmarking system is almost a corporate benchmarking system. During the work for this thesis there were some lively discussions with some members of NEBC project team about the question: What is process benchmarking? This is one of the reasons why the NEBC benchmarking project has to be described within this work.

The North European Benchmarking Co-Operation started in 2004 on the basis of a decision by the national water associations and several utilities of Denmark, Finland, the Netherlands, Norway and Sweden to co-operate on benchmarking performances of water services (NEBC 2007).

The objective of the North European Benchmarking Co-operation is to improve efficiency and transparency by

- exchange of knowledge on benchmarking
- development of a common, international benchmarking programme
- exchange of best practices of management and operations

After a comparison of different national benchmarking programmes of NEBC partners a first pilot international project on benchmarking costs of water supply was organised in 2005/2006. Using the existing Dutch VEWIN model for benchmarking at the level of business processes, 15 utilities from three countries participated in this pilot project. After an evaluation of this pilot project, NEBC partners decided to continue their international benchmarking programme for water as well as for wastewater activities and to focus not only on costs, but on all the relevant performance areas (NEBC 2007).

The NEBC benchmarking system focuses on 5 target areas:

- water quality
- reliability
- service
- sustainability
- finance and efficiency

Three different benchmarking levels enable a participation in different detailedness (Figure 9).

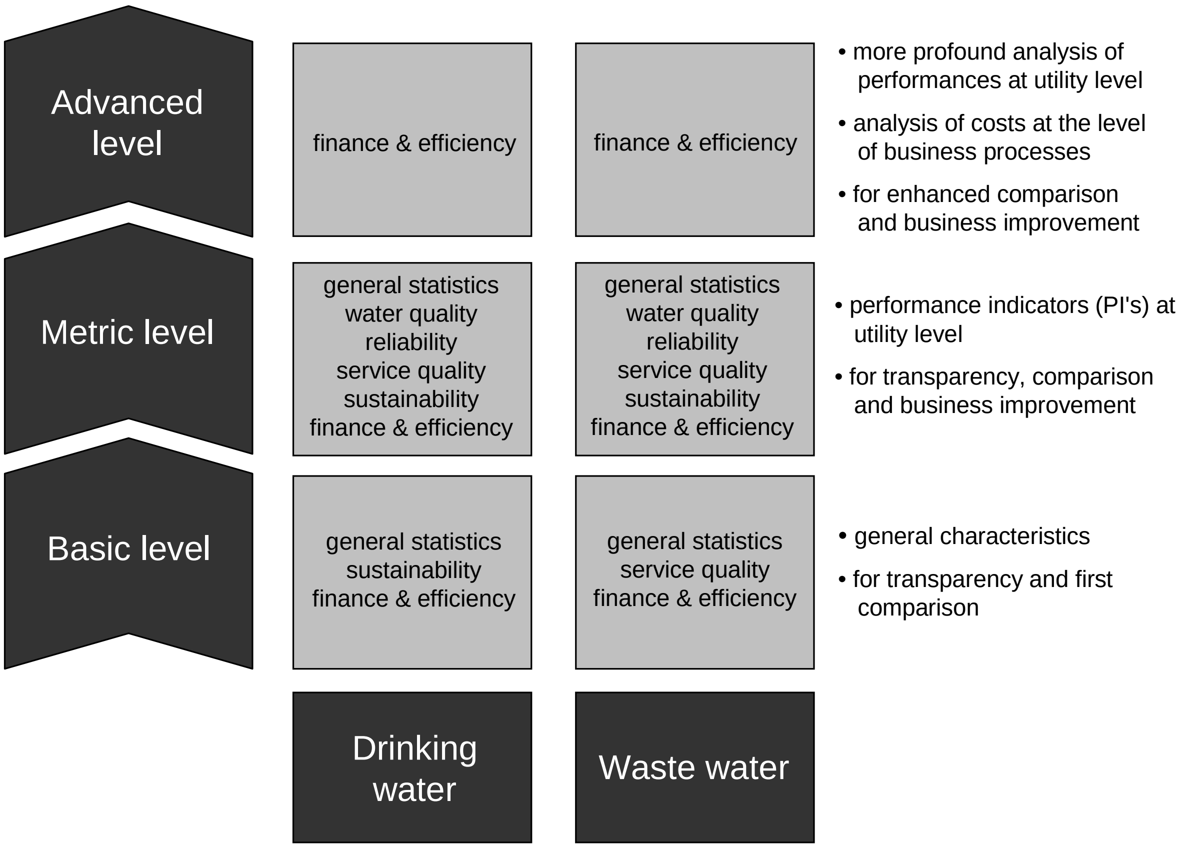


**Figure 9: NEBC benchmarking levels (NEBC 2007, amended)**

The advanced level includes a comparison of costs at the level of business processes (Figure 10). The process structure is deduced from the Dutch VEWIN benchmarking model for drinking water (NEBC 2007). The costs per m³ are calculated for the different process steps but there is no direct evaluation of the process quality.

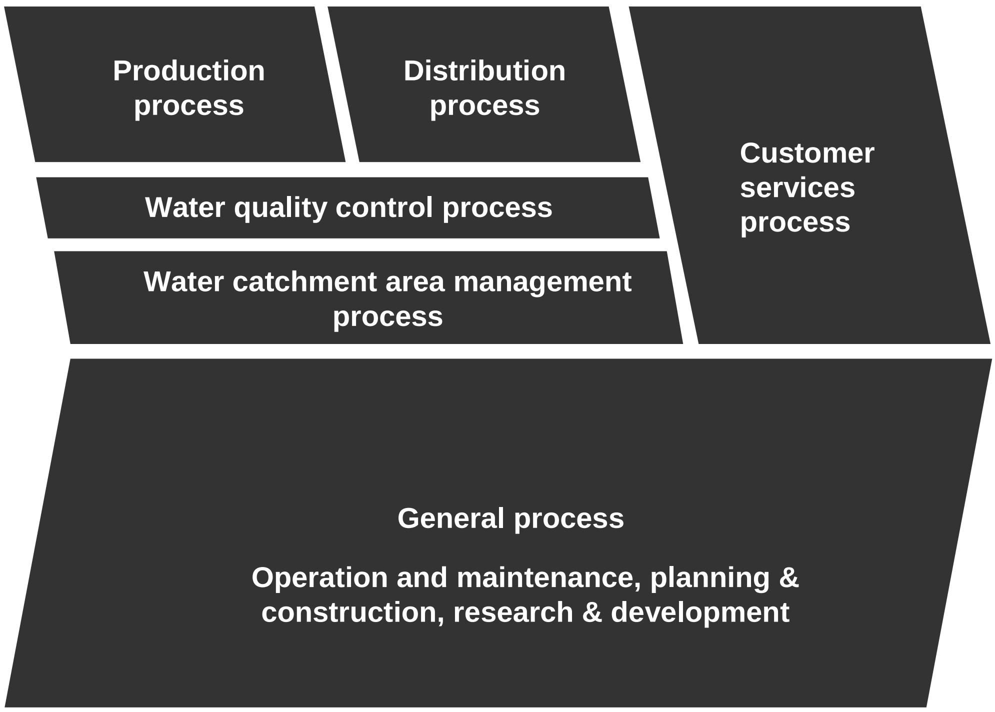


**Figure 10: NEBC Process structure (NEBC 2007)**

Therefore the NEBC model is not a “real” process benchmarking model because the assessment of the quality in process operation is missing and evaluations are done at a highly aggregated level with the focus only on costs.

### 3.2.4. The Austrian OVGW benchmarking initiative

Similar to many mid-European countries, the Austrian water supply sector is small structured. Around 3000 water undertakings centrally supply 8 million inhabitants in rural, urban and metropolitan areas. Based upon the international and national debates on requirements concerning the improvement of efficiency and the assurance of quality of drinking water services, the Austrian Association for Gas and Water (OVGW) has developed a mid-term strategy for setting up and carrying out benchmarking activities (Figure 11). The pilot study in the year 2002 was followed by the pilot project (“stage A”) which was completed in summer 2004. The following stage B (2004 project) with a larger number of participants was completed in June 2006. Future projects on metric benchmarking will be organised in time intervals of three years (KOELBL et al. 2006). In the time between two metric benchmarking projects, projects on process benchmarking are organised.

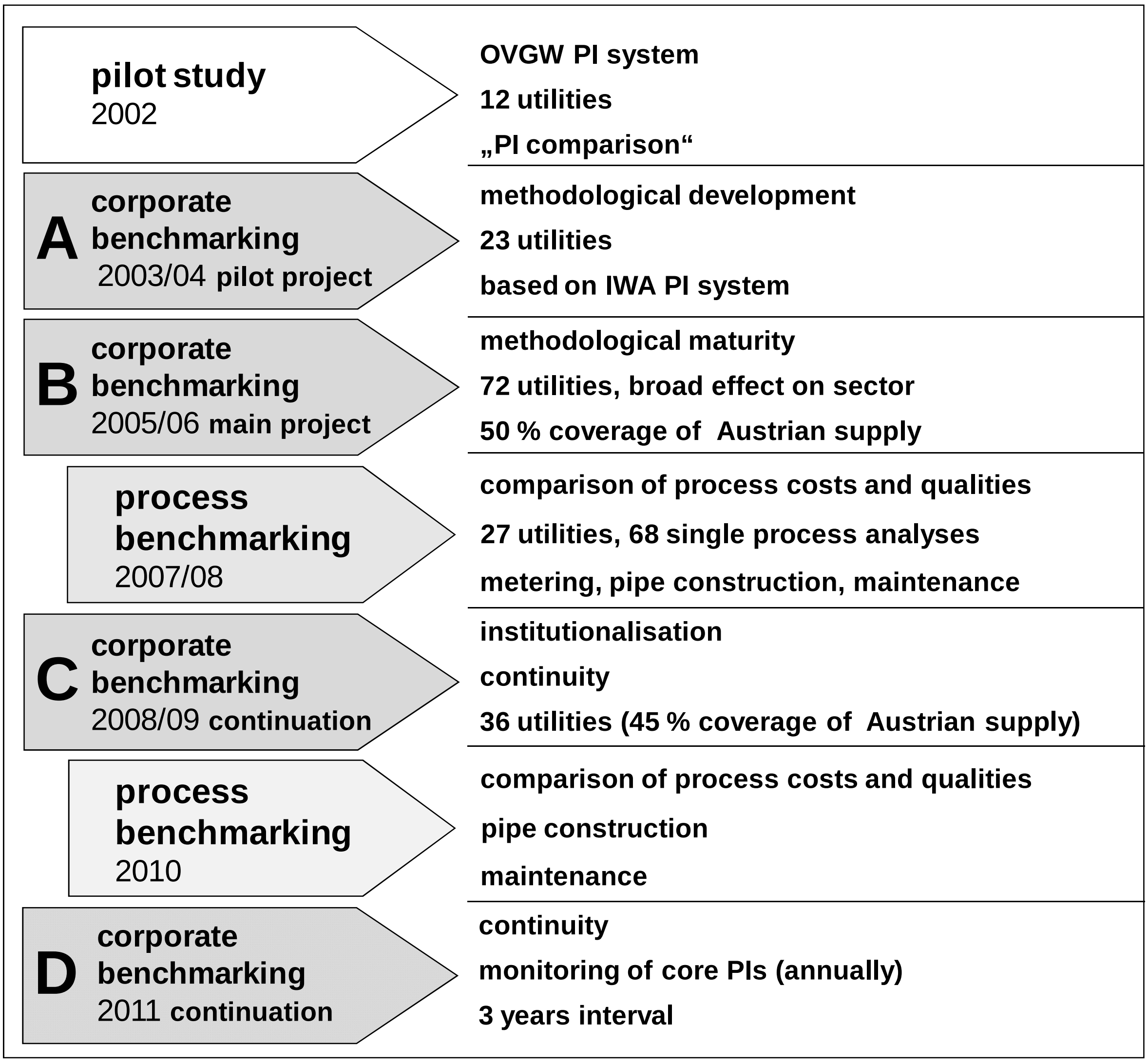


**Figure 11: OVGW benchmarking strategy (THEURETZBACHER-FRITZ & KOELBL 2003, amended)**

### 3.2.4.1. OVGW Corporate Benchmarking

#### *3.2.4.1.1. Stage A (pilot project)*

The Austrian "Benchmarking and Best Practices of Austrian Water Supply Enterprises – Stage A" pilot project (NEUNTEUFEL et al. 2004), in which 23 water supply enterprises (from 40,000 m³ up to 140 million m³ supplied water per year) participated, was launched and conducted by OVGW and largely funded by the Austrian Ministry of Agriculture, Forestry, Environment and Water Management (BMLFUW). The OVGW commissioned three academic institutes to operationally run the pilot project from an external, objective and confidential point of view: Graz University of Technology, the Vienna University of Natural Resources and Applied Life Sciences and the Wiener Neustadt University of Applied Sciences (THEURETZBACHER-FRITZ et al. 2005).

Some of the participating enterprises joined the OVGW benchmarking working group for project supervision and to incorporate practice needs into the indicator system. Thus, the OVGW system can be called a system by water suppliers for water suppliers.

The co-operation with the Bavarian (Germany) *EffWB* project (KIESL & SCHIELEIN 2002 and 2005), which is also based on the IWA performance indicator system, has been important for the development of the OVGW system. Due to the similar water supply structure of Austria and Bavaria, a cross border co-operation was defined to develop a compatible system and to conduct trans-national comparisons. The Bavarian-Austrian co-operation can be seen as an innovative application and further development of the IWA system generating the chance of large participation (200 participants and more) in these benchmarking activities (THEURETZBACHER-FRITZ et al. 2005).

The main aim of the pilot project was to implement a benchmarking system in Austria's drinking water sector in line with the following sub-objectives. The project strongly emphasises the utilisation of benchmarking for internal purposes, serving as a controlling instrument for continual improvement ("learning from the best"). It also provides public transparency of the sector's performance and shows the sector's free will to arrange a quasi competition, based upon the principles of voluntary and anonymous participation. A strong focus is laid on aspects of comparability (homogeneous data collection, data verification including company visits, classification of similar enterprises etc.), on a holistic approach (according to the IWA performance indicator system, ALEGRE et al. 2000) and on data security and confidentiality.

Based on the five-columns-model (compare HIRNER & MERKEL 2002, Figure 12), the OVGW corporate benchmarking system is a holistic system considering the five target categories supply safety, supply quality, customer service, sustainability and efficiency but also the task fulfilment, outsourcing and organisation.

The OVGW pilot project system consists of 120 performance indicators calculated from 150 variables. In addition to these variables, 100 questions about task fulfilment and outsourcing, 80 questions about organisation and 150 facts as background information for high comparability complete the system.

Although the aim of a working benchmarking system was reached, a need for an optimisation of this system was seen before starting the next stage.

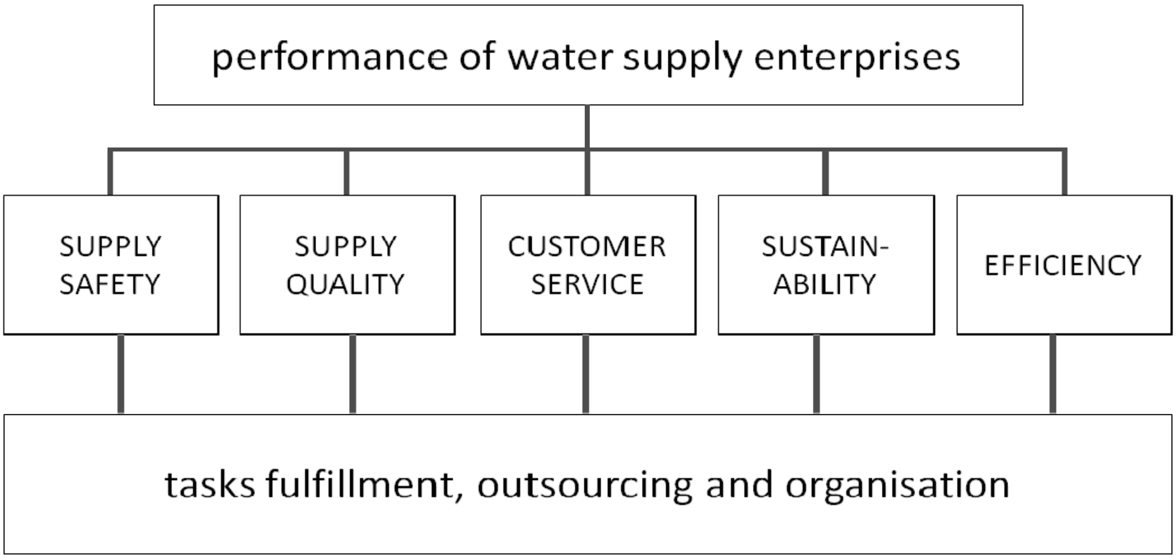


**Figure 12: Target categories of OVGW benchmarking system (HIRNER & MERKEL 2002, amended, in NEUNTEUFEL et al. 2004)**

*3.2.4.1.2. Stage B (2004 project)*

The aim of the 2004 project was the further improvement and the use of the system to achieve a broad effect on the water sector.

One of the main improvements was the reduction of the number of performance indicators to 75 performance indicators instead of 120 and the concentration on 90 facts as background information instead of 150. To benchmark the level of customer services 30 questions concerning three different topics were defined (“Service Quality”, “Tariffs & Billing”, “Customer Information & Relationship”).

Other innovations which are not covered by the current IWA PI system (ALEGRE et al. 2006) are an “Average Network Age Index” (NEUNTEUFEL et al. 2007), which takes life-cycles of material groups into account and is used for comparisons of rehabilitation rates, water losses and failure rates. Also the “ILI - Infrastructure Leakage Index”, a very important water loss PI, was implemented in the OVGW Benchmarking system.

A homogeneous collection of personnel figures is crucial for comparable results. Besides outsourcing of tasks to external organisations, the fulfilment of tasks by overhead service units is taken into consideration. Water utilities in Austria are either embedded in larger organisations like city works and municipal administrations or have to fulfil their tasks “stand-alone” like water co-operations and water co-operatives. Therefore an index value for in-house outsourcing was developed in order to confine the employees of the water supply unit from overhead units and to better assess PIs like personnel costs and outsourcing costs (THEURETZBACHER-FRITZ et al. 2007).

With a respectable amount of 72 water supply enterprises participating in the OVGW 2004 project, a high representativeness is given (about 332 million m³ water intake per year or about 50 % of water supplied in Austria).

The Austrian experience shows that voluntary and anonymous participation is an essential precondition for motivated participants and, therefore, good data quality. Company visits by the project team also proved to be necessary for the project success.

The results of this corporate benchmarking project were published in two reports, one individually for each company and a public report (THEURETZBACHER-FRITZ et al. 2006) and are not discussed within this work. Generally speaking, the results confirm the high quality and efficiency of the Austrian water supply sector even if there are potentials for improvements.

#### 3.2.4.2. OVGW Process Benchmarking 2007

As in other countries, process benchmarking is seen in Austria as the logical continuation and complement of the accomplished corporate benchmarking. Therefore the OVGW started its process benchmarking initiative in 2006. The aim of the OVGW process benchmarking is a comparative analysis and the optimisation of different working processes of water undertakings.

The frame conditions of the OVGW process benchmarking are similar to the OVGW corporate benchmarking:

- The Austrian benchmarking is a voluntary and anonymous comparison of company performances.
- The project is conducted by the OVGW (Austrian Association for Gas and Water). The OVGW in the rule of project executing organisation is the strategic project coordinator and represents the interests of water undertakings.
- Strong focus is put on data security and data confidentiality. All company-data are governed and interpreted confidentially by a neutral and objective project team.
- The project team consists of two academic institutes: Graz University of Technology, Institute of Urban Water Management and Water Landscape Engineering and the Vienna University of Natural Resources Applied Life Sciences - Institute of Sanitary Engineering and Water Pollution Control.
- The Austrian system of process benchmarking was developed by the project team, which works closely with water suppliers. This approach was also successful in the corporate benchmarking project and enables practical applicability.
- The OVGW process benchmarking system is a modular system. Therefore it is not necessary to participate in all the processes.
- Participants have to pay a participation fee, depending on the size of the water company and the complexity of the analysed process.
- It is important that the effort for data collection is in due proportion to the benefits expected. Therefore process analyses are based on characteristic random samples.

Based upon a best practice approach, the results of the comparison are discussed in workshops. Thus, the participants can exchange experiences and derive measures for improvements of each process (KOELBL et al. 2007a).

The OVGW process benchmarking focuses on three subject areas. In the first attempt, six of the eight offered processes were analysed (Table 8). Depending on companies needs, others can follow.

**Table 8: Processes of OVGW process benchmarking 2007**

| | |
|---|---|
| **Sales Process** | Customer meter reading |
| | Customer meter replacement |
| **Construction of pipes** | Construction of new mains |
| | Construction of new service connection (not realised) |
| | Rehabilitation of mains |
| | Rehabilitation of service connections |
| **Mains network operation and maintenance** | Water loss management |
| | Network inspection (not realised) |

The following sub-chapters give a short overview about the single processes.

*3.2.4.2.1. Process 1: Customer meter reading*

The aim of benchmarking this process is to analyse all the activities for customer meter reading and billing regarding costs and quality of execution. A specific challenge in benchmarking customer meter reading is the evaluation of three possible variants in process operation: meter reading by water supply utility personnel (variant 1), reading by customers (variant 2) and remote meter reading (RMR, variant 3). The process structures of the different variants are shown in Figure 13.

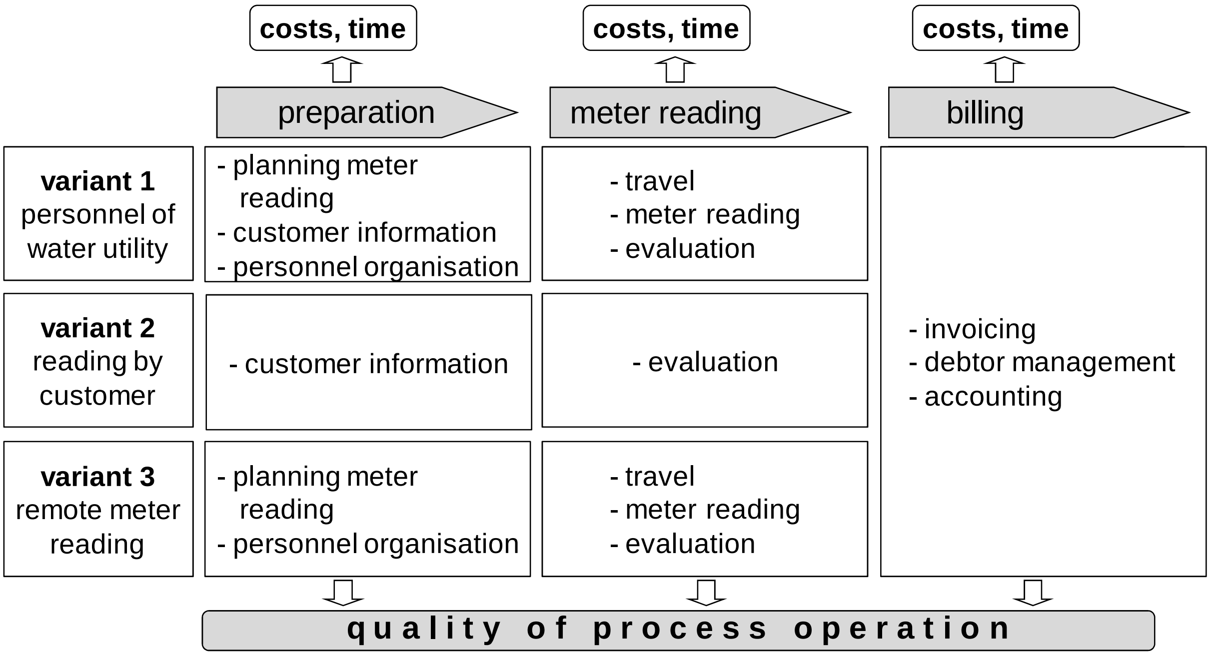


**Figure 13: Process structure of customer meter reading (KOELBL et al. 2008b)**

Depending on the variants, the process includes customer information about the meter reading (fixing a date), the meter reading itself (by water company personnel or outsourced personnel, by customer or with remote meter reading) but also additional meter readings and processing of meter readings by customers (postcards, online data management). Furthermore, accounting and debtor management are analysed. The aim is the comparison of different meter reading and accounting methods in order to find an optimal (most efficient) approach for each company, depending on individual frame conditions (KOELBL et al. 2008b).

### 3.2.4.2.2. Process 2: *Customer meter replacement*

To benchmark this process, all the activities for routine meter replacements (in accordance with Austrian law every 5 years) are analysed. The first step is customer information and fixing a date (by postcard or telephone call). Changing meters can be done by water utility personnel or by external companies. But the management of customer meters and storage or disposals of used meters is also part of this process (see Figure 14). To avoid a comparison of apples with oranges, three different variants have to be considered: replacement of conventional meters, replacement of remote meters and installation of new remote meters (KOELBL et al. 2008b).

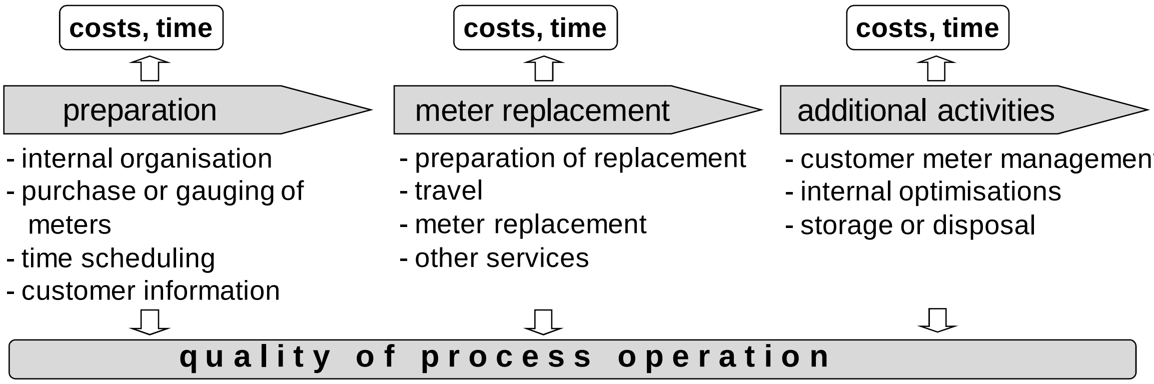


**Figure 14: Process structure of customer meter replacement (KOELBL et al. 2008b)**

### 3.2.4.2.3. Process 3: *Construction of new mains*

All the activities and costs for constructing new mains are analysed in this process. The first steps of this process are the planning and tender processes (e.g. done by a civil engineer). After the awarding of a contract, the construction process follows. One aim is the evaluation of costs per meter mains dependent on different frame conditions (open land or city) and different materials and diameters. For costing it does not matter whether the construction is done by company personnel or by external companies (often digging and rebuilding of streets is done by external companies whereas piping is done by personnel of the water undertakings). The documentation of constructed mains in maps and GIS (geographic information systems) and in accounting is also part of the process.

### 3.2.4.2.4. Process 4: *Construction of new service connections*

(Note: not realised in the 2007 project due to less participants)

All the activities and costs for constructing new service connections are analysed in this process. The process starts with customer information and fixing a date. Next, the water undertaking builds the service connection or connects the pipe (which was laid by the customer) to the main and installs the meter at the end of the service connection. The last steps are the documentation of service connections in maps and GIS (geographic information systems) and in the accounting system.

### 3.2.4.2.5. Process 5: *Rehabilitation of mains*

The process starts with rehabilitation planning and determining mid-term and long-term rehabilitation measures. The experiences have shown that this step is done in many different ways. Whereas larger water undertakings use IT-based programs which work on the basis of failure statistics, smaller companies often act “on personal experience” or in correlation with other constructions (for example gas pipes or sewers) by defining which pipes to be renewed. The next steps are similar to process 3 (Construction of new mains). After analysing costs for planning and the tender process, the costs per meter mains dependent on different frame conditions (open land or city) and different materials and diameters and different methods (for example new pipe or relining) are evaluated. But the documentation of rehabilitated mains in maps and GIS (geographic information systems) and in accounting systems is also part of the process.

###### *3.2.4.2.6. Process 6: Rehabilitation of service connections*

In this process all the activities and costs for rehabilitation of service connections are analysed. The process starts with rehabilitation planning and determining mid-term and long-term rehabilitation measures for service connections. Rehabilitations of service connections often occur simultaneously with mains rehabilitation, but also in separated programs (for example replacement of lead pipes). In addition to planning and construction, the documentation of rehabilitated service connections in maps and GIS (geographic information systems) and in the accounting system is also analysed.

###### *3.2.4.2.7. Process 7: Water loss management*

The process of water loss management probably represents one of the most complex processes within the OVGW 2007 project. The process of physical water management is a highly integrative process which is influenced by many single tasks of almost all the operating duties of a water supply utility (see chapter 5). The objectives of benchmarking the process of water loss management are qualitative and quantitative comparisons of different strategies and methodologies in water loss management (leakage monitoring, leak detection). Thereby not only different methods with the associated costs but also the success of these methods are analysed. The calculation of the IWA water balance is necessary as a basis for the process comparison, and one aspect is the accuracy of water balance.

Chapter 6 describes the results and experiences of benchmarking the process of water loss management within the 2007 OVGW process benchmarking.

###### *3.2.4.2.8. Process 8: Network inspection*

(Note: not realised in the 2007 project due to less participants)

Network inspections are preventative and routine measures (for example visual checkups on the existence and readability of warning and information signs, functional checks of valves, hydrants etc., status checks of shafts or smaller maintenance like cleaning or lubricating). The activities analysed are adapted to the ÖNORM B 2539 - OVGW W 59 guideline (2005). The process starts with the planning of inspection and maintenance activities on basis of a network analysis. Besides the activities of inspection, the management of these activities within a database for planning future measures is also part of this process. Not only the activities themselves but also the associated costs are analysed.

# 4. Basics of Water Loss Management

Within the last two decades many developments in the sector of water loss management have been made. Many of these developments have been driven by problems with water losses in developing countries, which in general have much higher water losses in their water supply systems than networks in central Europe like those in Austria, Germany or Switzerland. Experts from the UK, where the water infrastructure is often in a worse condition in comparison to Austria, or from countries with limited resources like Australia or Cyprus have made especially substantial contributions. But some Austrian experts are also very active in the international water loss scene.

Since 1996 a separate task force within the IWA Efficient Operation and Management of Urban Water Distribution Systems Specialist Group has been dealing with this topic – the Water Loss Task Force (WLTF). The aim of this group is to bring experts from all over the world together to develop effective and sustainable international "best practises" in the management of water losses.

A main concern of the WLTF is sharing information with a broad user stratum (especially water supply utilities in developing countries). Therefore many publications, e.g. guidelines, are free available from the WLTF website. Other important information platforms are the Specialist Conferences which are organised biannually. In September 2007 the Water Loss 2007 took place in Bucharest (Romania) and before this there were conferences in Halifax (Canada, 2005) and Lemesos (Cyprus, 2002).

One of the first important duties of the WLTF was to work out a consistent terminology, a standardised water balance and various performance indicators for the comparison of water losses. In 2000 the IWA Blue Pages of "Losses in Water Supply Systems" were published (LAMBERT & HIRNER 2000). The terminology, the water balance and the performance indicators described in the Blue Pages were implemented to the IWA "Performance Indicators for Water Supply Services" Manual of Best Practices (ALEGRE et al. 2000 and 2006).

A short overview about the most important aspects of the IWA methodology in water loss management and the earliest developments in this field is given in the following pages. References to the DVGW W 392 (2003) German standard – "Network inspections and water losses – activities, procedures and assessment" and several Austrian standards are made.

## 4.1. *Why Water Loss Management?*

Unlike the situation in countries with high water losses, it seems to be quite unattractive to undertake extensive water loss management for a typical Austrian water utility. Often the water production costs are very low in cases no treatment is necessary. Many Austrian water works are in the lucky situation that a high amount of their water does not have to be pumped (e.g. natural springs with gravitation pipes) and therefore also the costs for distributing the water can be very low.

The installation of leakage monitoring systems and leak detection are expensive and time consuming. The repair of leaks is expensive, too. So if the costs of lost water are compared with the effort for the minimisation of leakage only from an economic point of view, water loss management does not seem to make sense for many Austrian water supply utilities.

But beside these economic aspects there are many reasons to keep the level of water losses low. In the OVGW W 63 Austrian standard (1993 and in press) – “Water Losses in Water Supply Systems” and in DVGW W 392 (2003), the following aspects are described:

- hygienic aspects
  - each leak represents a risk of contamination by entering water from outside in the distribution system (e.g. in case of pressure decline)
- aspects of supply techniques and supply safety
  - leakage can lead to quantitative problems (e.g. in situations of peak supply)
  - leakage can cause decrease of service pressure and can lead to customer complaints
- ecological aspects
  - water losses contravene recent ecological concepts
  - low water losses reduce the energy demand of pumps, treatment stations etc. and reduce therefore the $CO_2$ emissions
  - low water losses help saving resources
- economic aspects
  - in general high water losses cause higher running costs (e.g. energy costs, treatment chemicals, higher maintenance costs)
  - low water losses prevent (or postpone) the exploitation of new resources

It is stated in DVGW W 392 (2003) that economical aspects only play a role at high levels of water losses. This strategy is completely different from that of the privatised English water sector, where economic aspects are most relevant (compare LIEMBERGER 2005).

The OVGW W 100 Austrian directive (2007) – “Water supply pipes – operation and maintenance” also urges for low leakage levels. Furthermore, in DVGW W 392 (2003) the importance of low water loss levels as decisive indicator for the condition of the pipe network and the fact that low water losses lead to a reduced effort for the maintenance of the pipe network are described.

Therefore the calculation of water loss PIs not only for the whole water supply system but also for single network zones provides important information about the condition of the pipe network. This information is essential for an effective maintenance and rehabilitation planning and shows the importance of water loss management even in water supply systems with low leakage levels.

Beside these technical criteria legal aspects are also relevant e.g. claims for indemnification after settlements in consequence of washouts.

## 4.2. *IWA Blue Pages – definitions and standardised water balance*

The objectives of the “Losses from Water Supply Systems: Standard Terminology and Recommended Performance Measures” IWA Blue Pages (LAMBERT & HIRNER 2000) are to prepare a recommendation for a basic standard terminology for the calculation of real and apparent losses and to recommend preferred performance indicators of water losses for international comparisons.

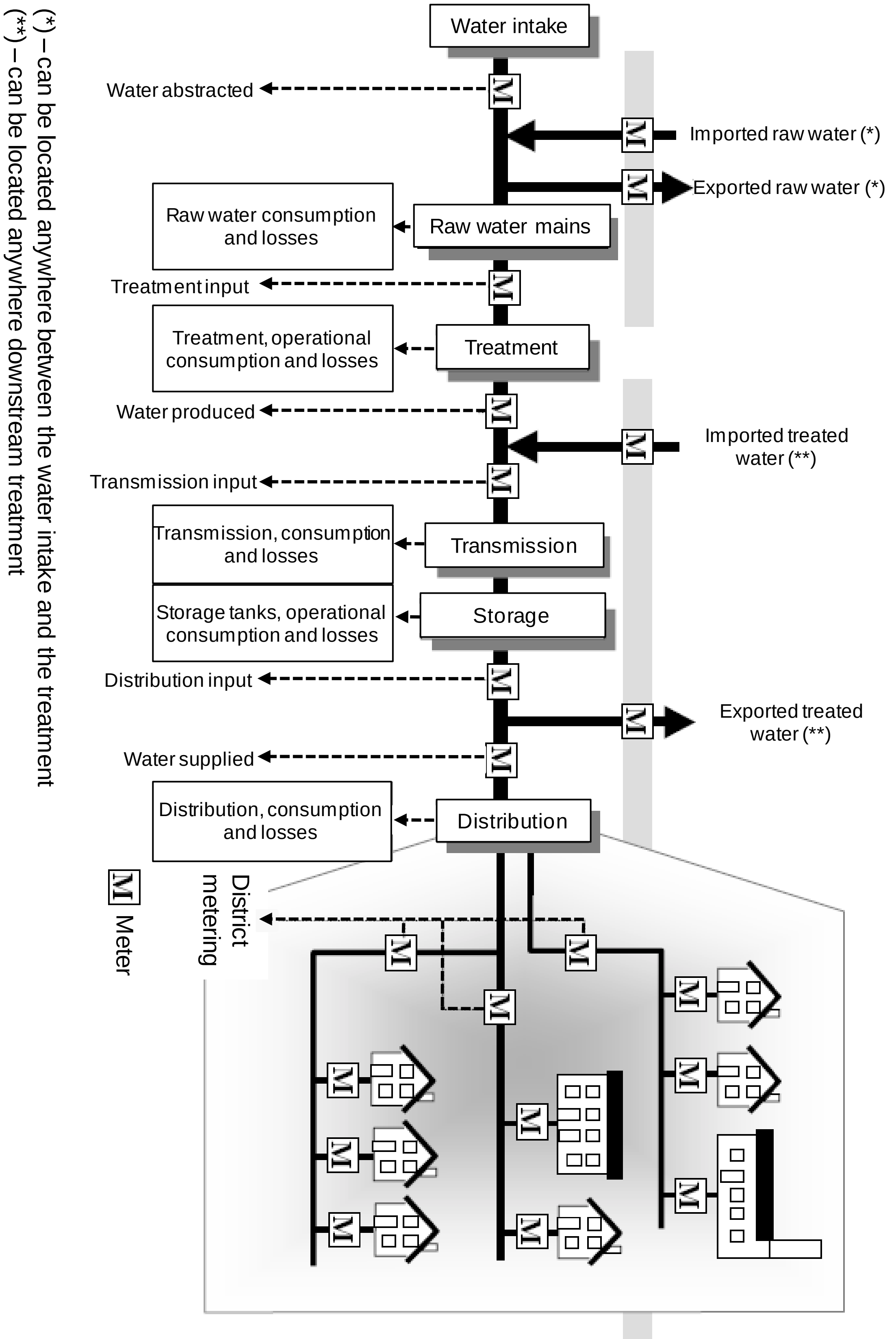


**Figure 15: Definition of water supply system inputs and outputs (LAMBERT & HIRNER 2000)**

According to LAMBERT & HIRNER (2000), reliable metering of all water volumes should and must be an integral component of the water supply, water demand management and loss determination. The most important part of determining how much water is being lost in a system is to accurately quantify the volume of water which is entering that system. Metering of source meters for abstraction, treatment works production, imported and exported water, input volumes and inflows to sectorised distribution systems is essential for water balance calculations (Figure 15).

The DVGW W 392 (2003) also claims that exact definitions of all components of a water balance are a precondition for discussions about water losses. It is also mentioned that all the inputs and outputs of a water supply system need to be measured.

ALEGRE et al. (2006) describe following definitions:

*Water abstracted*: the volume of water obtained for input to water treatment plants (or directly to the transmission and distribution systems) that was abstracted from raw water sources during the assessment period.

*Raw water, imported or exported*: the volume of bulk transfers of raw water across operational boundaries during the assessment period. The transfer can occur anywhere between the abstraction point and the treatment plant.

*Treatment input*: the volume of raw water input to treatment works during the assessment period.

*Water produced*: the volume of water treated for input to water transmission lines or directly to the distribution system during the assessment period. (The volume of water that is distributed to consumers without previous treatment shall be also accounted for in water produced).

*Treated water, imported or exported*: the volume of bulk transfers of treated water across operational boundaries during the assessment period. The transfer can occur anywhere downstream treatment. *(The volume of water – if any – that is abstracted and delivered to consumers without any treatment shall be also accounted for as treated water in scope of the water balance).*

*Transmission input*: the volume of treated water input to a transmission system during the assessment period.

*Distribution input*: the volume of treated water input to a distribution system during the assessment period.

*Supplied water*: the *distribution input* minus *treated water exported*. *(When it is not possible to separate transmission from distribution, supplied water is the transmission input minus treated water exported).*

*System input*: the volume input to water supply system during the assessment period.

*Authorised consumption*: the volume of metered and/ or non-metered water taken by registered customers, the water supplier and others who are implicitly or explicitly authorised to do so by the water supplier, for residential, commercial and industrial purposes, during the assessment period. It includes *water exported*. *(Note: Authorised consumption may* *include items such as fire fighting and training, flushing of mains and sewers, street cleaning, watering of municipal gardens, public fountains, frost protection, building water, etc. These may be billed or unbilled, metered or unmetered, according to local practice. Authorised consumption also includes leakage and waste by registered customers that are unmetered.).*

*Real losses*: physical water losses from the pressured system, up to the point of measurement of customer use during the assessment period. The volume lost through all types of leaks, bursts and overflows depends on frequencies, flow rates and average duration of individual leaks. *(Note: Although physical losses after the point of customer flow measurement are excluded from the assessment of real losses, they are often significant - particularly where customers are unmetered – and worthy of attention for demand management purposes.).*

*Apparent losses*: accounts for all types of inaccuracies associated with production metering and customer metering, plus unauthorised consumption (theft or illegal use). *(Note: Under-registration of production meters, and over-registration of customer meters, leads to under-estimation of real losses and the opposite way around.).*

*Non-revenue water*: the difference between the volumes of system input and billed authorised consumption. Non-revenue water includes not only the real losses and apparent losses, but also the unbilled authorised consumption.

**Table 9: Components of IWA water balance (LAMBERT & HIRNER 2000)**

<table>
<tr><td rowspan="9">System Input Volume</td><td rowspan="4">Authorised Consumption</td><td rowspan="2">Billed Authorised 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 Authorised 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>Unauthorised Consumption</td></tr>
<tr><td>Customer Metering Inaccuracies</td></tr>
<tr><td rowspan="3">Real Losses<br><br>(= Physical 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>

Note: All parameters in $m^3$ per year ($m^3$/year)

Based on these system definitions a standardised water balance is described within the IWA Blue Pages (Table 9). Meanwhile, this type of water balance described by IWA is being used in many countries all over the world, e.g., Australia, Germany, Canada, New Zealand, South Africa and by the American Water Works Association (LIEMBERGER 2006). It was implemented into the IWA PI-system (ALEGRE et al. 2006) and also into the DVGW W 392 worksheet of the German Association for Gas and Water, which is the valid standard for German water utilities. The Austrian Association for Gas and Water uses also this system within the OVGW benchmarking project (compare NEUNTEUFEL et al. 2004) and it is implemented in the new OVGW W 63 directive (in press).

An exact metering of the system input and the authorised consumption are essential for a meaningful water balance. Inexact metering leads to an inexact result and the amount of physical losses can then be over or under estimated (compare DVGW W 392, 2003). Therefore LAMBERT & HIRNER (2000) point out the importance of an accurate metering of the system input but also of consumption.

Another important point for calculating a water balance is the determination of “unbilled unmetered consumption”, e.g. water for fire fighting, washing streets or public gardening. These consumptions are often not metered and in many cases not documented. So a special focus should be laid on training how to meter and document the unbilled consumption.

To confine the system input correctly it is necessary to deduct “returned water” from the system input (see Table 10). For the water supply sector “returned water” can be defined as water that is consciously taken from the water supply system at another point than before the system input (e.g. spring collection shafts), e.g. unused water that is abstracted of reservoirs or water used for producing electricity at drinking water power stations, which are very common in the alpine regions of Austria. The points of water abstraction can be situated in the transport or the distribution system.

This definition must not be mistaken for “returned water” as defined by NAGY et al. (2007) for the OECD/Eurostat Joint Questionnaire on Inland Waters where returned water is water abstracted from any fresh water source and discharged into fresh waters without use, or before use. This occurs primarily during mining and construction activities. Discharges to the sea are excluded.

**Table 10: Water balance including consideration of returned water**

<table>
<tr><td rowspan="12">Abstracted Water</td><td colspan="5">Water Losses before Treatment</td></tr>
<tr><td colspan="5">Returned Water</td></tr>
<tr><td rowspan="10">System Input Volume</td><td rowspan="4">Authorised Consumption</td><td rowspan="2">Billed Authorised 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 Authorised Consumption</td><td>Unbilled Metered Consumption</td><td rowspan="8">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>Unauthorised Consumption</td></tr>
<tr><td>Customer Metering Inaccuracies</td></tr>
<tr><td rowspan="3">Real Losses<br><br>(= Physical 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>

## 4.3. *Four basic methods for managing physical water losses*

Beside other publications on this topic, FARLEY & TROW (2003) describe the IWA methodology in water loss management very clearly. Figure 16 shows an overview of the basic correlations.

The white rectangle in Figure 16 represents the unavoidable annual real losses (UARL). These are losses which usually can not be prevented even with an optimal water loss management system. The surrounding grey rectangle represents potentially recoverable physical (= real) water losses. These potential savings change with the strength of the arrows acting on this square.

The double arrow (**pressure management**) above the square indicates that the water losses decrease by reducing the service pressure and also the other way round. The burst frequency can also be decreased significantly with pressure reduction (see chapter 4.6). There are also many international examples for high savings of water through temporary pressure reduction over the night hours (e.g. MCKENZIE et al. 2007).

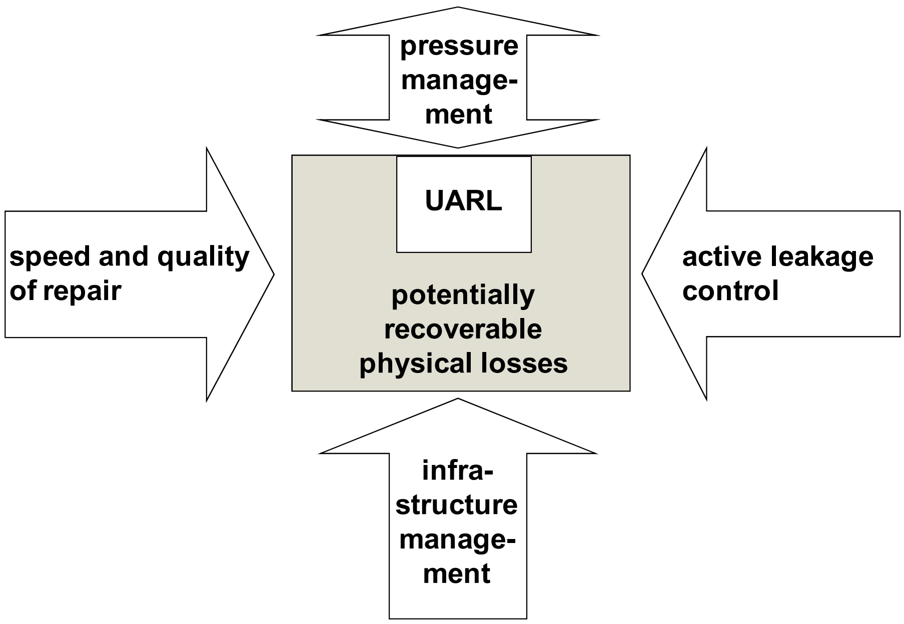


**Figure 16: The four basic methods for managing physical water losses (FARLEY & TROW 2003, amended)**

The type and extent of leakage control are very important for the amount of water losses. The term **Active Leakage Control** includes not only measures of leakage detection (e.g. step testing, common sounding surveys, noise logging or gas checks) but also measures of leakage monitoring. This means monitoring the system input and also single zones or DMAs (District Metered Areas) and managing all the technical equipment for these measurements (see chapter 4.5). Depending on the existing technical equipment of a water supply utility, two different strategies in leakage detection are possible:

- “cause based” leak detection or
- leak detection “on rotational basis” (in fixed intervals, e.g. annual leak detection campaigns without a concrete guess for failures).

**Infrastructure management** covers various tasks which directly or indirectly influence the amount of water losses. Beside the technical equipment of a water supply utility, the rehabilitation management (including analyses of pipe group based failure statistics), the management of maintenance (fittings, pumps, flow meters, valves etc.) but also the customer meter management (average age of customer meters, methodology of meter reading etc.) and hydraulic modelling of the supply system are part of this topic. In general, infrastructure management covers long-term measures which can not be influenced over short time periods.

The **speed and quality of repair** is also essential for the amount of water losses. The repair time is the time taken from locating a leak to the recovery of the functionality of the pipe. The amount of water lost at a single leak is calculated by the product of the flow rate and the run time of the leak.

**Formula 1: Calculation of volume lost**

$$\textit{volume lost } (m^3 \text{ or } l) = \textit{flow rate } (m^3/d \text{ or } l/h) \times \textit{run time } (d \text{ or } h)$$

For the total volume lost at leaks this means that small leaks, which are often not recognised by leakage monitoring and therefore have a long run time, might lead to high water losses (Figure 17). Unreported leaks which are found in the course of leak detection campaigns (subject to interval and methodology) often have middle flow rates and lead to middle or high losses. On the other hand, reported leaks usually have high flow rates but due to a short run time the total volumes of losses are relatively small.

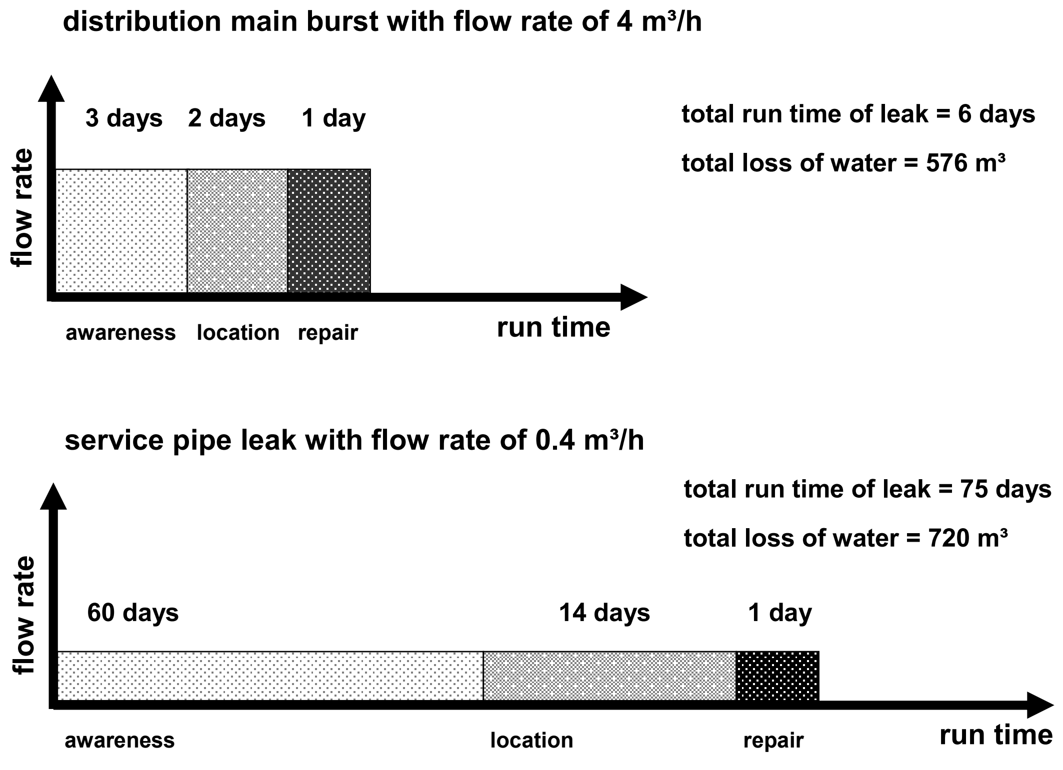


**Figure 17: Effect of burst duration on total leakage (MORRISON et al. 2007)**

It also has to be mentioned that one of the most important criteria in water loss management is the qualification of the staff. All the tasks described in this chapter (pressure management, active leakage control, infrastructure management or repair of leaks) require well trained, motivated and experienced personnel to achieve success.

## 4.4. *Quantification of Water Losses with Performance Indicators*

Defined performance indicators (PIs) are required to quantify the amount of water losses in order to compare them for internal purposes (e.g. monitoring the development of leakage or comparison of different DMAs) or external purposes (comparison with other water utilities).

One problem in the use of PIs is the influence of frame conditions of different water supply systems. Different PIs favour or penalise certain structures. Therefore it is very important to consider the frame conditions of the utilities compared (e.g. KOELBL et al. 2007b). The most important influencing factors on the amount of water losses are:

- the structure of the distribution system (the urbanity – rural, small city or large city; note: within the OVGW benchmarking system the urbanity considers the network delivery rate, the service connection density and the consumption per customer meter, compare NEUNTEUFEL et al. 2004),
- the condition of the water supply network (proportion, age and condition of single pipe groups),
- the average service pressure but also
- the soil conditions (compare DVGW W 392, 2003).

The following discussion of various water loss PIs should help finding out the appropriate PIs for the comparisons of water losses. The following PIs are discussed:

- water loss ratio (%)
- real losses per mains length (m³/km·h)
- real losses per connection and day (l/conn·d)
- real losses per connection and day per metre service pressure (l/conn·d·m)
- Infrastructure Leakage Index
- non-revenue-water (%),(m³/km·h) or (l/conn·d)

### 4.4.1. Water Loss Ratio (%)

The water loss ratio represents the percentages of the real losses related to the system input. This PI is still very common although it is definitely unsuitable for the assessment of water losses (compare LAMBERT & HIRNER 2000 or DVGW W 392, 2003).

**Formula 2: Water loss ratio**

$$water\ loss\ ratio\ (\%) = \frac{annual\ real\ losses\ (m^3/a) * 100}{annual\ system\ input\ (m^3/a)}$$

This performance indicator should only act as a first reference value for discussing water losses. This PI is insufficient for a technical interpretation of water losses because the structure of the supply system (length of mains, number of service connections etc.) is not considered. Furthermore, within the calculation there is a division by the system input, a value that changes every year depending on the weather conditions but also from the consumption of large consumers (industry). So it is possible that the actual losses of a certain year are higher than those of another year whereas the water loss ratio is smaller because the system input and the consumption have also increased (see example in Table 11).

**Table 11: Example of a comparison of water loss ratios for two years**

| | year 1 | year 2 |
|---|---|---|
| **system input** | *1,400.000 m³* | *1,000.000 m³* |
| **consumption (households)** | *880.000 m³* | *880.000 m³* |
| **consumption (industry)** | *385.000 m³* | *0 m³ (industry closed)* |
| **apparent losses** | *20.000 m³* | *20.000 m³* |
| **real losses** | ***115.000 m³*** | ***100.000 m³*** |
| **water loss ratio** | ***8 %*** | ***10 %*** |

### 4.4.2. Real Losses per Mains Length (m³/km·h)

Unlike the water loss ratio this PI has the advantage that the structure of the supply system is considered with the total mains length. The mains length is a more or less statically denominator. Therefore this PI can be used to watch the development of water losses within a supply system or a single DMA.

**Formula 3: Real losses per mains length**

$$real\ losses\ per\ mains\ length\ (m^3/km \cdot h) = \frac{annual\ real\ losses\ (m^3/a)}{total\ mains\ length\ (km)\ x\ 8760\ (h/a)}$$

In DVGW W 392 (2003) the real losses per mains length are the decisive PI and assessments in subject to the structure of the distribution network (rural, urban or metropolitan) can be done (see Table 12; note: in contrast to the OVGW benchmarking system DVGW W 392 classifies the structure of a water supply system on basis of the network system input rate).

**Table 12: Standard values for real water losses per mains length in water distribution networks in m³/km·h according to DVGW W 392 (2003)**

| *assessment of water losses* | *structure of distribution network* | | |
|---|---|---|---|
| | *area 1 (metropolitan) spec. network system input rate >15.000 m³/km·a* | *area 2 (urban) spec. network system input rate 5.000-15.000 m³/km·a* | *area 3 (rural) spec. network system input rate <5.000 m³/km·a* |
| low water losses | < 0.10 | < 0.07 | < 0.05 |
| medium water losses | 0.10 - 0.20 | 0.07 - 0.15 | 0.05 - 0.10 |
| high water losses | > 0.20 | > 0.15 | > 0.10 |

The differentiated classification scheme of DVGW W 392 (2003) determines that comparisons of this PI are only allowed within a group of comparable and similar structured water utilities. The real losses per mains length of a rural water utility cannot be compared with those of a metropolitan one.

The IWA Water Loss Task Force (WLTF) criticises the decision of DVGW to select this indicator as the decisive PI because experience shows that the majority of water losses usually appear at service connections. Therefore the PI "real losses per connection and day" described below should have been preferred (compare LIEMBERGER 2005, LAMBERT et al. 1999 and LAMBERT & HIRNER 2000).

Nevertheless, the WLTF (LIEMBERGER 2007) and also ALEGRE et al. (2006) recommend using this PI for supply systems with service connection densities smaller than 20 per kilometre.

### 4.4.3. Real Losses per Connection per Day (l/conn·d)

The main origins of water losses are considered with the number of service connections.

**Formula 4: Real losses per connection and day**

$$real\ losses\ per\ connection\ per\ day\ (m^3/conn.\cdot d) = \frac{annual\ real\ losses\ (m^3/a)}{number\ of\ service\ connections\ x\ 365\ (d/a)}$$

Concerning the comparability of this PI, similar constraints to those for real losses per mains length have to be made. So comparisons have to be done within a group of supply systems with the same structure.

The IWA, WLTF (LIEMBERGER 2007) and also ALEGRE et al. (2006) recommend using this PI for supply systems with service connection densities higher than 20 per kilometre.

### 4.4.4. Real Losses per Connection per Day per Metre Service Pressure Head (l/conn·d·m)

Beside the service connection density this PI considers the average service pressure. The average service pressure head is a very important parameter because the flow rate of leaks is mainly influenced by the pressure.

**Formula 5: Real losses per connection and day per metre service pressure head**

$$real\ losses\ p.conn.\ p.day\ p.serv.press.\ head = \frac{annual\ real\ losses\ (m^3/a)\ x\ 1000}{nb.\ of\ serv.conn.\ x\ 365\ (d/a)\ x\ av.service\ press.\ head\ (m)}$$

Up to now the use of this PI has not been very common in Austria.

### 4.4.5. Infrastructure Leakage Index (ILI)

Compared to other water loss PIs like "real losses per mains length" or "real losses per connection and day", the Infrastructure Leakage Index (ILI) also includes essential influencing factors like the average network pressure and the service connection density as well as the mains length and the length of service connections (Formula 6). Therefore the ILI is the only PI that enables performance comparisons of different structured water supply systems.

To calculate the ILI the Current Annual Real Losses (CARL) are divided by the so-called Unavoidable Annual Real Losses (UARL). The ILI indicates the multiple by which the real losses are higher than the unavoidable annual real losses. The unavoidable annual real losses are a theoretical (reference) value which was developed and calibrated by the IWA WLTF on basis of statistical analysis of international data, including 27 different water supply systems in 20 countries (LAMBERT & HIRNER 2000). The ILI is also part of the IWA PI system (ALEGRE et al. 2006).

**Formula 6: ILI – Infrastructure Leakage Index**

$$ILI = CARL / UARL$$

CARL = Current Annual Real Losses (litre/connection·day)

UARL = Unavoidable Annual Real Losses (litre/connection·day)

**Formula 7: UARL – Unavoidable Annual Real Losses**

$$UARL = \left(18 \times \frac{Lm}{Nc} + 0{,}8 + 0{,}025 \times Lp\right) \times P$$

Lm = length of mains (km)

Nc = number of service connections

Lp = average length of service connections from property boundary to measurement point (m)

P = metre of average service pressure (m)

Even if, on the first view, ILI represents a quite complex indicator, this PI has been implemented for water loss calculations in many countries all over the world. International experiences show that the calculation of this indicator works quite well and therefore also cross-border comparisons are possible without further groupings (e.g. urbanity).

In the Austrian drinking water sector this PI was not common until the beginning of the OVGW benchmarking activities. First the ILI was implemented into the OVGW benchmarking system for the purpose of testing. Experiences with ILI within the OVGW benchmarking are almost all positive, even if this highly aggregated indicator seems to be too complex for some participants in the first instance (THEURETZ-BACHER-FRITZ et al. 2006 and KOELBL et al. 2007b).

However there are some limitations on applying the UARL formula. Originally the equation should not have been used for systems with less than 5000 service connections, less than 20 connections per km of mains, and less than 25 metres of service pressure head (LAMBERT & MCKENZIE 2002). On the basis of the following research, the lower limits for number of service connections have been reduced to 3000 and the lower limit on the density of service connections has been removed. The lower limit of 25 metres for pressure was introduced to avoid significant errors from extrapolating the assumption of a linear pressure : leakage relationship to systems with 100 % flexible pipes at low pressures, where the N1 exponent would be close to 1.5 (note: leakage varies with pressure$^{N1}$, compare Formula 11 in chapter 4.6), (LIEMBERGER & MCKENZIE 2005).

Recent experiences with the calculation of ILIs show that lower limits for the number of service connections are not necessary in developed countries. GANGL & KOELBL (2009) describe the relationship between ILI and real losses per mains length for 34 Austrian water utilities, which participated in the OVGW corporate benchmarking 2008 (data of 2007). Figure 18 shows the maximal possible values for ILI and real losses per mains length. These values consider the possible error margins for real losses and for the mains' length. Therefore, the values shown are probably a little bit too high; in fact the "true value" for each utility has to be anywhere between the value calculated directly from the variables and the maximum possible value. But this aspect is irrelevant for the purpose of showing that there is a good correlation of these two PIs and that no influence of the system size is evident.

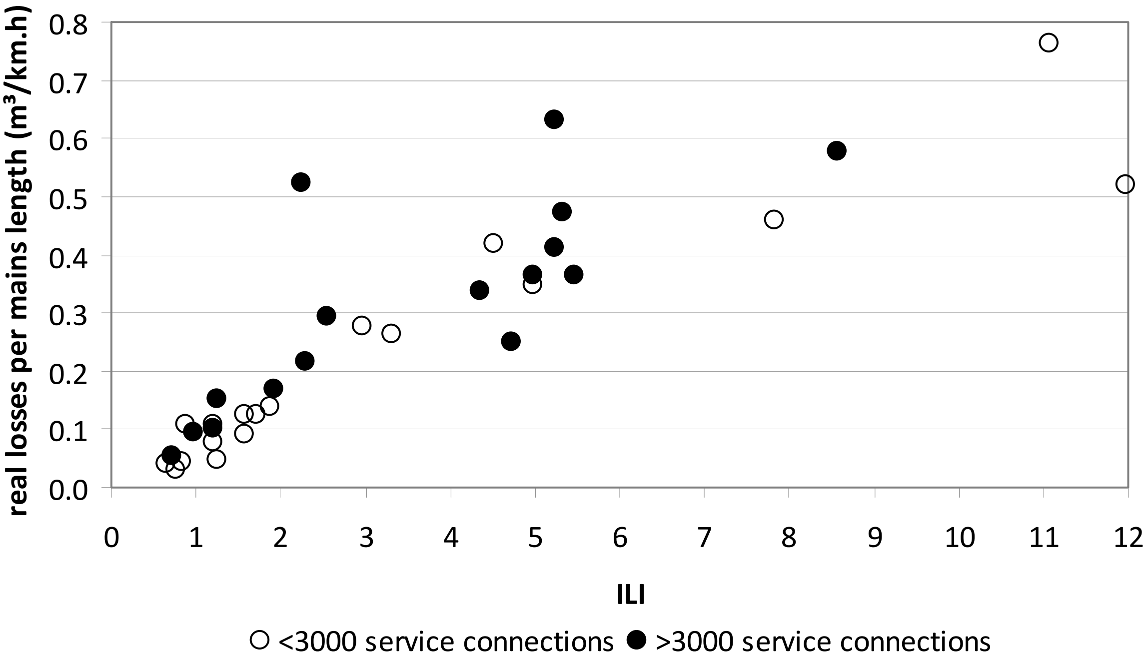


**Figure 18: Comparison of maximal possible values of ILI with real losses per mains length (GANGL & KOELBL 2009; data source: OVGW benchmarking 2008 – stage C)**

The same is valid for the correlation between ILI and real losses per connection per day (Figure 19).

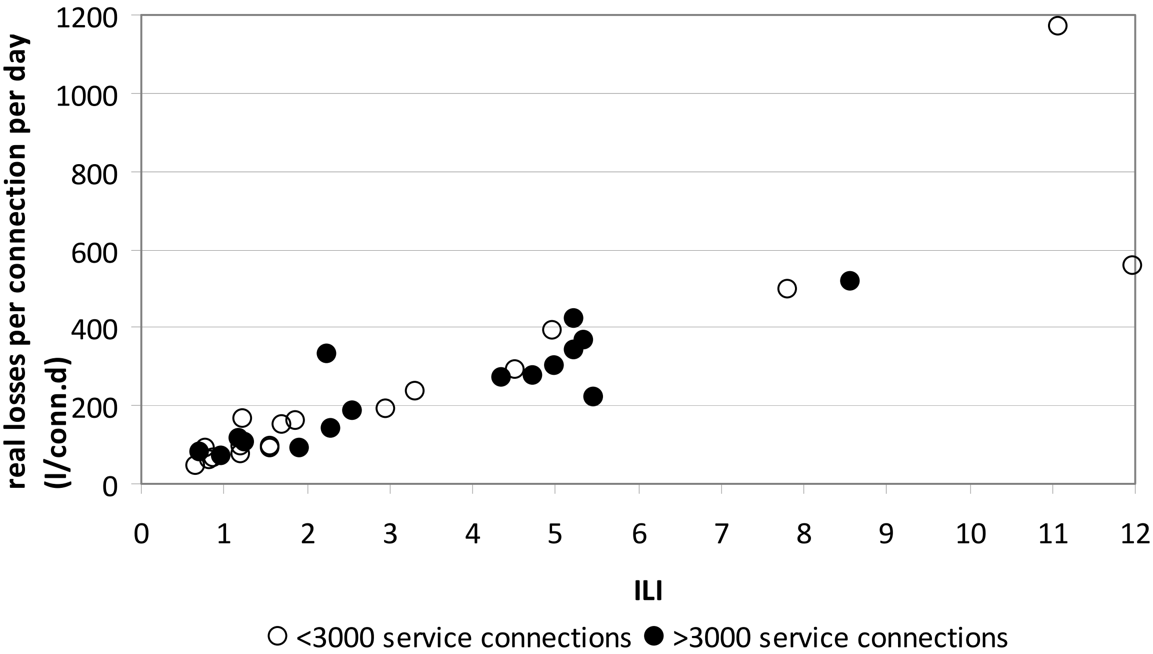


**Figure 19: Comparison of maximal possible values of ILI with real losses per connection per day (data source: OVGW corporate benchmarking 2008 – stage C)**

Because practical experiences show that it is possible (under special frame conditions, e.g., no unreported leaks, young network) to achieve ILI values smaller than 1.0 (note: values down to 0.7 are known, compare LAMBERT, in press; e.g. for very well managed systems in Australia and in Austria), it is discussed to rename the

UARL from “unavoidable annual real losses” to any kind of reference value (note: the World Bank Institute uses the term “Minimal Achievable Annual Physical Losses”, MAAPL). The results of the 2008 OVGW corporate benchmarking show that even under consideration of all possible error margins for single water balance and supply system data some of the utilities have ILIs under 1 (Figure 18). Such an adaptation of the UARL definition might increase the acceptance of the ILI in developed countries where the water supply systems are in a very good condition. But it also has to be mentioned, that recent investigations show, that small ILI values are often a result of inappropriate water balance data. When the real losses are very low, systematic failures (e.g. accuracy of system input meters) in the water balance can lead to large possible error margins. LAMBERT (in press) agrees that “unavoidable” is not a precisely accurate term when applied to annual real losses (UARL) but it has its merits of simplicity and is well established after 10 years of use. Therefore a change in the terminology might lead to more confusion than the original term “unavoidable annual real losses”.

It also has to be mentioned that the calculation of ILIs for water supply systems with very low service pressure and / or intermittent supply (e.g. in developing countries) can result in very high ILI values. So other reference values are necessary for these systems than for systems in developed countries and it does not make sense to compare such different systems with each other (e.g. MCKENZIE et al. 2007)

Meanwhile, several international standard values for ILI have become available. Table 13 gives an overview of Australian ILI standard values, which are quite rigorous in comparison to the more tolerant standard values of the American Water Works Association (AWWA) in Table 14.

**Table 13: Draft version of Australian ILI standard values (LIEMBERGER 2005)**

| ILI | Description |
|---|---|
| 1,0 - 1,5 | excellent |
| 1,5 - 2,0 | good |
| 2,0 - 2,5 | reasonable |
| 2,5 - 3,0 | fair |
| 3,0 - 3,5 | poor |
| 3,5 - 4,0 | unacceptable |

**Table 14: ILI standard values of AWWA (2003) in LIEMBERGER (2005)**

| Target ILI range | Water resources considerations | Operational considerations | Financial considerations |
|---|---|---|---|
| 1 – 3 | Available resources are greatly limited and are very difficult and/or environmentally unsound to develop | Operating with system leakage above this level would require expansion of existing infrastructure and/or additional water resources to meet the demand | Water resources are costly to develop or purchase<br>Ability to increase revenues via water rates is greatly limited due to regulation or low ratepayer affordability |
| 3 – 5 | Water resources are believed to be sufficient to meet long term needs, but demand management interventions (leakage management, water conservation) are included in the long-term planning | Existing infrastructure capability is sufficient to meet long-term demand as long as reasonable leakage management controls are in place | Water resources can be developed or purchased at reasonable expense<br>Periodic water increases can be feasibly effected and are tolerated by customer population |
| 5 - 8 | Water resources are plentiful, reliable and easily extracted | Superior reliability capacity and integrity of water supply infrastructure make it relatively immune to supply shortages | Cost to purchase of obtain/treat water is low, as are rates charged to customers |
| > 8 | While operational and financial considerations may allow a long-term ILI greater than 8, such a level of leakage is not an effective utilization of water as a resource. Setting a target greater than 8 – other than as an incremental goal to a smaller long-term target – is discouraged. | | |
| < 1 | Either world class performance or error in data | | |

Table 15 shows the physical loss target matrix from the World Bank Institute`s Non-Revenue-Water training program. There is a differentiation of target values for developed and developing countries. Beside the ILI values there is also a classification scheme for real losses per connection per day for various average service pressure heads. The band for the classification of the technical performance is from A (“very good”) to D (“very poor”).

The values in Table 15 are calculated for a service connection density of 40 per km and for an average length of service connections (from property boundary to measurement point) of 0 m.

**Table 15: Physical Loss Target Matrix from World Bank Institute (in LIEMBERGER 2006)**

| technical performance category | | ILI | litres/connection/day (when the system is pressurised) at an average pressure of: | | | | |
|---|---|---|---|---|---|---|---|
| | | | 10 m | 20 m | 30 m | 40 m | 50 m |
| developed countries | A | 1 - 2 | | < 50 | < 75 | < 100 | < 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 |
| developing countries | A | 1 - 4 | < 50 | < 100 | < 150 | < 200 | < 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 | 500-1000 |
| | D | > 16 | > 200 | > 400 | > 600 | > 800 | > 1000 |

A Further loss reduction may be uneconomic unless there are shortages; careful analyses needed to identify cost effective improvement.

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

C Poor leakage record; tolerable only if water is plentiful and cheap; even then analyse level and nature of leakage and intensify leakage reduction efforts.

D Horrendously inefficient use of resources; leakage reduction programs imperative and of high priority

### 4.4.6. Non-Revenue-Water (NRW, %, m³/km·d, l/conn·d)

NRW expressed in percentages represents the portion of the system input that is not billed. According to LIEMBERGER (2007), it is absolutely necessary to subtract exported water from the system input when calculating NRW.

**Formula 8: NRW (%)**

$$non-revenue-water\ (\%) = \frac{annual\ non-revenue-water\ (m^3/a)*100}{annual\ system\ input\ -\ annual\ \text{exp}orted\ water\ (m^3/a)}$$

The IWA Water Loss Task Force disapproves of using NRW expressed in percentages as a technical indicator. This PI only can be used as financial PI, but even then it is better to compare the marginal costs of NRW with the total operational costs (LIEMBERGER 2007).

For technical assessment it is necessary to calculate NRW in litre per connection per day (Formula 9) or in m³ per kilometre per day (Formula 10) because the system input (Formula 8) is not a stable denominator (LIEMBERGER 2007). This problem was also discussed for the water loss ratio in chapter 4.4.1.

**Formula 9: NRW (l/conn·d)**

$$non-revenue-water\ (l/conn\cdot d) = \frac{annual\ non-revenue-water\ (m^3/a)\ x\ 1000}{number\ of\ service\ connections\ x\ 365\ (d/a)}$$

**Formula 10: NRW (m³/km·d)**

$$non-revenue-water\ (m^3/km\cdot d) = \frac{annual\ non-revenue-water\ (m^3/a)}{mains\ length\ (km)\ x\ 365\ (d/a)}$$

### 4.4.7. Recommended classification schemes

Based on the experiences of several benchmarking projects within the Austrian water supply sector, the need for recommending a suitable classification scheme for ILI and also the need for the development of a new easy to apply classification scheme for real losses per connection per day has become evident.

#### 4.4.7.1. ILI (Infrastructure Leakage Index) classification

The Australian ILI standards of Table 13 seem to be too strict for the Austrian situation, but of course these standards are useful for the Australian situation because of the limited resources there.

On the other hand, the ILI standard values of AWWA (Table 14) do not seem to be rigorous enough for the Austrian situation. More than 50 % of ILI values (19 of 34 values) of the participants of OVGW benchmarking 2008 are under 2.0 (compare Figure 20).

The ILI classification used by the World Bank Institute (Table 15) seems to be suitable for the Austrian situation.

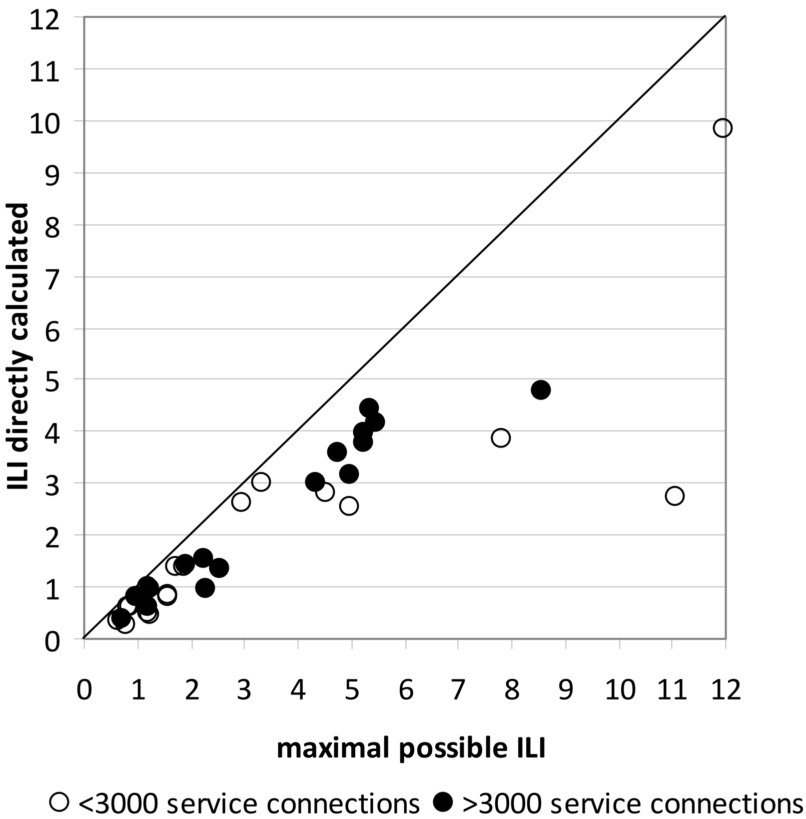


**Figure 20: ILIs of OVGW benchmarking 2008, considering possible error margins**

Figure 20 gives an overview of recent ILI values of the 2008 OVGW corporate benchmarking (data from 2007). The y-axis indicates the ILI values directly calculated from the water balance (without consideration of error margins). The x-axis indicates ILI values with consideration of maximal possible error margins. Most of the ILI data are not far away from the diagonal line, which is an indication for good data quality with small error margins. But some of the values have high error margins, which are indicated by large differences between the directly calculated value and the maximum possible value. Therefore these values are far right from the diagonal line, e.g. the value on the lower right side with a directly calculated ILI of 2.7 and an ILI of more than 11 when considering error margins. In this special case the system input volume is not metered (estimation on basis of the delivery of springs) and therefore the error margin for real losses is very high (>400 %). Nevertheless 16 of 34 ILI values of the 2008 OVGW corporate benchmarking (data from 2007) are under 2.0 even if maximal possible error margins are considered. Therefore following ILI classification (Table 16) depending on the Physical Loss Target Matrix from World Bank Institute (Table 15) is recommended for Austria:

**Table 16: Recommended ILI classification scheme (on basis of World Bank Institute)**

| ILI | category | assessment |
|---|---|---|
| **< 2** | **A** | **low water losses**, further loss reduction may be uneconomic unless there are shortages |
| **2 – 4** | **B** | **medium level of water losses**, potential for marked improvements, consider pressure management, better active leakage control practices and better network maintenance |
| **4 – 8** | **C** | **high level of water losses**, analyse level and nature of leakage and intensify leakage reduction efforts, tolerable only if water is plentiful and cheap |
| **> 8** | **D** | **very high water losses**, horrendously inefficient use of resources, leakage reduction programs imperative and of high priority |

#### 4.4.7.2. Classification for real losses per connection per day

Additional to an ILI classification the Physical Loss Target Matrix of the World Bank Institute also enables a classification for real losses per connection and day depending on the average system pressure (Table 15). This matrix is calculated on basis of the ILI formula (Formula 6 and Formula 7) for the following frame conditions:

- a service connection density of 40 connections per km
- an average length of service connection of 0 m.

Therefore this matrix is not applicable for all supply structures without additional calculations which would include these important frame conditions.

The matrix in Table 17 was developed to enable an easy use of a classification scheme for real losses per connection and day for all utilities, depending on the average system pressure and the service connection density on basis of the ILI classification from Table 16 (categories A to D). To simplify the matrix the average length of service connections (from property boundary to measurement point) was estimated at 5 m, which represents an average value for the Austrian situation (on basis of the experiences within the OVGW benchmarking).

The matrix is divided into three parts depending on the average service pressure head (20 m to 100 m). Each row of the matrix stands for a certain service connection density. To determine values for the service connection densities between two rows, an interpolation has to be done. Each of the three parts of the matrix is divided into three large columns for average service pressures. Further, each of these columns is subdivided into 4 sub-columns which indicate the categories A to D with the corresponding values for real losses per connection per day. For values between two given service pressures it is necessary to interpolate.

**Table 17: New classification scheme for real losses per connection per day**

| service connection density (No./km) | real losses per connection per day (l/conn·d) at an average service pressure head of | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 20 m | | | | 30 m | | | | 40 m | | | |
| 10 | <110 | 110-220 | 220-435 | >435 | <165 | 165-325 | 325-655 | >655 | <220 | 220-435 | 435-870 | >870 |
| | A | B | C | D | A | B | C | D | A | B | C | D |
| 15 | <85 | 85-170 | 170-340 | >340 | <130 | 130-255 | 255-510 | >510 | <170 | 170-340 | 340-680 | >680 |
| | A | B | C | D | A | B | C | D | A | B | C | D |
| 20 | <75 | 75-145 | 145-290 | >290 | <110 | 110-220 | 220-440 | >440 | <145 | 145-290 | 290-585 | >585 |
| | A | B | C | D | A | B | C | D | A | B | C | D |
| 30 | <60 | 60-120 | 120-245 | >245 | <90 | 90-185 | 185-365 | >365 | **<120** | **120-245** | **245-490** | **>490** |
| | A | B | C | D | A | B | C | D | A | B | C | D |
| 40 | <55 | 55-110 | 110-220 | >220 | <85 | 85-165 | 165-330 | >330 | **<110** | **110-220** | **220-440** | **>440** |
| | A | B | C | D | A | B | C | D | A | B | C | D |
| 50 | <50 | 50-105 | 105-205 | >205 | <75 | 75-155 | 155-310 | >310 | <105 | 105-205 | 205-410 | >410 |
| | A | B | C | D | A | B | C | D | A | B | C | D |

| service connection density (No./km) | real losses per connection per day (l/conn·d) at an average service pressure head of | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 50 m | | | | 60 m | | | | 70 m | | | |
| 10 | <275 | 275-545 | 545-1090 | >1090 | <325 | 325-655 | 655-1310 | >1310 | <380 | 380-765 | 765-1525 | >1525 |
| | A | B | C | D | A | B | C | D | A | B | C | D |
| 15 | <215 | 215-425 | 425-850 | >850 | <255 | 255-510 | 510-1020 | >1020 | <300 | 300-595 | 595-1190 | >1190 |
| | A | B | C | D | A | B | C | D | A | B | C | D |
| 20 | <185 | 185-365 | 365-730 | >730 | <220 | 220-440 | 440-875 | >875 | <255 | 255-510 | 510-1020 | >1020 |
| | A | B | C | D | A | B | C | D | A | B | C | D |
| 30 | **<155** | **155-305** | **305-610** | **>610** | **<185** | **185-365** | **365-730** | **>730** | <215 | 215-425 | 425-855 | >855 |
| | A | B | C | D | A | B | C | D | A | B | C | D |
| 40 | **<140** | **140-275** | **275-550** | **>550** | **<165** | **165-330** | **330-660** | **>660** | <195 | 195-385 | 385-770 | >770 |
| | A | B | C | D | A | B | C | D | A | B | C | D |
| 50 | <130 | 130-255 | 255-515 | >515 | <155 | 155-310 | 310-615 | >615 | <180 | 180-360 | 360-720 | >720 |
| | A | B | C | D | A | B | C | D | A | B | C | D |

| service connection density (No./km) | real losses per connection per day (l/conn·d) at an average service pressure head of | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 80 m | | | | 90 m | | | | 100 m | | | |
| 10 | <435 | 435-870 | 870-1745 | >1745 | <490 | 490-980 | 980-1960 | >1960 | <545 | 545-1090 | 1090-2180 | >2180 |
| | A | B | C | D | A | B | C | D | A | B | C | D |
| 15 | <340 | 340-680 | 680-1360 | >1360 | <385 | 385-765 | 765-1530 | >1530 | <425 | 425-850 | 850-1700 | >1700 |
| | A | B | C | D | A | B | C | D | A | B | C | D |
| 20 | <290 | 290-585 | 585-1170 | >1170 | <330 | 330-655 | 655-1315 | >1315 | <365 | 365-730 | 730-1460 | >1460 |
| | A | B | C | D | A | B | C | D | A | B | C | D |
| 30 | <245 | 245-490 | 490-975 | >975 | <275 | 275-550 | 550-1100 | >1100 | <305 | 305-610 | 610-1220 | >1220 |
| | A | B | C | D | A | B | C | D | A | B | C | D |
| 40 | <220 | 220-440 | 440-880 | >880 | <250 | 250-495 | 495-990 | >990 | <275 | 275-550 | 550-1100 | >1100 |
| | A | B | C | D | A | B | C | D | A | B | C | D |
| 50 | <205 | 205-410 | 410-820 | >820 | <230 | 230-465 | 465-925 | >925 | <255 | 255-515 | 515-1030 | >1030 |
| | A | B | C | D | A | B | C | D | A | B | C | D |

Note: The calculation is based on the assumption of an average lenght of service connections (from property boundary to measurement point) of 5 m. Typical classification values for the Austrian situation are in bold letters (service connection density of 30 to 40 per km and average service pressure head of 40 to 60 m).

This matrix, which is also implemented to the new OVGW W 63 Austrian directive (in press), enables a quick estimation of the water loss situation. For an exact assessment and classification it is recommended to calculate the ILI directly because the ILI formula considers exact values of pressure, service connection density and average service connection length.

Figure 21 shows the application of this classification scheme described in Table 17 on the data of the 2008 OVGW corporate benchmarking. The numbers in Figure 21 indicate the average service pressure. It becomes clear that lower service pressures at the same level of real losses per connection and day lead to a worse classification, and vice versa. 19 out of the 34 data sets are classified to category “A” (low water losses), 9 are in category "B" (medium level of water losses), 5 are in category "C" (high water losses) and only one utility has very high water losses (category "D").

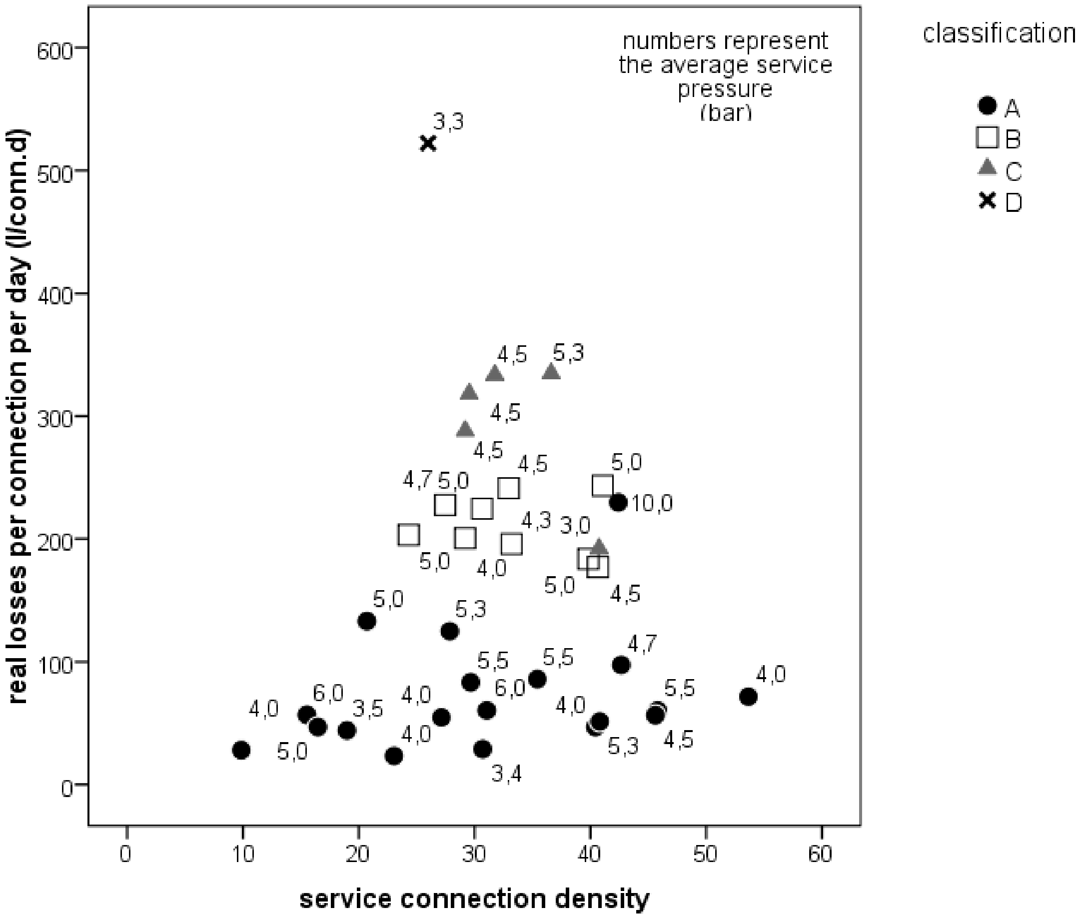


**Figure 21: Real losses per connection per day in subject to service connection density and average service pressure (data of 2008 OVGW corporate benchmarking, data of year 2007)**

There is no significant influence of the service connection density. As Figure 21 shows, very low or very high service connection densities do not result in another classification (higher or lower category). But a strong influence of the average service pressure becomes evident. On the one hand there is one utility with a very high average service pressure of 10.0 bar (real losses per connection per day: 230 l/conn·d; service connection density: 42 per km) which is classified to category "A" but has higher losses per connection per day than those utilities with lower service pressures. Therefore the average service pressure has to be considered in data interpretation. In the case of this utility a potential for reducing leakage by reducing the service pressure to an acceptable service pressure level can be derived.

On the other hand a low average service pressure leads to a worse classification for the same amount of leakage. For example a utility with an average service pressure of 3.0 bar (real losses per connection per day: 190 l/conn·d; service connection density: 41 per km) is classified to category "C" but the real losses are lower than those of the utility described above. In case this utility would have a higher service pressure, also the water losses would be higher.

## 4.5. *Active Leakage Control*

According to PILCHER (2007), Active Leakage Control can be described as follows:

> Active Leakage Control is a proactive strategy to reduce physical water loss by the detecting and pinpointing of non-visible leaks using highly trained engineers and technicians with specialised equipment followed by a prompt and good quality repair of these leaks. Best practice also includes the prompt repair of visible leaks.

In principle, two different strategies in Active Leakage Control can be differentiated:

- leak detection as a **routine survey** on a rotational basis (e.g. annual leak detection campaigns) and without educated guesses (e.g. an basis of district metered areas, DMAs)
- **cause related** leak detection e.g. on basis of DMAs

Mixed strategies are also common if parts of the network are developed as measuring zones or DMAs (e.g. outskirts, pressure zones).

For the "routine survey strategy", DVGW W 392 (2003) recommends inspection intervals for the test for leakage (Table 18) and describes possible measures for inspections and leak detection.

**Table 18: Recommended inspection intervals for networks according to DVGW W 392 (2003)**

| **classification of water losses (compare Table** 12**)** | **recommended inspection intervals** |
|---|---|
| high water losses | once a year |
| medium water losses | once in 3 years |
| low water losses | at least all 6 years (1) |

(1) if there are no other reasons for leak detection

### 4.5.1. Management of District Metered Areas (DMAs)

The basic principle of measuring zone management is to divide the water supply network into various sectors (zones) and DMAs and to permanently monitor the input into these zones with meters (Figure 22).

By monitoring the minimum night flow it is possible to become aware of occurring leaks (increase of minimum night flow). Consequently, systematic leak detection measures can be initiated (Figure 23). In general, DMAs are suited for keeping levels of leakage low and also making systematic leakage reduction easier in systems with high losses. In systems with high losses the leak detection measures should be focused on the zones with the highest losses.

In February 2007 the DMA Team of the IWA WLTF published a guideline for DMA Management, the "District Metered Areas – Guidance Notes" (MORRISON et al. 2007). The purpose of these guidance notes is to give practitioners an introduction to the benefits, design and management of active leakage control activities based on the use of DMAs. The appendix of this guideline includes some case studies of successful implementations of DMAs.

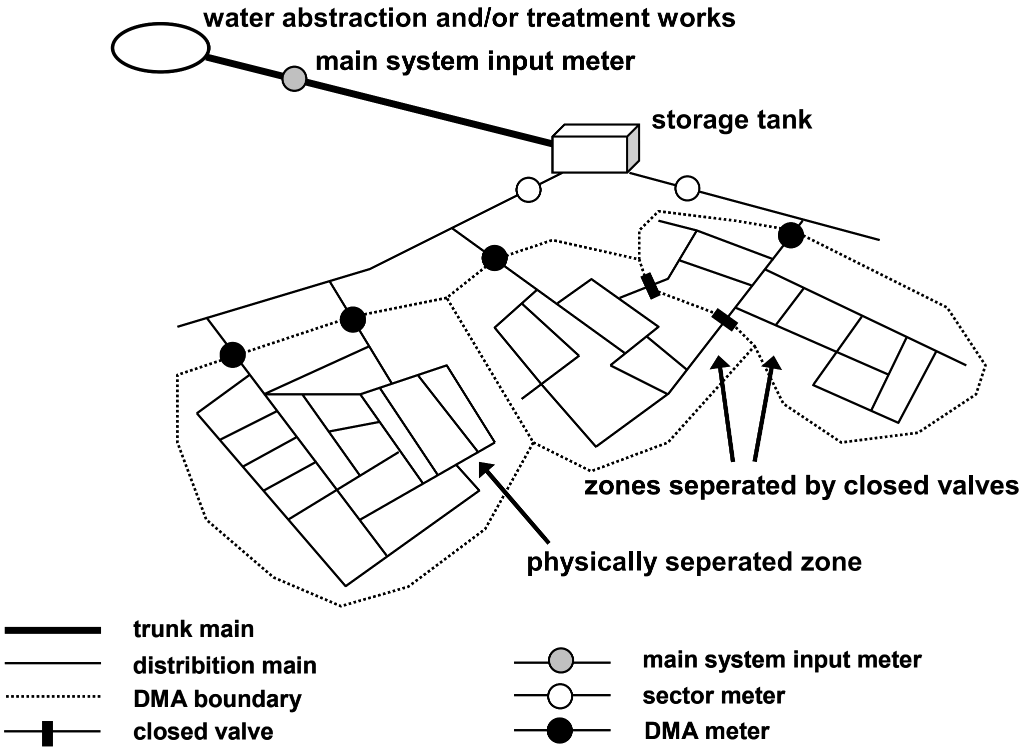


**Figure 22: Typical DMA configuration (MORRISON et al. 2007)**

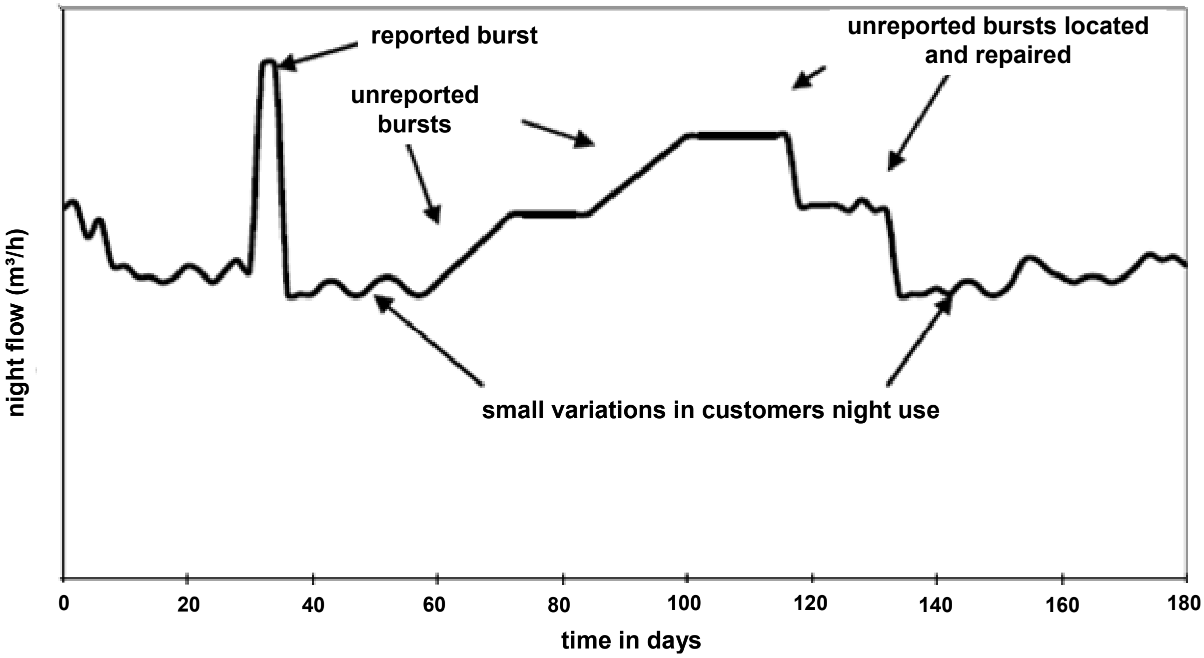


**Figure 23: Variation in minimum night flow over time (MORRISON et al. 2007)**

The optimal size of a DMA depends on the individual frame conditions of the zone (natural borders, e.g. rivers, geodetic situation, pressure conditions, conditions of infrastructure or fire fighting capacities). Practical experiences show that in urban areas DMAs should include 500 to 3000 properties. In DMAs with more than 5000 properties it is very difficult or even impossible to recognise single small leaks by monitoring minimum night flows. Leak detection also takes longer in larger zones. In networks where the infrastructure is in a poor condition it can be useful to have zones smaller than 500 properties (compare MORRISON et al. 2007).

Austrian water utilities often argument that DMAs also have some disadvantages:

- supply safety: closed valves might cause quantitative problems in peak situations, e.g., high water demand for dousing fire
- water quality: qualitative problems (hygiene) in stagnation zones at DMA boundaries

Therefore it might be useful to control the closing valves at DMA boundaries for zone separation (compare Figure 22) during short measurement periods in the night hours. During the night hours, e.g. from 2:00 a.m. to 4:00 a.m., the valves can be closed for a 2-hours night minimum flow measurement to the DMA. After the measurements the valves are opened again and the network is not hydraulically separated any more. Of course, this solution of automated temporary DMAs might be more expensive than common DMAs.

### 4.5.2. Leakage Monitoring without DMAs

Contrary to leakage monitoring in DMAs, which is mainly done by montoring the system input into DMAs, leakage monitoring in large network zones is more difficult. Due to the fact that the absolute system input volume of large zones is not significant for leakage monitoring, other methodologies need to be used.

One possibility is to measure relative flows at selected measurement points in the network. The objective of relative flow measuring is to build up "*virtual measuring zones*" to acquire information about relative variations of flows in the network which can be an indicator of leakage (compare Figure 24).

Another possibility is the installation of permanent noise measurements. But an area wide noise measurement has not so far proven to be cost efficient.

Recent developments provide combined measurements of various parameters (e.g. flow, pressure, noise). The technology of multiparameter measurements for the purpose of network monitoring (by virtual measuring zones) described in the following sub chapters (compare KOELBL et al. submitted) should enable area wide leakage monitoring. Even if this methodology is not widely-used nowadays, it is thought to play an essential rule in the future.

In addition to leakage monitoring, multiparameter measurements (eventually combined with step-testing) give also support in leak detection.

#### 4.5.2.1. Principles of multiparameter measurements

Multiparameter measurements used for physical water loss management are combined measurements of more than one of following parameters at selected locations of a water distribution network:

- flow (bidirectional)
- pressure
- noise

It is possible to combine two of these parameters, e.g. flow and pressure or flow and noise, but combinations of all three parameters are advantageous. There are sensors available containing all these parameters, but it is also possible to use single instruments to measuring the parameters separately.

Water lost at leaks causes an increase in system input, but the hydraulic conditions (flow, pressure) within the distribution network may also change. Practical experiences show that variations of flow and pressure due to leakage or other extractions can be tracked over large ranges of the distribution network, especially during times of low consumption (note: the size of this "detection" range depends on the leak rate and the hydraulically sensitivity of the distribution network). Therefore, flow measurements within the distribution network provide an indication for the area of the leak position. It is possible to create "**virtual measuring zones**" within the distribution network (Figure 24). Virtual measuring zones are parts of the distribution network which are not physically separated from the rest of the distribution network or from the rest of a district metered area (DMA). Variations in the hydraulic conditions or other parameters (noise) can be detected by surrounding measuring points in these virtual measuring zones.

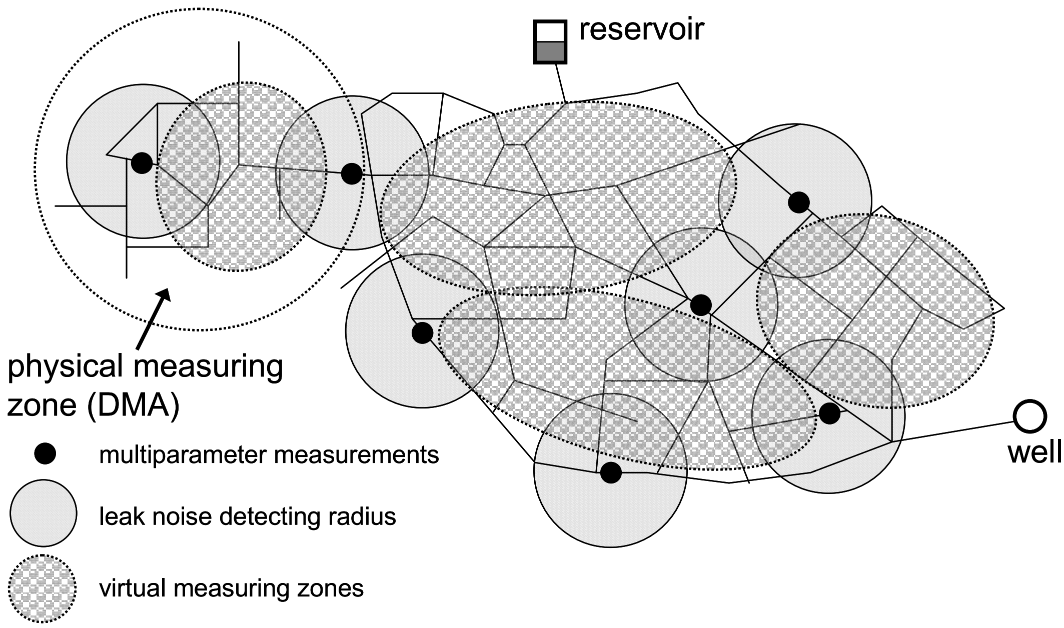


**Figure 24: Schematic diagram of virtual and physical measuring zones**

Due to additional measurements of (leak) noise, further information about the location of the leak can be obtained. Depending on the spatial density of multiparameter measurement points, radii of single noise measurements either overlap each other or do not. In any case, if one or more noise recorders detect a leak noise signal, a direct indication of the leak location is provided. If none of the measuring points detects a leak noise signal, the area of leak location can be narrowed down indirectly since the existence of a leak can be ruled out in a certain area around each measuring point (depending on the frame conditions pipe material, pipe diameter, soil etc.). For pinpointing the leaks various leak detection technologies can be used (see chapter 4.5.3.2).

#### *4.5.2.1.1. Flow and noise measurements*

The following types of flow meters are suitable for continuous flow measurements at measuring points within the distribution network:

- magnetic inductive flow meters of full-bore type
- magnetic inductive flow meters of insert type
- ultrasonic flow meters

The disadvantage of magnetic inductive flow meters of the full-bore type and, in general, of ultrasonic flow meters is that these types can only be installed in common shafts or measuring chambers, whereas magnetic inductive flow meters of the insert type can also be installed in cost-saving special shafts.

Noise recorders can be situated on the outside of pipes, on fittings or directly in the water medium. Noise measurements in the water medium can increase the “detection” radius since the sound propagation within the water is usually better than in the pipe wall, especially in plastic pipes.

Continuous noise loggings over the whole day have the advantage that leaks may be detected more easily than with noise measurements only during night hours. This is due to typical noise development of leaks. Usually the most intensive noise appears at the moment the leak occurs and the pipe bursts. After a certain time, the hollow space in the ground around the leak is filled with water and then the leak noise decreases. Therefore, the likelihood of detecting a leak noise is much higher using a continuous noise recording (Figure 25).

#### *4.5.2.1.2. Positioning of multiparameter measurements*

An adequate spatial density of measurement points is necessary for significant multiparameter measurements. The positioning of the multiparameter measurements is done on basis of hydraulical aspects. As mentioned above, these measurements can be used in non-divided networks or large measuring zones, as well as in DMAs.

The single measurement points should be equipped with data loggers and be connected to a SCADA system.

#### *4.5.2.1.3. Interpretation of multiparameter measurements*

Multiparameter measurements provide information about hydraulic and/or acoustic variations in water distribution systems due to leakage, but also due to changed positions of closing valves or water abstractions of hydrants (SAX & SCHREITMÜLLER 2007).

In general, the interpretation of multiparameter measurement data should be done by comparing current data with previous data from comparable hydraulic conditions. Figure 25 gives an example of how to interpret such measurements.

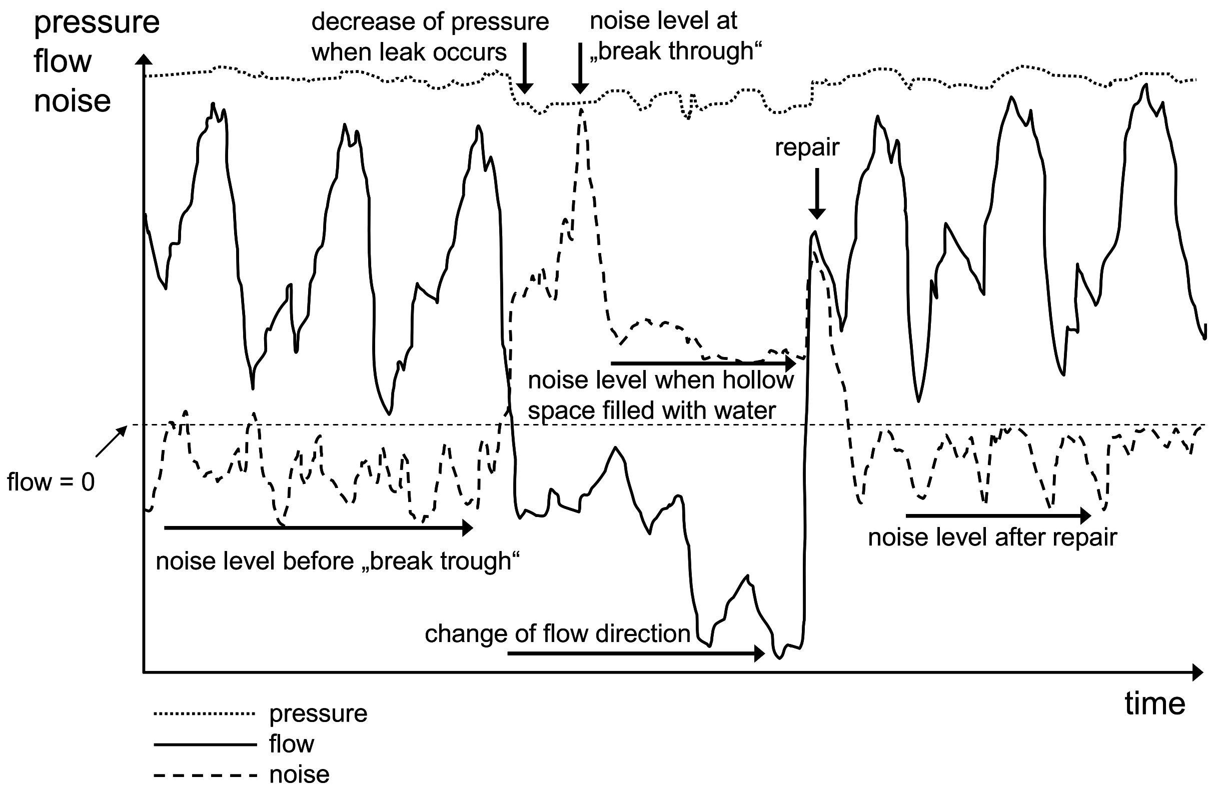


**Figure 25: Example of multiparameter measurements (schematic diagram)**

### 4.5.3. Leak detection

In March 2007 the IWA WLTF Leak Detection Practices, Techniques and Repair Team published a guideline for leak detection and repair, the “Leak Location and Repair Guidance Notes” (PILCHER et al. 2007). The purpose of these guidance notes is to give newcomers in leak detection an introduction to that topic and to inform experienced practitioners of recent technologies.

To give a detailed description of all recent leak detection technologies would be beyond the scope of this thesis. Therefore the aim of this chapter is to give a short overview of the current leak detection technologies described by PILCHER et al. (2007) and in additional literature.

In general, leak detection can be divided into two separate activities: leak localising and leak location, also called “pinpointing”.

Table 19 gives an overview of the most common, but also some specific, leak detection methodologies. Most of the descriptions of these methodologies are based on the definitions of PILCHER et al. (2007), PILCHER (2007), FARLEY & TROW (2003) and FARLEY (2007).

**Table 19: Leak detection methodologies**

<table>
<tr><th>Use</th><th>Type</th><th>Methodology</th><th colspan="2">Description of methodology and field of use</th></tr>
<tr><td rowspan="7">leak localising</td><td rowspan="4">acoustic</td><td>permanent noise loggers</td><td rowspan="2">noise loggers are fixed with strong magnets on fittings and are programmed to detect typical leakage noise</td><td>used in areas which are difficult to inspect with other technologies (city centres, roads with heavy traffic)</td></tr>
<tr><td>temporary noise loggers</td><td>used in short leak detection campaigns noise loggers are situated in parts of the network over short periods</td></tr>
<tr><td>listening stick (stethoscope)</td><td colspan="2">placed at fittings (valves, stopcocks or hydrants), leak noise is transferred from the fitting to the ear</td></tr>
<tr><td>electronic leak locator</td><td colspan="2">placed at fittings (valves, stopcocks or hydrants), leak noise is transferred from the fitting to a microphone</td></tr>
<tr><td rowspan="2">non-acoustic</td><td>visual checks</td><td colspan="2">visual checks for leaking water</td></tr>
<tr><td>step testing</td><td colspan="2">temporary successive valve closures for short duration (to reduce the size of district) whilst simultaneous flow measurements; a reduction in flow rate following the closure of a particular valve indicates the section with the leak</td></tr>
<tr><td>combined</td><td>combined multi-parameter measurements</td><td colspan="2">with multiparameter measurements (flow and/or pressure and/or noise) on several points in the supply system the area of a leak can be identified; a combination with step testing is useful; instead of multiparameter measurements also only flow measurements (virtual zones) are common, but this has the disadvantage of missing noise information</td></tr>
<tr><td rowspan="7">leak location (pin-pointing)</td><td rowspan="4">acoustic</td><td>ground microphone</td><td colspan="2">direct sounding: fixing it on a fitting<br>indirect sounding: used on the ground surface directly above the pipeline</td></tr>
<tr><td>leak noise correlator</td><td colspan="2">very common (esp. for metallic pipes); the sound of a leak is picked up by sensors at two locations e.g. two fittings, with the knowledge of the pipe material and the diameter combined with the difference between the two arrival times of the leak noise at the two sensors the leak position can be calculated by the correlator</td></tr>
<tr><td>leak finder</td><td colspan="2">listens to leak sound travelling through water by using hydrophones connected to fire hydrants; sound propagation in water is much higher than in pipe walls; enables location of leaks even in plastic pipes</td></tr>
<tr><td>internal noise/leak indicator</td><td colspan="2">a noise recorder is deployed into the water within the pipe, the velocity of the water carries the equipment along; even smallest leaks can be located</td></tr>
<tr><td rowspan="3">non-acoustic</td><td>tracer gas</td><td colspan="2">used when acoustic techniques fail; mainly industrial hydrogen (approximately 95 % nitrogen and 5 % hydrogen) are filled into the pipe, the hydrogen escapes at the leak and can be detected with a “sniffing” probe at the surface</td></tr>
<tr><td>ground penetrating radar (GPR)</td><td colspan="2">used when acoustic techniques fail; this geophysical methodology can detect pipes, cables and leakage in fact of the disturbed underground and eventually existing cavities around the leakage; used especially at transportation mains at which a regular sounding survey is not possible because of the rare fittings</td></tr>
<tr><td>intelligent pig</td><td colspan="2">in-pipe methodology; test control units use ultrasonic measurements to detect wall thickness, corrosion, deformation or cracks and bursts; used for transportation pipes without any fittings</td></tr>
</table>

#### 4.5.3.1. Leak localising

One of the most time consuming activities in finding leaks is the “leak localising” phase. The aim of leak localising is to narrow down the location of a leak to an individual road or length of main. Leak localising can be undertaken as a routine survey of the network but it also can be carried out in target areas (e.g. DMAs with increased night flow). Two methodologies for leak localising are currently state of the art: *step testing* (see Table 19) during times of low consumption (usually at night) and *noise logging* (PILCHER 2007).

Noise loggers are fixed with strong magnets on fittings and are programmed to detect typical leakage noise. Two different strategies are common for the use of noise loggers (PILCHER 2007):

- strategic basis: this is the use of noise logger in areas which are difficult to inspect with other technologies (e.g. city centres, roads with heavy traffic etc.), it is often a *permanent* insertion of the noise loggers
- tactical basis: noise loggers are situated in parts of the network over short periods (*temporary*), after locating leaks the loggers are situated in other areas; these kind of employment is used in short leak detection campaigns and in “crises”

*Visual checks* on leaks or other acoustic techniques like *listening sticks* or *electronic leak locators*, which are the electronic version of listening sticks, are used for leak localising. According to PILCHER et al. (2007), these two methodologies belong to leak location (pinpointing) techniques but practical experience has shown that listening sticks and electronic leak locators are also often used for leak localising. FARLEY & TROW (2003) describe the use of these techniques for leak localising.

*Listening sticks* and *electronic leak locators* are placed on fittings like valves, stopcocks or hydrants. The leak noise is transferred from the fitting to the ear or to a microphone (PILCHER et al. 2007).

#### 4.5.3.2. Leak location (pinpointing)

Leak location (or pinpointing) is the identification of the exact position of the leak. Most of the common leak location techniques are based on noise detection but there are also some non-acoustic techniques like tracer gas, ground penetrating radar (GPR) or infrared thermography (PILCHER 2007).

##### *4.5.3.2.1. Acoustic techniques*

There are a number of devices used for detecting the sound created by a leak or burst. Two traditional devices are the *listening stick* (stethoscope) and the *electronic leak locator*, which are described in Table 19.

A *ground microphone* can be used for locating leaks by fixing it to a fitting (direct sounding) or it can be used on the ground surface directly above the pipeline (indirect sounding), (PILCHER et al. 2007).

The use of *leak noise correlators* is also very common, (especially for metallic pipe materials). The sound of a leak is picked up by sensors at two locations, e.g. two fittings. The leak noise travels along the pipe at a constant velocity. The velocity of the leak noise depends on the diameter and the material of the pipe. So if the knowledge of the pipe material and the diameter is combined with the difference between the two arrival times of the leak noise at the two sensors, the leak position can be calculated by the correlator. The pinpointing can be done with an accuracy of a few centimetres, depending on the local conditions (PILCHER et al. 2007).

A further development of the leak noise correlator is the "*leak finder*". This new instrument listens to the leak sound travelling through the water by using hydrophones connected to fire hydrants. Because the sound propagation in water is much higher than in the wall of the pipe this technique enables the location of leaks even in plastic pipes (PILCHER et al. 2007).

Another methodology, which is preferably used in transportation mains, is an *internal noise/leak indicator*. This system works with a noise recorder which is deployed into the water within the pipe and uses the velocity of the water to carry the equipment along. Even the smallest leaks can be located with this device. The first of the systems working with this technology was the SAHARA system (PILCHER et al. 2007).

*4.5.3.2.2. Non-acoustic techniques*

The *tracer gas* methodology is used when acoustic techniques do not lead to success (e.g. low pressure mains or small leaks at small diameter non-metallic pipes). Therefore (mainly) industrial hydrogen (approximately 95 % nitrogen and 5 % hydrogen or helium) is pumped into the pipe. The hydrogen escapes at the point of leakage and can be detected with a "sniffing" probe at the surface (note: hydrogen is the smallest and lightest element and helium the second lightest). This specialised methodology requires special know-how and is therefore almost carried out by experts (PILCHER et al. 2007).

Another special methodology is *infrared thermography*, which tries to detect temperature differences underground. The first trials have been carried out in the United States. Experiences show that this methodology is only efficiently applicable for long transportation mains which can be overflown by planes equipped with infrared scanners (compare FARLEY 2007).

The *ground penetrating radar* (GPR) method can be used when a leak creates no or very little noise so that a location with acoustic techniques is not possible: e.g., because of other influences like traffic noise, noise of pumps or pressure reduction valves or others (PILCHER et al. 2007). This geophysical methodology has now been in existence for more than 30 years and was primarily developed to detect various objects underground (e.g. bunkers, cavities or walls). But also pipes, cables and leakage can be found by using this methodology because of the disturbed soil and cavities around the leakage. FARLEY (2007) describes the use of this methodology for finding "difficult" leaks, especially at transportation mains at which a regular sound survey is not possible because of rarely installed fittings. In such situations it is possible to walk or drive with a GPR-monitor car (15-30 km/h) along the main. The DWA-M 149-4 technical bulletin (draft version from November 2007) describes this technology for the use on drainage systems.

Another less common leak detection methodology for water supply systems are *intelligent pigs*. Pigs are test control units using ultrasonic measurements to detect wall thickness, corrosion, deformation or cracks and bursts while pipes are operational. In general, this methodology only can be used for transportation pipes without any fittings because the pig has to be inserted into the pipe and travels along the pipe with a velocity up to more than 1 m/sec.

## 4.6. *Pressure Management*

The amount of water lost from a leak very much depends on the service pressure. Therefore pressure management is an essential part of water loss management.

LAMBERT (2001) describes the relevant interactions of pressure and leakage and the basics of pressure management. A basic principle in pressure management is to avoid strong variations in pressure over a short time because this may lead to higher failure rates (note: there is a higher risk for systems without high level tanks which are supplied only over pumps).

Formula 11 can be used for simple analyses and estimations of pressure : leakage relationships.

**Formula 11: Pressure : leakage relationship**

$$L_1/L_0 = (P_1/P_0)^{N1}$$

$L_0$…leakage rate at pressure $P_0$
$L_1$…leakage rate at pressure $P_1$
$P_0$…initial service pressure
$P_1$…changed service pressure

The leakage rate varies with $P^{N1}$, whereby N1 especially depends on the pipe material and the type of leakage (background losses or detectable losses), (Figure 26). Typical values of N1 are in the range of 0.5 and 1.5 (THORNTON & LAMBERT 2005).

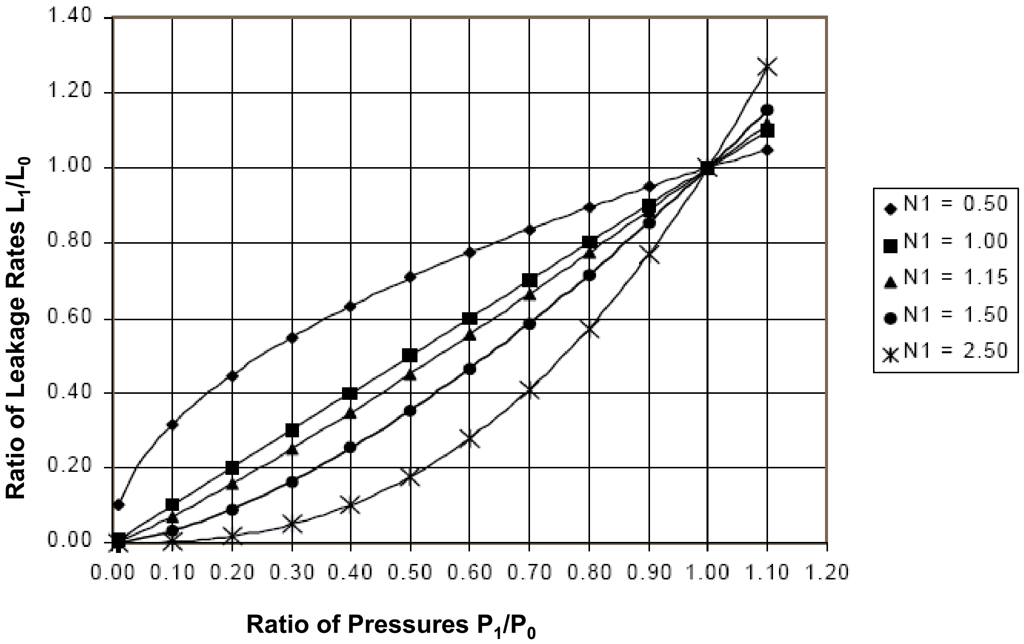


**Figure 26: General relationships between pressure and leakage rates using the N1 approach (LAMBERT 2001)**

According to Formula 11 it becomes clear that water losses decrease with a reduction in the service pressure. Another aspect of permanent pressure reductions are reduced burst frequencies. There are several examples where an acceptable (from the point of view of supply technology and customer service) reduction of the service pressure results in significantly lower burst rates at distribution mains and also at service connections. Beside other international examples, THORNTON &

LAMBERT (2006) describe the situation in Gracanica, Bosnia Herzegovina. A reduction in the service pressure head from 50 m to 40 m (20 %) led to a reduction of bursts of about 60 % at mains and about 70 % at service connections.

Great results in the reduction of leakage and also in reduction of burst frequencies can be achieved with pressure reduction, especially for water supply systems in poor condition. An optimisation of the service pressure in supply systems in good condition also, however, makes sense.

The conceptual approach of THORNTON & LAMBERT (2006) in Figure 27 shows that new pipes (in general) are designed in such a way that the working range of the pressure (area A in Figure 27) is clearly under the pressure that leads to failures. But the aging process and various external influences (e.g. traffic load, ground movements or low temperatures) lead to an increased occurrence probability of failures at lower pressure levels. With a reduction of the service pressure to working range B (in Figure 27) the occurrence probability of failures can be reduced.

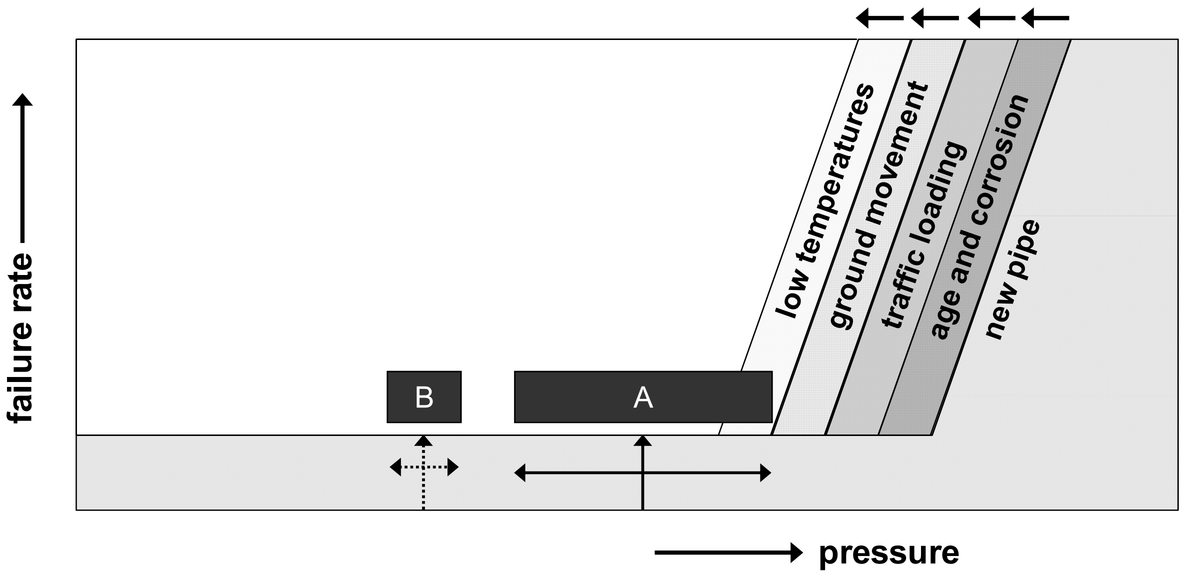


**Figure 27: Conceptual approach to pressure : break frequency (THORNTON & LAMBERT 2006, amended)**

It has to be mentioned that the pressure management philosophy in central Europe, especially in Austria, Germany and Switzerland, is clearly different from the IWA philosophy. In these countries pressure reduction under a level of 30 m to 40 m service pressure head is seen as an urgent measure in a system of poor infrastructure condition and it is seen as a fight against symptoms than against the real cause. Because most is the leak detection methodologies use acoustic technologies, leak detection in systems with low service pressure becomes very difficult or even impossible. To assure a sustainable infrastructure management with pipe networks in good condition it is necessary to operate the systems under adequate pressure. Of course, unnecessary high pressures should be avoided even in systems in good condition.

Table 20 shows the required service pressures for the two relevant cases (maximum demand and case of fire-fighting) according to the Austrian standard OeNORM B 2538 (2002).

**Table 20: Minimum service pressure in distribution mains according to OeNORM B 2538 (2002)**

| *number of floors* | *required service pressure in bar* | | *required service pressure head in m* | |
|---|---|---|---|---|
| | *case 1: maximum demand* | *case 2: fire-fighting* | *case 1: maximum demand* | *case 2: fire-fighting* |
| up to 3 | 3.0 | 1.7 | 30 | 17 |
| 4 | 3.6 | 2.2 | 36 | 22 |
| 5 | 4.2 | 2.7 | 42 | 27 |
| 6 | 4.8 | 3.2 | 48 | 32 |

## 4.7. *Infrastructure Management*

Infrastructure management includes a very broad field of duties. One aspect is the configuration of the supply system and the technical equipment in use. The central tasks of infrastructure management are the duties of maintaining various objects (storage tanks, pumping stations etc.) and of the supply network, including all kinds of fittings, hydrants and flow meters. Figure 28 gives an overview of the maintenance duties. Rehabilitation planning is especially important for water loss management (including strategic rehabilitation planning, analyses of failure rates, long and mid term planning, etc.).

Another topic is the customer meter management (type and age of customer meters, automatic meter reading or meter reading by personnel of water supply utility over larger periods of the year, key date problem) which has a great influence on the accuracy of water balance input-data. In general, infrastructure management activities are long term measures.

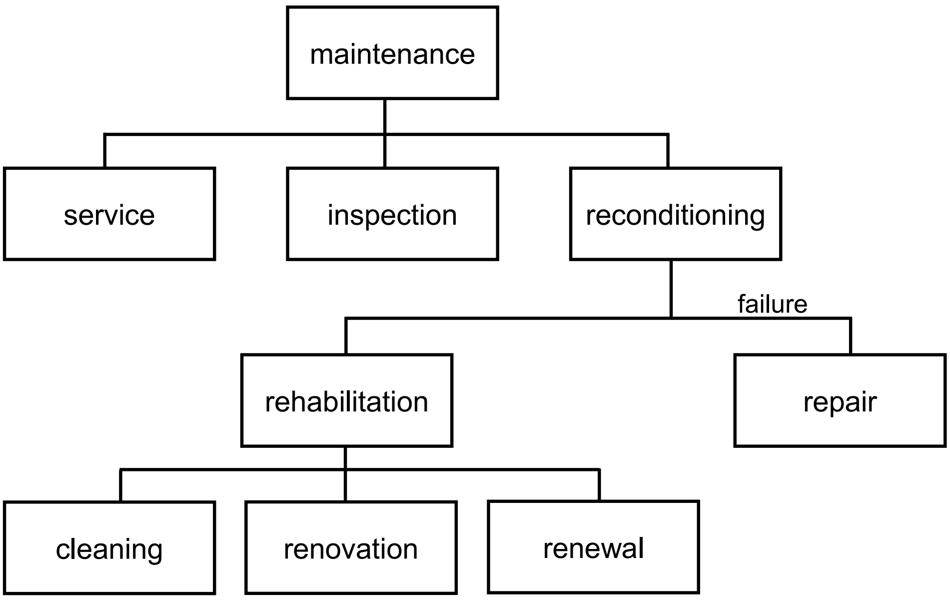


**Figure 28: Maintenance duties (OVGW W 100, 2007)**

When translating Figure 28 from German into English a problem occurred with the terms “rehabilitation” and “renovation”. In English the term “renovation” also stands for renewal, rehabilitation, refurbishment and sanitation. In our case “renovation” stands for the German word “Sanierung”. ALEGRE et al. (2006) uses the term “renovation” with the same meaning. The renovation of mains can be done with epoxy resine, cement mortar or other materials.

# 5. The process benchmarking system for managing physical water losses

## 5.1. *General remarks*

After the introductory chapters about performance indicators, benchmarking, and water loss management, chapter 5 and chapter 6 represent the core of this PhD thesis: the process benchmarking system for the management of physical water losses.

The challenge is to apply the methodology of process benchmarking to the topic of physical water loss management. To reach this aim the first step is the definition of a clear process structure (Figure 29). The process benchmarking system was created on the basis of the process structure described in chapter 5.2. This system consists of a part system for data collection (basis data, variables, context information) and a part system for data evaluation (performance indicators, quality matrix).

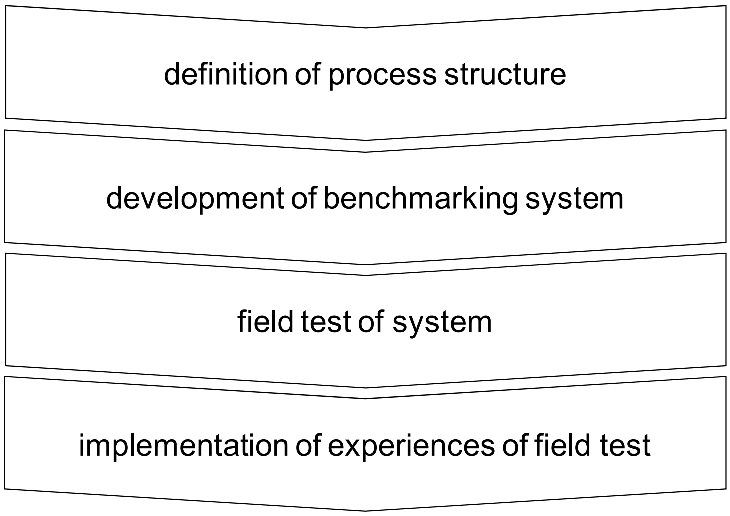


**Figure 29: Methodology in developing the process benchmarking system**

A big advantage for the successful development of this process benchmarking system was the possibility of a field test of the system developed within the 2007 OVGW process benchmarking project. Eleven water supply utilities in Austria with different supply structures and very different strategies in water loss management participated in this first project. The methodology chosen, with an extensive and hierarchical system of performance indicators, is a worldwide innovation. Selected results of this case study were first published by KOELBL et al. (2008a). Chapter 6 includes a detailed summary of the 2007 OVGW process benchmarking on physical water loss management.

Many important methodological findings were realised during the field test. **The process benchmarking system described in this work varies in some points from the 2007/08 OVGW system because the experiences of the field test were implemented to the process benchmarking system for the management of physical water losses.** Some very important improvements made after the field test are discussed in the following chapters which describe the process structure and the process benchmarking system.

Before starting with the description of the process benchmarking system the criteria for the process benchmarking system described in chapter 1.2 should be summarised:

- *Clear process structure*: The process structure has to be easy to understand and all parts of the process (sub processes, supporting processes) have to be well defined.
- *Hierarchical process structure:* The process structure has to be hierarchical, so that both the overall performance and the performance in single parts of the process can be assessed.
- *Practical applicability:* The system of process benchmarking has to be in step with actual practice and, therefore, it has to be developed closely with water supply utility experts.
- *For all structures:* The system has to be applicable for all structures and all sizes of water supply utilities.
- *Simple data gathering*: The allocation of costs should be simple. The query of context-information should be done with selective lists to keep the effort as low as possible.
- *Transparency:* The system has to be a transparent one: "black-box" solutions have to be avoided.
- *Data quality:* The accuracy and reliability of variables has to be considered.
- *Structural parameters:* The system should consider different frame conditions of water supply systems to allow a performance comparison in "comparable" groups (clusters).
- *Voluntary and anonymous system:* The system should be used for voluntary benchmarking and should allow anonymous evaluations.
- *Field test:* The system has to stand a field test in the Austrian water supply sector.

## 5.2. *Process mapping of physical water loss management*

As mentioned before, the process structure has to be easy to understand and all the parts of the process (sub processes, supporting processes) have to be well defined. Thus, first of all definitions of which duties a water supply utility has in the whole value chain have to be considered in the process of physical water loss management. Figure 30 gives an overview about all the different tasks that influence physical water loss management.

It becomes clear that the process of physical water loss management is a highly integrative process which is influenced by many single tasks of almost all the operating duties of a water supply utility. Therefore it is not possible to handle this process as a part of a holistic process benchmarking system which covers the whole value chain.

It is especially important to define the borders a process starts and ends for the definition of a selective process. The characteristics of this process and all the input and output factors of all the sub processes also need to be defined. It has to be specified what can be measured and how costs can be allocated. At the end of the process comparison it should become clear what the costs in the single process steps are and how successful the methodologies used have been. This can be expressed by the quality in process operation but also as performance, e.g. in water loss PIs.

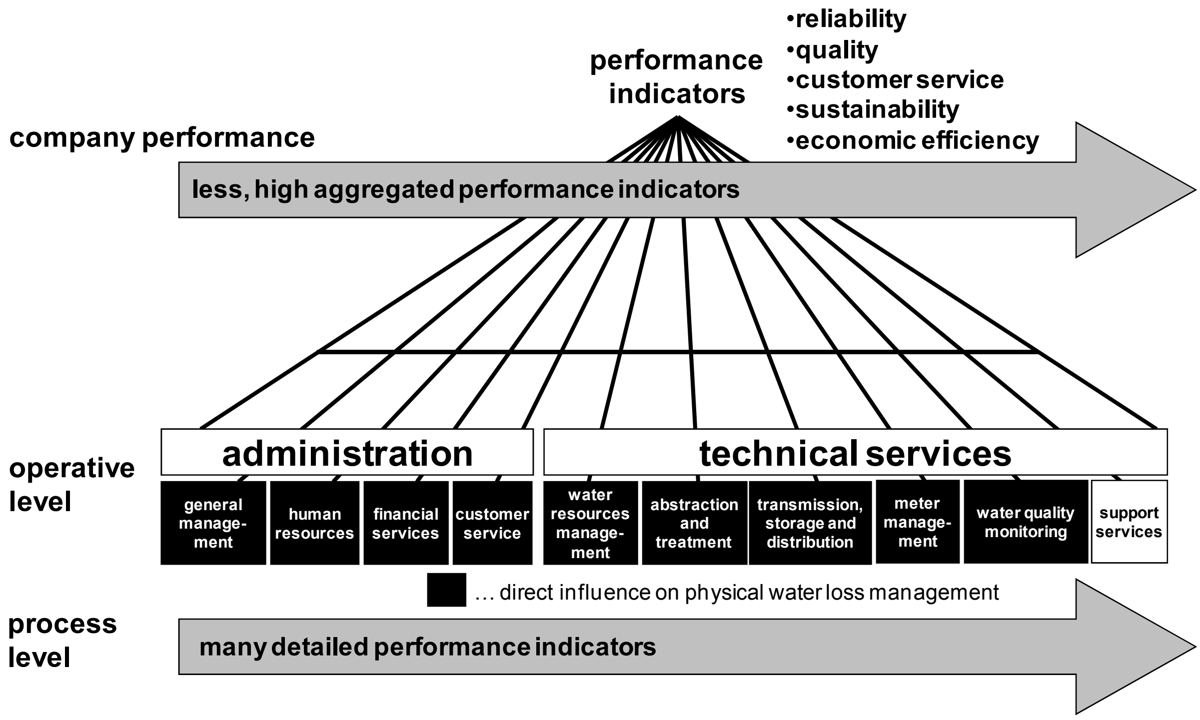


**Figure 30: Duties of water loss management within the whole value chain of a water utility (OVERATH & MERKEL 2004, amended)**

The basis for the definition of a process structure was the IWA methodology in water loss management. According to the descriptions in FARLEY & TROW (2003), Figure 31 gives an overview of the most important elements and topics in physical water loss management.

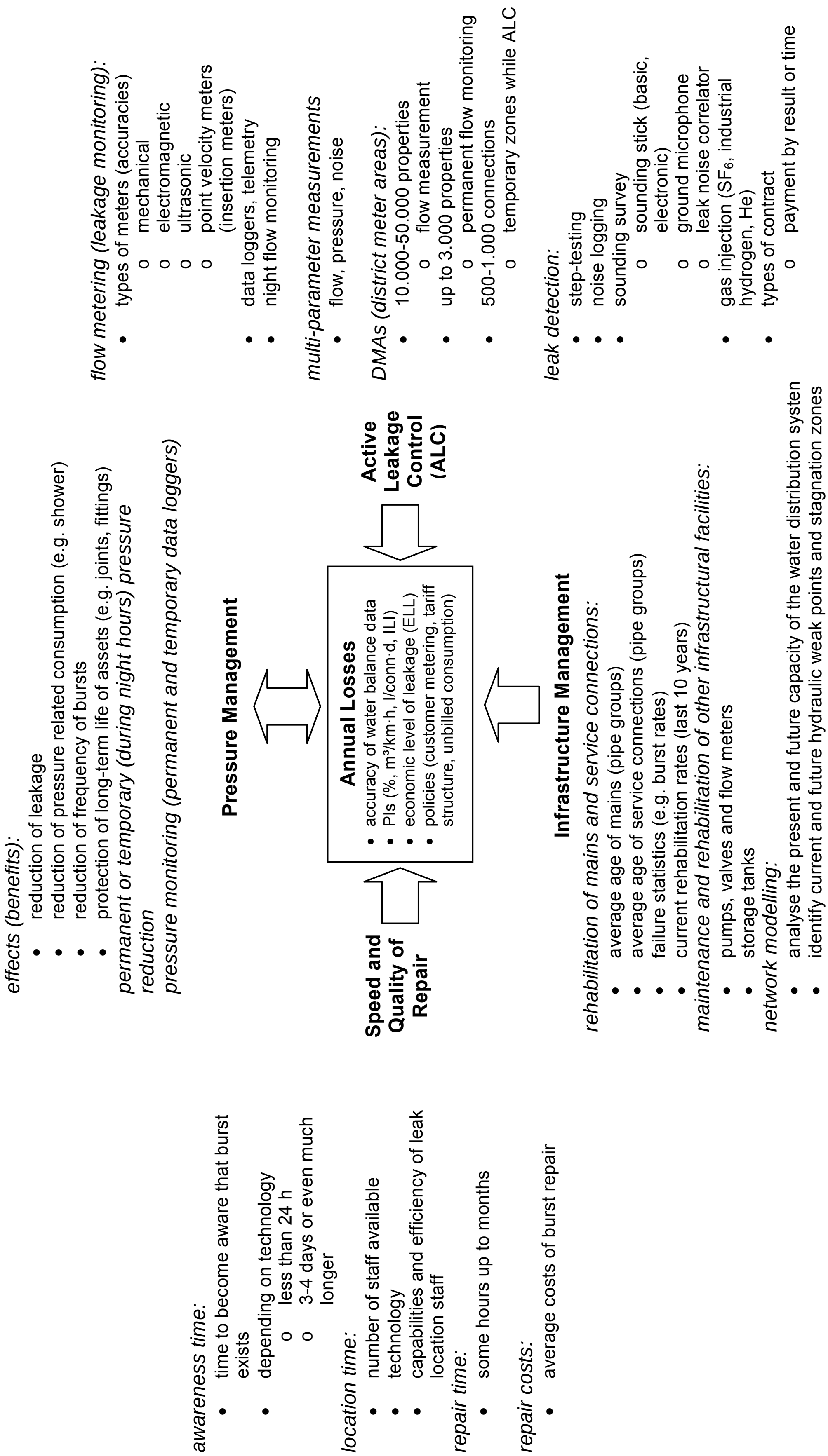


**Figure 31: Elements of physical water loss management (on basis of FARLEY & TROW 2003, amended)**

The process structure developed for the 2007 OVGW process benchmarking foresees a subdivision of the overall process into four sub processes and two supporting processes (Figure 32). The four sub processes are:

- leakage monitoring,
- leak detection,
- leak repair and
- analyses & planning.

The two supporting processes are

- infrastructure management and the
- qualification of staff.

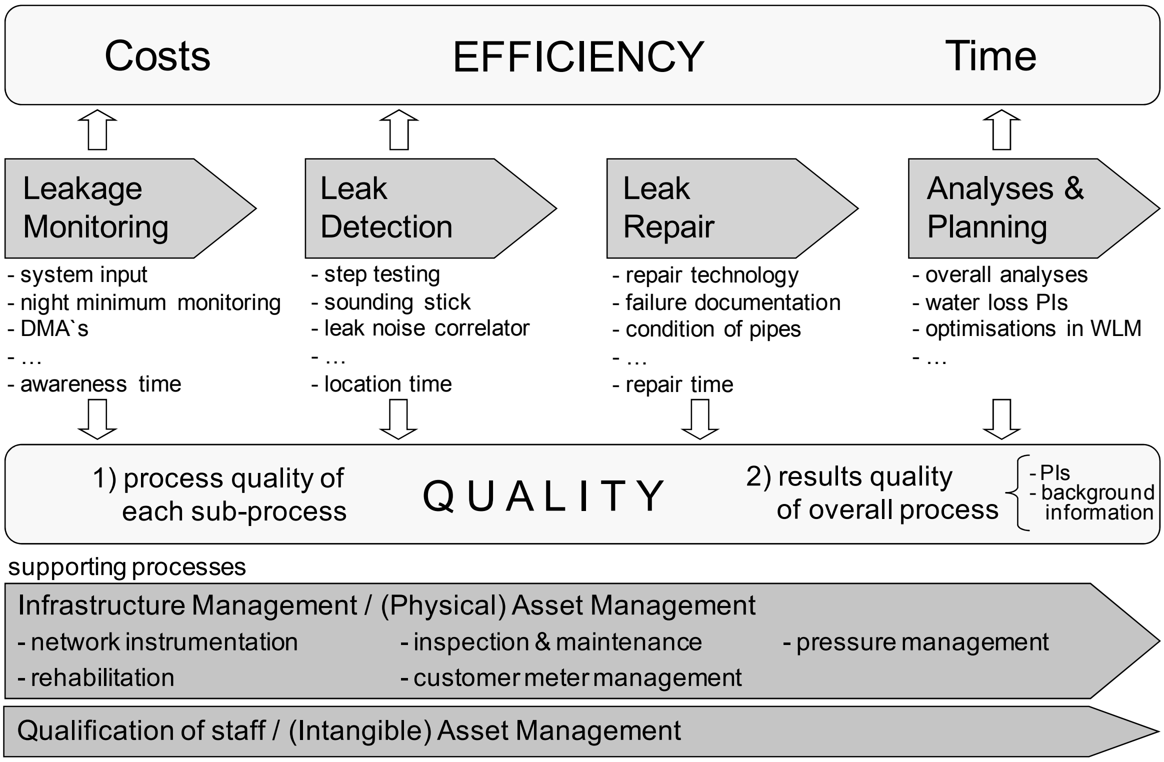


**Figure 32: Original 2007 OVGW process structure for managing physical water losses**

It can be seen that there is no sub process of pressure management. Pressure management is “only” considered as a part within the supporting process of infrastructure management. The reason for this is that pressure management in Austria is not as big a topic as it is internationally. In general, the Austrian water supply networks are operated with average service pressures between 3 and 5 bar. Due to aspects of customer service a reduction of service pressure under 3 bars has to be avoided. From the Austrian point of view, pressure reduction should only be a short-term measure and the aim of each utility should be to make adequate – but not unnecessary high - service pressures available. The precondition is an infrastructure in good condition.

Concerning assessment of efficiency and process quality, the idea was to calculate costs and working times for all of the sub processes and to ask for a lot of context information regarding sub processes and supporting processes for the assessment of the quality in process operation. No costs and working times are analysed for the supporting processes because the allocation of cost would be too difficult and the result would also be distorted. In fact, these supporting processes are often much more cost intensive (e.g. the process of rehabilitation) than the process of physical water loss management itself.

This problem was also realised with the leak repair sub process. A participating utility mentioned that the costs for the sub process leak repair in the company are nearly ten times higher than the costs for the rest of the process of physical water loss management. Therefore no costs for this sub process are considered in the overall process. However, for questions like the long-term economic level of leakage the costs for leak repair and also costs of other supporting processes like rehabilitation have to be taken into account (e.g. FARLEY & TROW 2003). Therefore for this sub process, as well as for some infrastructural management tasks, annual costs (e.g. depreciation costs for investments) are considered as context information. This information is available for additional analyses but these costs are not part of the overall performance in physical water loss management.

In fact, the sub process leak repair should better be defined as a supporting process and, therefore, the process structure changes to a subdivision of three sub processes (Figure 33).

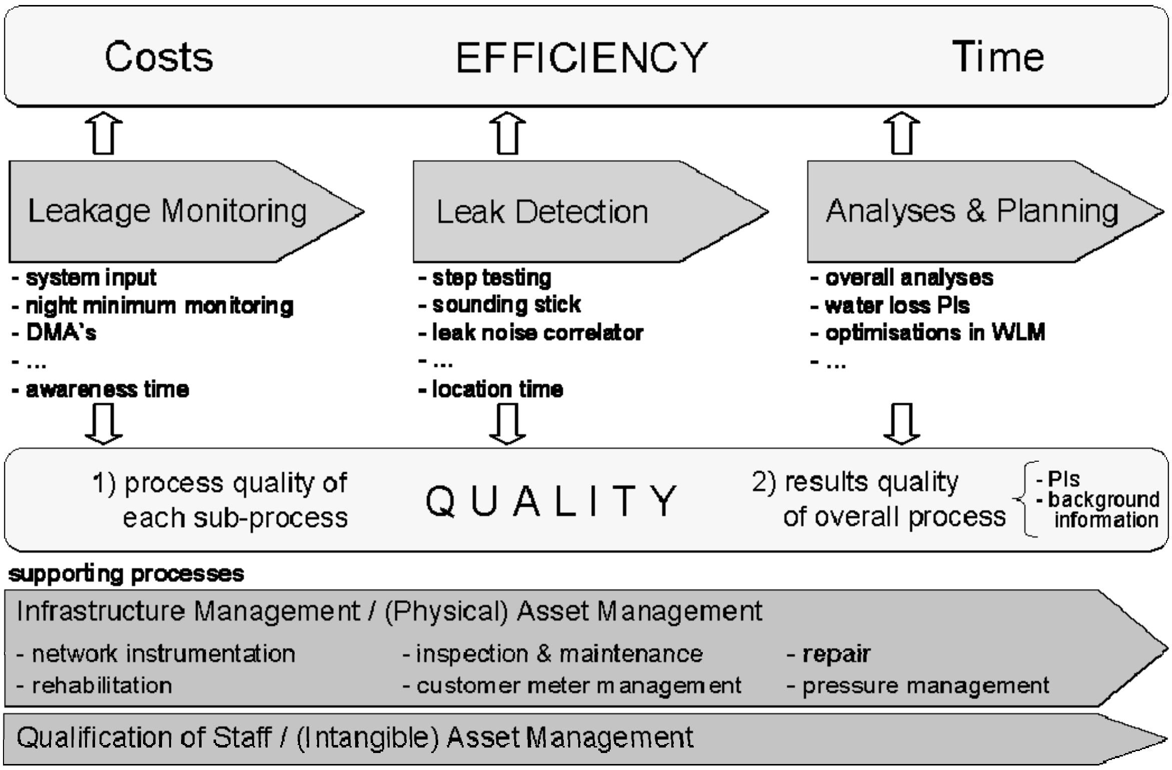


**Figure 33: Adapted process structure for managing physical water losses**

### 5.2.1. Sub processes of physical water loss management

5.2.1.1. Leakage Monitoring

The aim of the leakage monitoring sub process is to become aware of a failure caused increasing of the system input and / or recognising the exceeding of quantitative thresholds (flow, pressure, noise) and receiving the first information "where" the leakage is located (e.g. which district).

The following technologies are part of this sub process:

- flow measurements of system input (e.g. at wells, springs or storage tanks)
- zonal flow measurements (flow meters of DMAs)
- pressure measurements
- noise loggers (permanently installed in the network)
- combined (mulitparameter) measurements of flow, pressure and noise

Other aspects of this sub process are process control systems (SCADA) and their functionality for the purposes of water loss management and software tools for leakage monitoring. Figure 34 shows the input and output criteria and quality criteria for the input and output of this sub process.

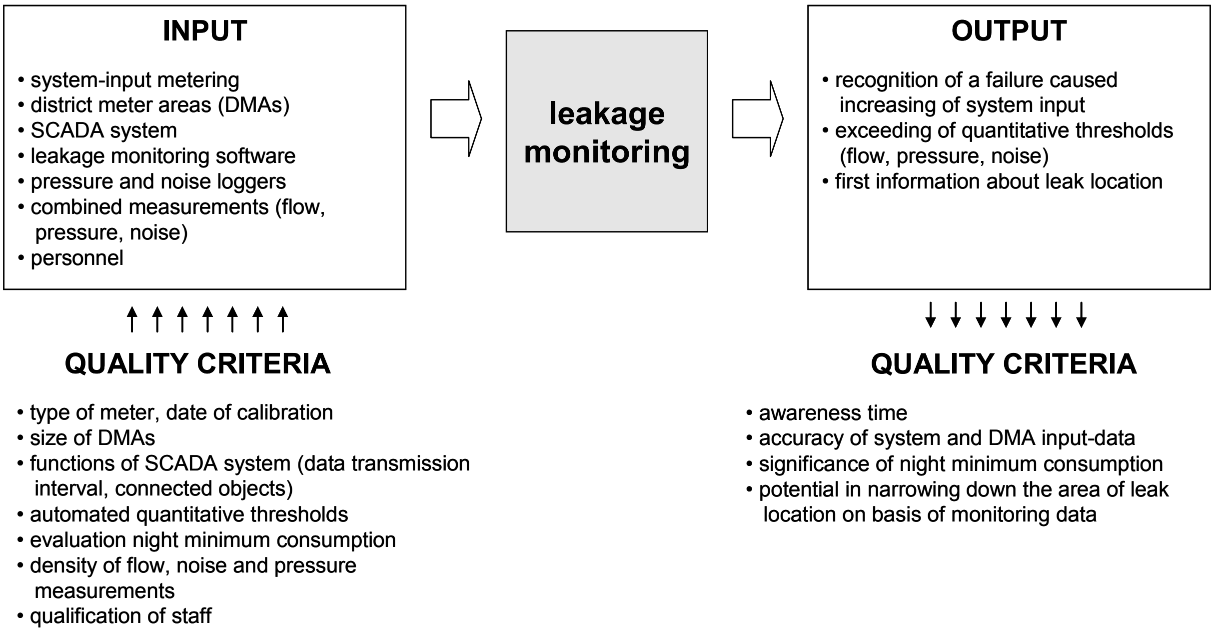


**Figure 34: Leakage monitoring sub process**

### 5.2.1.2. Leak detection

The aim of the sub process leak detection is the localisation of failures (leakage) in the supply network. The sub process starts due to advance information from the sub process leakage monitoring (caused based leak detection strategy) or is undertaken in routine leak detection campaigns on a rotational basis (e.g. once a year or larger intervals). The sub process results in the localisation of failures (leakages) and, if possible, information about the condition of pipes should also be generated (e.g. number of failures or the volume of water lost on a pipe section). This information can support the decision to repair or rehabilitate the affected pipe section (Figure 35).

Various leak detection methodologies belong to this sub process:

- step testing
- sounding surveys
    - sounding stick
    - ground microphone

- leak noise correlator
- noise loggers (temporarily installed)

- gas injection

Often smaller water utilities do not have personnel resources and adequate leak detection equipment. Therefore this sub process, or parts of it, is often outsourced to external specialists.

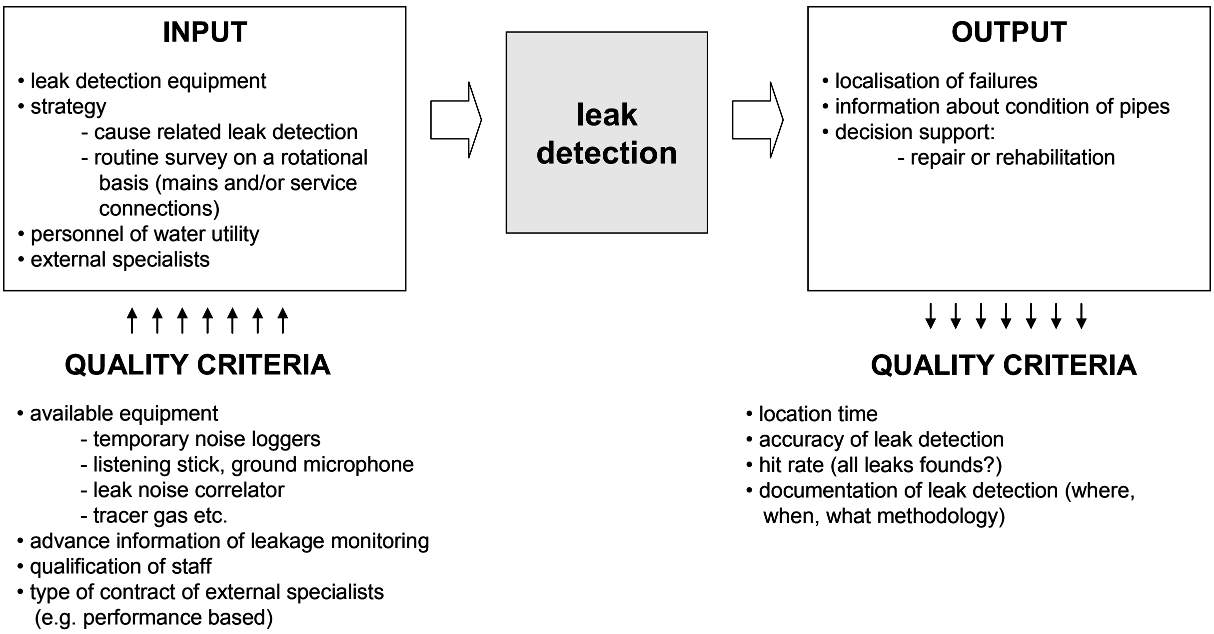


**Figure 35: Leak detection sub process**

### 5.2.1.3. Analyses & Planning

The aim of the analyses and planning sub process is to analyse the whole process of physical water loss management regarding efficiency and effectiveness at regular intervals, and to also define measures for improvement in infrastructure (e.g., metering systems, DMAs) as well as in process operation (e.g., staff education programmes, optimisation of operating instructions) (Figure 36). But the calculation of performance indicators, failure statistics and analyses and preparation of data for supporting processes (e.g. rehabilitation planning) are also part of this sub process.

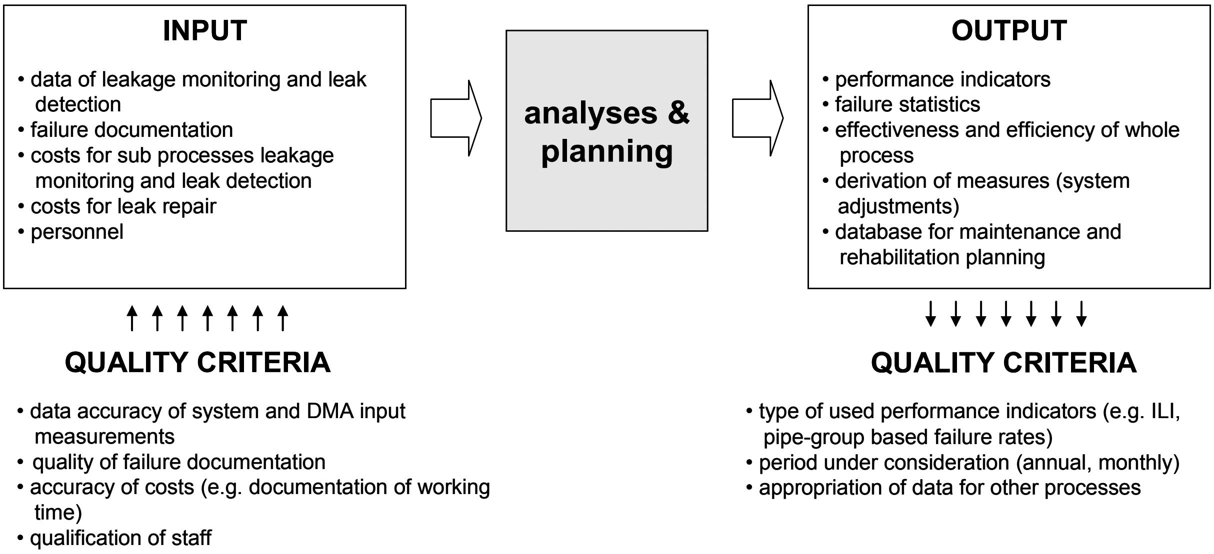


**Figure 36: Analyses & planning sub process**

### 5.2.2. Supporting Processes

Beside the three sub processes, the two supporting processes of infrastructure management (e.g. repair, inspection and maintenance, rehabilitation, pressure management or customer meter management) and qualification of staff are also very important for the process of physical water loss management.

#### 5.2.2.1. Infrastructure Management (Physical Asset Management)

Infrastructure management covers various tasks which directly or indirectly influence the amount of water losses. Beside a water supply utility's technical equipment, the rehabilitation management (including analyses of failure statistics based on pipe groups), the management of maintenance (fittings, pumps, flow meters, valves etc.) and also the customer meter management (average age of customer meters, methodology of meter reading etc.), hydraulic modelling of the supply system and the repair of failures are part of this supporting process. In general, infrastructure management covers long-term measures and many of them can not be influenced over short time periods.

##### *5.2.2.1.1. Leak Repair*

Because of its importance for the overall process of physical water loss management and the former status as a sub process, the supporting process of leak repair is briefly described.

Faults are repaired, the operating function of the affected pipe sections is re-established and water losses should be reduced within the supporting process of leak repair (Figure 37). The supporting process of leak repair starts after the localisation of failures and contains all the working steps of the leak repair. Another important aspect of leak repair is the failure documentation which gives:

- information about the condition of pipes
- a decision support for rehabilitation planning (repair or replace)
- and is the basis for the adaptation of the inspection and maintenance strategy

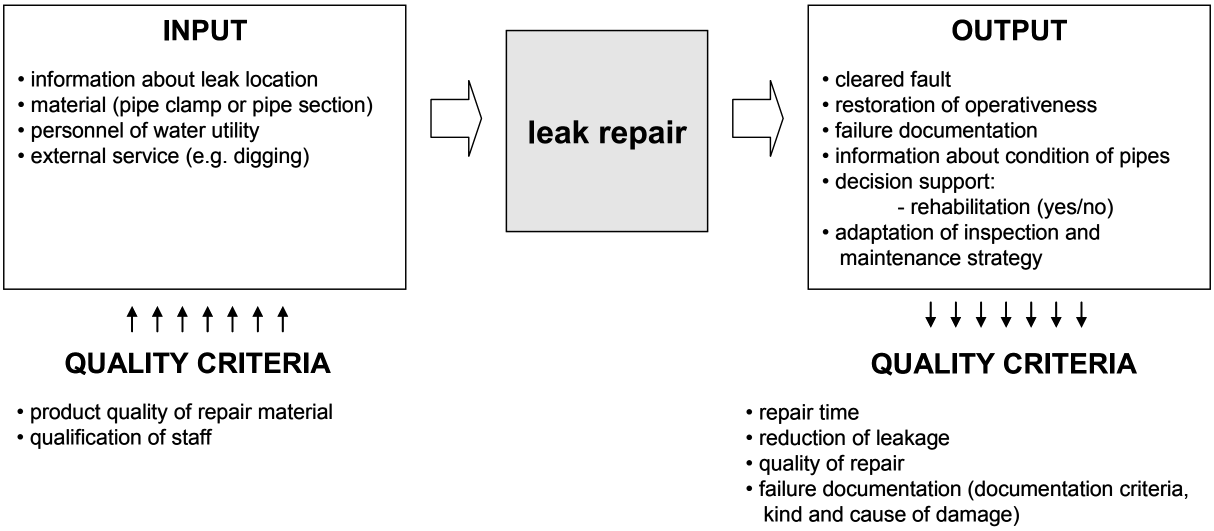


**Figure 37: Leak repair supporting process**

#### 5.2.2.2. Qualification of staff (Intangible Asset Management)

A well qualified staff is important for almost all the duties of water supply utilities. But for the process of physical water loss management these intangible assets are of especially great relevance. High technological leak detection equipment requires know-how and experience. Because this process covers so many aspects of many different fields of duties it is necessary to train the staff to think in "terms of water loss management", meaning keeping their eyes open and building up integrative understanding of the complexity of water supply systems, especially of pipe networks.

## 5.3. *Data collection system*

The data collection system developed consists of five parts (Table 21):

- contact details
- basis data
- water supply system data
- water balance data
- process specific data

There are three different types of collected data:

- variables
- supporting information and
- context information

Variables are data used for the calculation of performance indicators whereas context information is generally used for the evaluation of the process quality within the quality matrix and as background information for data interpretation.

Some variables are aggregated data which are calculated of the supporting data gathering tables, e.g. within the water balance or basis data.

All the elements of the data collection system (except supporting data) are indicated by a code. If the definitions of data elements are the same as those in the IWA-PI system (ALEGRE et al. 2006) the IWA-codes are also described within squared brackets in the tables of the appendix, where the whole data collection system is described in detail.

**Table 21: Structure of data collection system**

| data element | variables | supporting information | context information | total |
|---|---|---|---|---|
| contact data | - | - | 20 | 20 |
| basis data | - | ≥ 3 | 7 | ≥10 |
| water supply system data | 21 | - | - | 21 |
| water balance data | 22 | ≥ 53 | 2 | ≥ 77 |
| process specific data | 85 | - | 168 | 253 |
| **total** | **128** | **≥ 56** | **197** | **≥ 381** |

### 5.3.1. Data accuracy

Knowledge about data accuracy is essential for all types of performance comparisons. Therefore this process benchmarking system also includes data accuracy and reliability. There are two different kinds of indication of data accuracy and reliability:

- direct indication of the error margin as percentages of the input value
- indirect indication using the indicators A to D
  - A: very reliable data, error margin ± < 5 %
  - B: reliable data, error margin ± 5 to 25 %
  - C: unreliable data, error margin ± 25 to 100 %
  - D: very unreliable data, error margin ± > 100 %

Direct indications of error margins are used, for example, for water balance data and for some water supply system data like distribution mains length or the average service connection length.

### 5.3.2. Contact details

Beside the company's name, address and fax number the contact data (first and second name, title, sex, telephone number, email address) of the responsible person for the process benchmarking within the company and of a representative are also collected (Table 49 in appendix).

### 5.3.3. Basis data

Basis data include background information about a given water supply utility and supporting information about hourly rates of employees. This is used for the calculation of personnel costs for each sub process by multiplying the working time for a sub process of each employee or each employee group with the hourly rates (Table 50 and Table 51 in appendix).

### 5.3.4. Water supply system data

Water supply system data include variables about the structure (mains length, number of service connections, service pressure) and the instrumentation (number of DMAs, metering systems, pressure and noise loggers and pressure reduction valves) of the water supply system (Table 52 in appendix).

The data accuracy is specified with the indirect indication A to D for all water supply system data except for the “average service pressure head”, “distribution mains length” and “average service connection length” variables which are indicated directly (with possible error margins in percentages).

### 5.3.5. Water balance data

All the water balance data are variables or supporting data for the calculation of aggregated variables (Table 53 to Table 63 in appendix) except for two single data of context information. The water balance data collection system is designed along a flow chart from water abstraction to water treatment to water consumption and water losses like those described in LAMBERT & HIRNER (2000).

It is possible to give detailed answers for each single relevant point of the supply system for almost all water balance data (e.g. for abstracted water it is possible to describe each single well and each natural spring) which are generated to summarised variables.

The total amount of abstracted water is generated by summing up all single data and the data accuracy for the total amount of abstracted water is calculated by weighted data (according to abstracted volumes) from single data sets.

The data accuracy for all water balance data is indicated directly by error margins in percentages. The assessment period for water balance data is one year.

### 5.3.6. Process specific data

Process specific data include variables and context information for the three sub processes of leakage monitoring, leak detection and analyses and planning and for the supporting processes of infrastructure management and qualification of staff.

A data collection matrix for cost and working time data for each of the sub processes is used to evaluate the (sub-) process efficiencies (Table 22). Three years of summarised data are collected for this purpose, to avoid pure comparability due to annual variations in process operation.

The working hours are given for each single employee or each group of employees (e.g., engineers, plumbers). Together with basis data about the hourly rate of Table 51 (in appendix), the personal costs of the utility’s internal personal is calculated. Other running costs and material costs are declared in an extra field. If it is not possible to gather information about the working hours in an alternative field the summarised personal costs can be given. However, then a comparison of working hours is not possible.

Beside the internal costs of a utility, outsourcing costs also have to be considered. Therefore costs of outsourcing in-house and external outsourcing are collected. If it is possible, working hours should be given but personal costs and material costs should be differentiated for these two types of costs.

The sum of these single cost types (internal, outsourcing in-house, outsourcing externally) gives the total running costs for a sub process. The working times are also summarised for the sub process. Beside the data itself, the reliability and accuracy of the data also needs to be specified.

**Table 22: Data collection matrix for running costs and working time of sub processes**

| | **name or group of employees** | **working time [hh:mm] e.g.: 18:35** | **personal costs utility intern** (alternative, if working-time based calculation of personal costs is not possible) | **costs for outsourcing in-house** (apportionment of personal and material costs) | | **costs for outsourcing extern** (personal and material costs) | |
|---|---|---|---|---|---|---|---|
| **running costs and working time of sub process**<br><br>sum of last 3 years (e.g. 2004, 2005 und 2006) | engineer | 150:00 | | 4.000,00 | | 0,00 | |
| | technician | 420:00 | | | | | |
| | | | | | | | |
| | | | | | | | |
| | | | | working time: | 100:00 | working time: | 00:00 |
| | sum working time utility intern | 570:00 | | | | | |
| | sum personal costs utility intern | 28.500,00 | | personal costs: | 4.000,00 | personal costs: | 0,00 |
| | **other running costs and material costs utility intern [Euro]** | | 2.500,00 | material costs: | 0,00 | material costs: | 0,00 |
| | **total working time of sub-process [hh:mm]** | | **670:00** | | | | |
| | **total running costs of sub-process [Euro]** | | **35.000,00** | | | | |
| | **reliability and accuracy** of these data | | A | | | | |

#### 5.3.6.1. Data of sub process leakage monitoring

According to the data collection matrix described in Table 22, the variables for the sub process leakage monitoring are listed in Table 64 (in appendix). In addition to these variables, many data for background information and for quality assessment are collected (Table 65 in appendix).

Investment costs for leakage monitoring equipment (e.g. flow meters, SCADA system) are not considered for efficiency evaluation in the 2007 OVGW process benchmarking system. The reason is that almost all the participants in the benchmarking working group were of the opinion that the definition of these costs is not clear enough because almost all of the leakage monitoring equipment is also used for other purposes like process control. Further, data gathering can be difficult because these systems were often installed together with other measures. However, experiences within the field test showed that there is a need to consider investment costs of monitoring systems for reasons of comparability. Therefore the two variables v114 and v115 in Table 64 (in appendix) are used to calculate depreciation costs for an assumed depreciation period of 10 years, which are added to the total costs of sub process leakage monitoring (v101).

Another aspect which is not considered in the 2007 OVGW process benchmarking system is the methodology of multiparameter measurements described in chapter 4.5.2. Therefore an additional question as context information was implemented (ci107 in Table 65, in appendix).

#### 5.3.6.2. Data of sub process leak detection

Data gathering for running costs and working hours also follows the scheme described in Table 22. The variables for costs and working time are described in Table 66 (in appendix). Table 67 (in appendix) contains information about the current leak detection equipment and the investment cost for this equipment. On the basis of the original investment costs, depreciation costs for an assumed depreciation period of 10 years are calculated, which are added to the total costs for these sub process.

Table 68 and Table 69 (in appendix) give an overview of the variables for assessment of leak detection measures and detected failures in the assessment period.

Possible answers to context information data (Table 70 in appendix) with code ci201 to ci205 are described in detail in chapter 5.5.

#### 5.3.6.3. Data of sub process analyses and planning

Data of working hours and sub process costs are collected as for the other sub processes (Table 71 in appendix). There are no further cost data in this sub process except for some context information for process quality assessment, like questions about time intervals in which various analyses are operated or about which performance indicators are calculated for internal purposes or for publication, e.g. in annual reports (Table 72 and Table 73 in appendix).

#### 5.3.6.4. Data of supporting process infrastructure management

As mentioned before, no economic performance indicators are calculated for supporting processes but various kinds of context information is considered in the quality matrix, and a quality index for the supporting process is calculated.

Beside context information about network inspection, hydraulic modelling, pressure management, rehabilitation and customer meter management (Table 74 in appendix) activities in leak repair are also considered within this supporting process.

*5.3.6.4.1. Data of supporting process leak repair*

For the leak repair supporting process, which is part of the infrastructure management supporting process, the following data are gathered (Table 75 to Table 79 in appendix):

- variables about number of repairs and about repair costs
- context information about repair time and information for planning
- context information about failure documentation
- context information about type of failures and
- context information about cause of failures.

5.3.6.5. Data of supporting process qualification of staff

The last part of process specific data is some context information about the water supply utilities' employees' qualifications (Table 80 in appendix).

## 5.4. *Process performance indicators*

Chapter 5.3 described the subsystem for data collection (variables, context information). As with the subsystem for data collection, the subsystem for data evaluation (performance indicators, quality matrix) is also based on the process structure. Figure 38 gives an overview of the number of variables, context information and the calculated performance indicators.

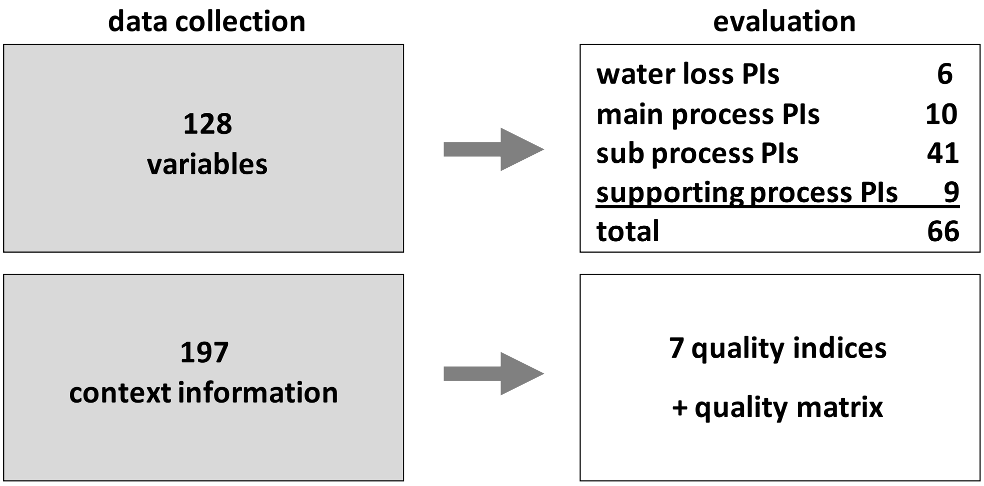


**Figure 38: Process performance indicator system**

The whole system of performance indicators for the process of physical water loss management consists of 66 PIs and 7 quality indices. Figure 39 shows the structure of performance indicators for the process of physical water loss management and gives an overview about the performance indicators calculated for the single sub- and supporting processes and for the main process (overall process).

| Category | Sub-category | Indicators | Indicators (continued) |
|---|---|---|---|
| 6 water loss PIs | | • water loss ratio<br>• real losses per connection per day<br>• real losses per connection per day per meter service pressure head<br>• real losses per km per hour<br>• ILI<br>• non-revenue water | |
| 10 main process PIs & 1 quality index | | • total process costs per km mains<br>• total process costs per 100 service conn.<br>• utility internal costs per km mains<br>• utility internal costs per 100 service conn.<br>• outsourcing in-house costs per km mains<br>• outsourcing in-house costs per 100 s. conn. | • outsourcing extern costs per km mains<br>• outsourcing extern costs per 100 s. conn.<br>• total working time per km mains<br>• total working time per 100 service conn.<br>• **quality index main process** |
| 41 sub process PIs & 3 quality indices | sub process leakage monitoring 10 PIs & 1 quality index | • sub-process costs per km mains<br>• sub-process costs per 100 service conn.<br>• utility internal costs per km mains<br>• utility internal costs per 100 service conn.<br>• outsourcing in-house costs per km mains<br>• outsourcing in-house costs per 100 s. conn.<br>• outsourcing extern costs per km mains | •outsourcing extern costs per 100 s. conn.<br>• working time per km mains<br>• working time per 100 service conn.<br>• **quality index leakage monitoring** |
| | sub process leak detection 21 PIs & 1 quality index | • sub-process costs per km mains<br>• sub-process costs per 100 service conn.<br>• utility internal costs per km mains<br>• utility internal costs per 100 service conn.<br>• outsourcing in-house costs per km mains<br>• outsourcing in-house costs per 100 s. conn.<br>• outsourcing extern costs per km mains<br>• outsourcing extern costs per 100 s. conn.<br>• working time per km mains<br>• working time per 100 service conn.<br>• proportion of transportation mains annually inspected by leak detection methodologies<br>• proportion of distribution mains annually inspected by leak detection methodologies<br>• proportion of service connections annually inspected by leak detection methodologies | • <u>cause based leak detection:</u><br>• localised leaks at transmission mains<br>• localised leaks at distribution mains<br>• localised leaks at service connections<br>• portion of costs for cause based leak detection<br><u>routine survey:</u><br>• localised leaks at transmission mains<br>• localised leaks at distribution mains<br>• localised leaks at service connections<br>• portion of costs for routine surveys<br>• **quality index leak detection** |
| | sub process analyses & planning 10 PIs & 1 quality index | • sub-process costs per km mains<br>• sub-process costs per 100 service conn.<br>• utility internal costs per km mains<br>• utility internal costs per 100 service conn.<br>• outsourcing in-house costs per km mains<br>• outsourcing in-house costs per 100 s. conn.<br>• outsourcing extern costs per km mains<br>• outsourcing extern costs per 100 s. conn. | • working time per km mains<br>• working time per 100 service conn.<br>• **quality index analyses & planning** |
| supporting processes 3 quality indices & 9 sub-PIs | supporting processes 3 quality indices | • **quality index infrastructure management**<br>• **quality index leak repair**<br>• **quality index qualification of staff** | |
| | supporting process leak repair 9 sub-PIs | • average repair costs of pipe failures / fitting failures at transmission mains<br>• average repair costs of pipe failures / fitting failures at distribution mains<br>• average repair costs of pipe failures / fitting failures at service connections<br>• failure rate transmission mains<br>• failure rate distribution mains<br>• failure rate service connections | |

**Figure 39: Structure of performance indicators**

For both the main process and the sub processes, the costs and also the working time are calculated. Outsourcing (in-house and external) of tasks is also considered, and separately visualised.

Except water loss PIs, which are calculated for a single year, all performance indicators are average values for the assessment period of three years.

### 5.4.1. Water loss PIs

Table 23 gives an overview of the water loss PIs (note: abbreviation "WL" stands for Water Loss), which are calculated for the whole water supply system. Because the accuracy is specified in percentages of possible error margins for all water flow data, the accuracy of water loss PIs is also expressed in percentages. The codes used in row "calculation" are the variable codes (see appendix).

A detailed description of all water loss PIs is given in chapter 4.4.

**Table 23: Water loss PIs**

| code | performance indicator | calculation | unit | accuracy |
|---|---|---|---|---|
| WL01 | Water loss ratio | (wb20 * 100) / wb07 | % | ± in % |
| WL02 | Real losses per (total) mains length | Wb20 / (v004 * 8760) | m³/km·h | ± in % |
| WL03 [Op27] | Real losses per connection and day | (wb20 * 1000) / (v005 * 8760) | [l/conn·d] | ± in % |
| WL04 | Real losses per connection and day per metre service pressure | (wb20 * 1000) / (v005 * 8760 * v007) | l/conn·d·m | ± in % |
| WL05 [Op29] | Infrastructure Leakage Index (ILI) | [CARL / UARL] definition see chapter 4.4.5 | [-] | ± in % |
| WL06 [Fi46] | Non-revenue water (NRW) | [(wb21 * 100) / wb07] | [%] | ± in % |

[IWA Code], [IWA definition] and [IWA unit]…according to ALEGRE et al. (2006)

### 5.4.2. Main process PIs

The ten economic main process PIs (M01-M10) are summarised values of the three sub processes of leakage monitoring, leak detection and analyses & planning, which are structured in the same way as the main process PIs (Table 24).

The economic indicators (for the main process and for the sub processes) are structured into the 5 different topics:

- total process (or sub process) cost
- utility internal costs
- outsourcing in-house costs
- outsourcing extern costs
- working time

and each of these PIs is expressed as:

- Euro per kilometre of distribution mains per year (€/km·a) and as
- Euro per service connection per year (€/conn·a).

The data accuracy for economic indicators is expressed in categories A-D.

The quality index of the main process (M11) is a weighted value which is calculated out of the quality indices of the single sub processes and supporting processes. A detailed description of all the quality indices is given in chapter 5.4.6.

**Table 24: Main process PIs**

| code | performance indicator | Calculation | unit | accuracy |
|---|---|---|---|---|
| M01 | total process costs per km distribution mains | (v101 + v201 + v301) / (3 * v019) | €/km·a | A-D |
| M02 | total process costs per 100 service connections | (v101 + v201 + v301) * 100 / (3 * v005) | €/conn·a | A-D |
| M03 | utility internal costs per km distribution mains | (v101 + v201 + v301) / (3 * v019) | €/km·a | A-D |
| M04 | utility internal costs per 100 service connections | (v101 + v201 + v301) * 100 / (3 * v005) | €/conn·a | A-D |
| M05 | outsourcing in-house costs per km distribution mains | (v104 + v105 + v204 + v205 + v304 + v305) / (3 * v019) | €/km·a | A-D |
| M06 | outsourcing in-house costs per 100 service connections | (v104 + v105 + v204 + v205 + v304 + v305) * 100 / (3 * v005) | €/conn·a | A-D |
| M07 | outsourcing extern costs per km distribution mains | (v110 + v210 + v310) / (3 * v019) | €/km·a | A-D |
| M08 | outsourcing extern costs per 100 service connections | (v110 + v210 + v310) * 100 / (3 * v005) | €/conn·a | A-D |
| M09 | total working time per km distribution mains | (v102 + v202 + v302) / (3 * v019) | €/km·a | A-D |
| M10 | total working time per 100 service connections | (v102 + v202 + v302) * 100 / (3 * v005) | €/conn·a | A-D |
| M11 | quality index main process | see chapter 5.4.7.7 | % | - |

### 5.4.3. PIs of leakage monitoring sub process

The PIs of leakage monitoring sub process are in the same structure as the main PIs (Table 25).

**Table 25: PIs of leakage monitoring sub process**

| code | performance indicator | Calculation | unit | accuracy |
|---|---|---|---|---|
| S101 | sub process leakage monitoring costs per km distribution mains | v101 / (3 * v019) | €/km·a | A-D |
| S102 | sub process leakage monitoring costs per 100 service connections | v101 * 100 / (3 * v005) | €/conn·a | A-D |
| S103 | sub process leakage monitoring utility internal costs per km distribution mains | (v104 + v105) / (3 * v019) | €/km·a | A-D |
| S104 | sub process leakage monitoring utility internal costs per 100 service connections | (v104 + v105) * 100 / (3 * v005) | €/conn·a | A-D |
| S105 | sub process leakage monitoring outsourcing in-house costs per km distribution mains | v106 / (3 * v019) | €/km·a | A-D |
| S106 | sub process leakage monitoring outsourcing in-house costs per 100 service connections | v106 * 100 / (3 * v005) | €/conn·a | A-D |
| S107 | sub process leakage monitoring outsourcing extern costs per km distribution mains | v110 / (3 * v019) | €/km·a | A-D |
| S108 | sub process leakage monitoring outsourcing extern costs per 100 service connections | v110 * 100 / (3 * v005) | €/conn·a | A-D |
| S109 | sub process leakage monitoring working time per km distribution mains | v102 / (3 * v019) | €/km·a | A-D |
| S110 | sub process leakage monitoring working time per 100 service connections | v102 * 100 / (3 * v005) | €/conn·a | A-D |
| S111 | quality index leakage monitoring sub process | see chapter 5.4.7.1 | % | - |

### 5.4.4. PIs of leak detection sub process

For the sub process of leak detection, beside the ten economic PIs and the quality index (Table 26), technical PIs about the leak detection activities (Table 27) and localised leaks at transmission, distribution mains and at service connections (Table 28) in the assessment period are also calculated.

**Table 26: Economic PIs and quality index of leak detection sub process**

| code | performance indicator | Calculation | unit | accuracy |
|---|---|---|---|---|
| S201 | sub process leak detection costs per km distribution mains | v201 / (3 * v019) | €/km·a | A-D |
| S202 | sub process leak detection costs per 100 service connections | v201 * 100 / (3 * v005) | €/conn·a | A-D |
| S203 | sub process leak detection utility internal costs per km distribution mains | (v204 + v205) / (3 * v019) | €/km·a | A-D |
| S204 | sub process leak detection utility internal costs per 100 service connections | (v204 + v205) * 100 / (3 * v005) | €/conn·a | A-D |
| S205 | sub process leak detection outsourcing in-house costs per km distribution mains | v206 / (3 * v019) | €/km·a | A-D |
| S206 | sub process leak detection outsourcing in-house costs per 100 service connections | v206 * 100 / (3 * v005) | €/conn·a | A-D |
| S207 | sub process leak detection outsourcing extern costs per km distribution mains | v210 / (3 * v019) | €/km·a | A-D |
| S208 | sub process leak detection outsourcing extern costs per 100 service connections | v210 * 100 / (3 * v005) | €/conn·a | A-D |
| S209 | sub process leak detection working time per km distribution mains | v202 / (3 * v019) | €/km·a | A-D |
| S210 | sub process leak detection working time per 100 service connections | v202 * 100 / (3 * v005) | €/conn·a | A-D |
| S211 | quality index leak detection sub process | see chapter 5.4.7.2 | % | - |

**Table 27: Leak detection activities in assessment period**

| code | performance indicator | calculation | unit | accuracy |
|---|---|---|---|---|
| S212 | proportion of transmission mains annually inspected by leak detection methodologies | (v234a + v234b) * 100 / (3 * v018) | % | A-D |
| S213 | proportion of distribution mains annually inspected by leak detection methodologies | (v234c + v234d) * 100 / (3 * v019) | % | A-D |
| S214 | proportion of service connections annually inspected by leak detection methodologies | (v237 + v237a) * 100 / (3 * v005) | % | A-D |
| S215 | portion of costs for routine surveys | v235 * 100 / v201 | % | A-D |
| S216 | portion of costs for cause based leak detection | v236 * 100 / v201 | % | A-D |

**Table 28: Localised leaks in relation to the inspected pipe length rather number of inspected service connections**

| code | performance indicator | calculation | Unit | accuracy |
|---|---|---|---|---|
| S217 | localised leaks at transmission mains by routine surveys | v239 * 100 / (3 * v234a) | No./100 km·a | A-D |
| S218 | localised leaks at transmission mains by cause based leak detection | v240 * 100 / (3 * v234b) | No./100 km·a | A-D |
| S219 | localised leaks at distribution mains by routine surveys | v242 * 100 / (3 * v234c) | No./100 km·a | A-D |
| S220 | localised leaks at distribution mains by cause based leak detection | v243 * 100 / (3 * v234d) | No./100 km·a | A-D |
| S221 | localised leaks at service connections by routine surveys | v245 * 1000 / (3 * v237) | No./1000 conn·a | A-D |
| S222 | localised leaks at service connections by cause based leak detection | v246 * 1000 / (3 * v237a) | No./1000 conn·a | A-D |

### 5.4.5. PIs of analyses & planning sub process

Ten economic PIs and a quality index are calculated for this sub process (Table 29).

**Table 29: PIs of analyses & planning sub process**

| code | performance indicator | definition/calculation | unit | accuracy |
|---|---|---|---|---|
| S301 | sub process analyses & planning costs per km distribution mains | v301 / (3 * v019) | €/km·a | A-D |
| S302 | sub process analyses & planning costs per 100 service connections | v301 * 100 / (3 * v005) | €/conn·a | A-D |
| S303 | sub process analyses & planning utility internal costs per km distribution mains | (v304 + v305) / (3 * v019) | €/km·a | A-D |
| S304 | sub process analyses & planning utility internal costs per 100 service connections | (v304 + v305) * 100 / (3 * v005) | €/conn·a | A-D |
| S305 | sub process analyses & planning outsourcing in-house costs per km distribution mains | v306 / (3 * v019) | €/km·a | A-D |
| S306 | sub process analyses & planning outsourcing in-house costs per 100 service connections | v306 * 100 / (3 * v005) | €/conn·a | A-D |
| S307 | sub process analyses & planning outsourcing extern costs per km distribution mains | v310 / (3 * v019) | €/km·a | A-D |
| S308 | sub process analyses & planning outsourcing extern costs per 100 service connections | v310 * 100 / (3 * v005) | €/conn·a | A-D |
| S309 | sub process analyses & planning working time per km distribution mains | v302 / (3 * v019) | €/km·a | A-D |
| S310 | sub process analyses & planning working time per 100 service connections | v302 * 100 / (3 * v005) | €/conn·a | A-D |
| S311 | quality index analyses & planning sub process | see chapter 5.4.7.3 | % | - |

## 5.4.6. Sub-PIs of leak repair supporting process

Six performance indicators about average repair costs and three indicators about average failure rates of the three year assessment period are calculated for the leak repair supporting process (Table 30).

**Table 30: PIs of leak repair supporting process**

| code | performance indicator | definition/calculation | Unit | accuracy |
|---|---|---|---|---|
| R101 | average repair costs of pipe failures at transmission mains | v507 / v501 | € | A-D |
| R102 | average repair costs of pipe failures at distribution mains | v508 / v502 | € | A-D |
| R103 | average repair costs of pipe failures at service connections | v509 / v503 | € | A-D |
| R104 | average repair costs of fitting failures at transmission mains | v510 / v504 | € | A-D |
| R105 | average repair costs of fitting failures at distribution mains | v511 / v505 | € | A-D |
| R106 | average repair costs of fitting failures at service connections | v512 / v506 | € | A-D |
| R107 | failure rate transmission mains | v501 / (3 * v018) | No./100 km·a | A-D |
| R108 | failure rate distribution mains | v502 * / (3 * v019) | No./100 km·a | A-D |
| R109 | failure rate service connections | v503 / (3 * v005) | No./1000 conn·a | A-D |

## 5.4.7. Quality indices

The aim of quality indices (QI) is to quantify the quality in process operation. Therefore many individual questions are asked for each sub and supporting process (see chapter 5.3.6 and chapter 5.5). Most of these questions allow five possible answers (from low to high performance). Beside quality indices for sub and supporting processes, a quality index for the main process (chapter 5.4.7.7) is also calculated.

The systematic for the calculation of the quality indices for the leakage monitoring sub process is described in chapter 5.4.7.1.

### 5.4.7.1. QI of leakage monitoring sub process

Table 31 shows the quality index for the sub process of leakage monitoring. The calculation of the quality indices is discussed in the following section on the basis of this example.

**Table 31: Quality index of leakage monitoring sub process**

| A | B | C | D | E | F | G | H |
|---|---|---|---|---|---|---|---|
| sub or supporting process | Code | Criteria | maximum points for single criteria | weighting within sub or supporting process | max. points of sub or supporting process | reached points | quality index of sub or supporting process |
| leakage monitoring S111 | 1.1 | system input metering | 4 | 5 | 296 Σ (D * E) | No. of points (points of single critera * weighting) | G / F * 100 |
| | 1.2 | district metered areas (DMA) | 4 | 5 | | | |
| | 1.3 | evaluation of night minimum consumption | 4 | 5 | | | |
| | 1.4 | SCADA system | 4 | 2 | | | |
| | 1.4.1 | functions of SCADA system | 4 | 1 | | | |
| | 1.4.1.1 | data transmission interval system input data | 4 | 1 | | | |
| | 1.4.1.2 | data transmission interval DMA input data | 4 | 1 | | | |
| | 1.4.1.3 | data transmission interval pressure data | 4 | 1 | | | |
| | 1.4.1.4 | data transmission interval reservoir level | 4 | 1 | | | |
| | 1.4.1.5 | data transmission interval pumping station data | 4 | 1 | | | |
| | 1.4.2 | automated evaluation of night minimum consumption | 4 | 1 | | | |
| | 1.4.3 | automated alarm when tresholds exceeded | 4 | 1 | | | |
| | 1.5 | pressure monitoring | 4 | 5 | | | |
| | 1.6 | permanent noise loggers | 4 | 5 | | | |
| | 1.7 | virtual measuring zones | 4 | 5 | | | |
| | 1.8 | recognition of leakage | 4 | 5 | | | |
| | 1.9 | first information about leak location | 4 | 5 | | | |
| | 1.10 | accuracy of system input metering | 4 | 5 | | | |
| | 1.11 | max. zone size (according mains length) | 4 | 2 | | | |
| | 1.12 | max. zone size (according No. of service connections) | 4 | 5 | | | |
| | 1.13 | average zone size (weighted onto No. of service connections) | 4 | 5 | | | |
| | 1.14 | average zone size (weighted onto mains length) | 4 | 2 | | | |
| | 1.15 | portion of DMA of whole supply system (according mains length) | 4 | 5 | | | |

A maximum of 4 points can be attained for each single criterion (column D). These points are weighted (column E), which leads to a maximum number of points for the whole sub or supporting process by multiplying the points of D with the weighting of E and summing up all these values. In the example of sub process leakage monitoring a maximal number of 296 points can be reached (column F). The quality index for this sub process (column H) is calculated by dividing the points reached (column G) by the maximum possible number of points (column F).

Practices in system metering, functions of SCADA systems, practises in pressure and noise logging and the size of measuring zones are especially relevant criteria for the quality of sub process leakage monitoring. On the basis of these criteria it should be possible to determine how well the supply system can be monitored regarding leakage.

### 5.4.7.2. QI of leak detection sub process

The quality of the leak detection sub process is characterised by the general procedure in leak detection, which means which leak detection strategy is used (routine surveys in different intervals, cause based leak detection). Other quality aspects are the leak location time (time from being aware there is a leak to leak location), the hit rate which expresses if leaks are found, (meaning how successful the leak detection is), or the accuracy in pinpointing leaks as a measure of how accurately leaks can be located (Table 32).

**Table 32: Quality index of leak detection sub process**

| A | B | C | D | E | F | G | H |
|---|---|---|---|---|---|---|---|
| sub or supporting process | Code | Criteria | maximum points for single criteria | weighting within sub or supporting process | max. points of sub or supporting process | reached points | quality index of sub or supporting process |
| leak detection<br>S211 | 2.1 | general procedure in leak detection (strategy) | 4 | 2 | 48<br>Σ (D * E) | No. of points<br>(points of single critera * weighting) | G / F * 100 |
| | 2.2 | leak location time | 4 | 2 | | | |
| | 2.3 | hit rate (success in leak detection) | 4 | 1 | | | |
| | 2.4 | accuracy in pinpointing leaks | 4 | 1 | | | |
| | 2.5 | documentation of leak detection | 4 | 2 | | | |
| | 2.6 | existing leak detection equipment | 4 | 2 | | | |
| | 2.7 | routine leak detection at service connections | 4 | 2 | | | |

Another aspect is the documentation of leak detection measures. The success achievable in detecting leaks also depends on the available leak detection equipment. An often discussed aspect is the efficiency and effectiveness of routine leak detection surveys at service connections, e.g. together with meter replacement or meter reading activities.

### 5.4.7.3. QI of analyses & planning sub process

The general procedure in analyses and planning takes into account if such analyses are done and what aspects are considered. The procedures in calculating water balances and water loss performance indicators give information about the general frequency of calculation and about the type of water balance (IWA water balance or other) and the different water loss PIs (Table 33). In addition to this general information, a series of detailed questions is considered in the calculation of the quality index for this sub process, e.g., the time interval different aspects are analysed or what kind of PIs are calculated for internal purposes and which PIs are published in annual reports.

Also the accuracy of information about unbilled consumption, apparent loss data and the question of returned water are quality criteria for this sub process because these criteria indicate how well a water supply system is planned and analysed.

**Table 33: Quality index of analyses & planning sub process**

| A | B | C | | D | E | F | G | H |
|---|---|---|---|---|---|---|---|---|
| sub or supporting process | Code | Criteria | | maximum points for single criteria | weighting within sub or supporting process | max. points of sub or supporting process | reached points | quality index of sub or supporting process |
| analyses & planning<br>S311 | 3.1 | general procedure in analyses and planning | | 4 | 5 | 168<br>Σ (D * E) | No. of points<br>(points of single critera * weighting) | G / F * 100 |
| | 3.2 | general procedure in calculating a water balance | | 4 | 3 | | | |
| | 3.3 | general procedure in calculating water loss PIs | | 4 | 5 | | | |
| | 3.4.1 | time interval in which different criteria are analysed or planned | calculation of water loss PIs for whole supply system | 4 | 1 | | | |
| | 3.4.2 | | calculation of water loss PIs for single DMAs | 4 | 1 | | | |
| | 3.4.3 | | analyses to trends in night minimum consumption of single zones | 4 | 1 | | | |
| | 3.4.4 | | investigations if existing measuring systems (flow, pressure etc.) and SCADA systems are sufficient | 4 | 1 | | | |
| | 3.4.5 | | internal analyses of costs (efficiency) and success (affectivity) of water loss management | 4 | 1 | | | |
| | 3.4.6 | | derivation of measures for improvement of process operation (e.g. working instructions) | 4 | 1 | | | |
| | 3.4.7 | | generation of failure statistics for whole supply system without analyses of single pipe-groups | 4 | 1 | | | |
| | 3.4.8 | | generation of failure statistics for single DMAs without analyses of single pipe-groups | 4 | 1 | | | |
| | 3.4.9 | | generation of failure statistics for whole supply system with analyses of single pipe-groups | 4 | 1 | | | |
| | 3.4.10 | | generation of failure statistics for single DMAs with analyses of single pipe-groups | 4 | 1 | | | |
| | 3.4.11 | | derivation of measures for improvement in maintenance (e.g. for critical pipe groups) | 4 | 1 | | | |
| | 3.4.12 | | provision of pipe-group based failure statistics for rehabilitation planning | 4 | 1 | | | |
| | 3.5.1 | PIs calculated for internal purposes | water loss ratio (%) | 1 | 6 | | | |
| | 3.5.2 | | real losses per connection per day | 1 | 6 | | | |
| | 3.5.3 | | real losses per connection per day per metre pressure | 1 | 6 | | | |
| | 3.5.4 | | real losses per mains length | 1 | 6 | | | |
| | 3.5.5 | | ILI | 1 | 6 | | | |
| | 3.5.6 | | Non-revenue water (NRW) (%) | 1 | 6 | | | |
| | 3.6.1 | PIs published in annual report (e.g. for stake-holders) | water loss ratio (%) | 1 | 2 | | | |
| | 3.6.2 | | real losses per connection per day | 1 | 2 | | | |
| | 3.6.3 | | real losses per connection per day per metre pressure | 1 | 2 | | | |
| | 3.6.4 | | real losses per mains length | 1 | 2 | | | |
| | 3.6.5 | | ILI | 1 | 2 | | | |
| | 3.6.6 | | Non-revenue water (NRW) (%) | 1 | 2 | | | |
| | 3.7 | accuracy of unbilled consumption | | 4 | 2 | | | |
| | 3.8 | accuracy of apparent losses | | 4 | 2 | | | |
| | 3.9 | Are overflows of springs returned directly at the spring collection shaft or at other points within the transport or distribution system (e.g. returned water at reservoirs or drinking water power stations)? | | 4 | 1 | | | |

### 5.4.7.4. QI of infrastructure management supporting process

Quality criteria for the infrastructure management supporting process are aspects of mapping (existing maps of supply system and GIS) and network inspection (inspection intervals of different fittings and hydrants and calibration intervals of system input and DMA input meters). Aspects of hydraulic modelling, pressure management, rehabilitation planning (general procedure and rehabilitation criteria) and aspects of customer meter management are also considered within this quality index (Table 34).

**Table 34: Quality index of infrastructure management supporting process**

<table>
<tr><th>A</th><th>B</th><th colspan="2">C</th><th>D</th><th>E</th><th>F</th><th>G</th><th>H</th></tr>
<tr><th>sub or supporting process</th><th>Code</th><th colspan="2">Criteria</th><th>maximum points for single criteria</th><th>weighting within sub or supporting process</th><th>max. points of sub or supporting process</th><th>reached points</th><th>quality index of sub or supporting process</th></tr>
<tr><td rowspan="21">infrastructure management<br><br>H001</td><td>4.1</td><td colspan="2">mapping / GIS</td><td>4</td><td>5</td><td rowspan="21">120<br><br>Σ (D * E)</td><td rowspan="21">No. of points<br><br>(points of single critera * weighting)</td><td rowspan="21">G / F * 100</td></tr>
<tr><td>4.2.1</td><td colspan="2">inspection interval closing valves</td><td>4</td><td>1</td></tr>
<tr><td>4.2.2</td><td colspan="2">inspection interval hydrants</td><td>4</td><td>1</td></tr>
<tr><td>4.2.3</td><td colspan="2">inspection interval pressure reduction valves</td><td>4</td><td>1</td></tr>
<tr><td>4.2.4</td><td colspan="2">calibration interval system input meters</td><td>4</td><td>1</td></tr>
<tr><td>4.2.5</td><td colspan="2">calibration interval DMA meters</td><td>4</td><td>1</td></tr>
<tr><td>4.3</td><td colspan="2">accomplishment of hydraulic modelling</td><td>4</td><td>2</td></tr>
<tr><td>4.4</td><td colspan="2">Were optimisation potentials in pressure management investigated by hydraulic modelling?</td><td>4</td><td>1</td></tr>
<tr><td>4.5</td><td colspan="2">general procedure in pressure management</td><td>4</td><td>2</td></tr>
<tr><td>4.6</td><td colspan="2">average service pressure head</td><td>4</td><td>5</td></tr>
<tr><td>4.7</td><td colspan="2">maximal service pressure head</td><td>4</td><td>1</td></tr>
<tr><td>4.8</td><td colspan="2">general procedure in rehabilitation planning</td><td>4</td><td>2</td></tr>
<tr><td>4.9.1</td><td rowspan="5">rehabilitation criteria</td><td>experience of network engineer</td><td>1</td><td>0,8</td></tr>
<tr><td>4.9.2</td><td>on basis of failure rates</td><td>1</td><td>0,8</td></tr>
<tr><td>4.9.3</td><td>on basis of water losses</td><td>1</td><td>0,8</td></tr>
<tr><td>4.9.4</td><td>coordination with other construction sites</td><td>1</td><td>0,8</td></tr>
<tr><td>4.9.5</td><td>with special software</td><td>1</td><td>0,8</td></tr>
<tr><td>4.10</td><td rowspan="4">customer meter management</td><td>metering equipment</td><td>4</td><td>2</td></tr>
<tr><td>4.11</td><td>meter age and replacement interval</td><td>4</td><td>2</td></tr>
<tr><td>4.12</td><td>time frame for meter readings</td><td>4</td><td>1</td></tr>
<tr><td>4.13</td><td>theft of water, illegal connections, bypasses, manipulations</td><td>4</td><td>1</td></tr>
</table>

### 5.4.7.5. QI of leak repair supporting process

The quality of the process operation of the leak repair supporting process is mainly expressed by the repair time (time from locating a leak to the recovery of the functionality of the pipe) for distribution mains and service connections and by the modality of failure documentation (Table 35). The information provided by failure documentation is an essential basis for the rehabilitation planning.

**Table 35: Quality index of leak repair supporting process**

<table>
<tr><th>A</th><th>B</th><th colspan="2">C</th><th>D</th><th>E</th><th>F</th><th>G</th><th>H</th></tr>
<tr><th>sub or supporting process</th><th>Code</th><th colspan="2">Criteria</th><th>maximum points for single criteria</th><th>weighting within sub or supporting process</th><th>max. points of sub or supporting process</th><th>reached points</th><th>quality index of sub or supporting process</th></tr>
<tr><td rowspan="23">leak repair<br><br>H002</td><td>5.1</td><td colspan="2">repair time for reported leaks at distribution mains</td><td>4</td><td>1</td><td rowspan="23">44<br><br>Σ (D * E)</td><td rowspan="23">No. of points<br><br>(points of single critera * weighting)</td><td rowspan="23">G / F * 100</td></tr>
<tr><td>5.2</td><td colspan="2">repair time for unreported leaks at distribution mains</td><td>4</td><td>1</td></tr>
<tr><td>5.3</td><td colspan="2">repair time for reported leaks at service connections</td><td>4</td><td>1</td></tr>
<tr><td>5.4</td><td colspan="2">repair time for unreported leaks at service connections</td><td>4</td><td>1</td></tr>
<tr><td>5.5</td><td colspan="2">Does it happen that leaks are located but repaired weeks or month later?</td><td>4</td><td>1</td></tr>
<tr><td>5.6</td><td colspan="2">modality of failure documentation</td><td>4</td><td>1</td></tr>
<tr><td>5.7</td><td colspan="2">information for maintenance and rehabilitation planning</td><td>4</td><td>1</td></tr>
<tr><td>5.8.1</td><td rowspan="16">criteria of failure docu-mentation<br><br>(according to OVGW guideline W 100)</td><td>name of documenting person</td><td>1</td><td>1</td></tr>
<tr><td>5.8.2</td><td>place and time of failure</td><td>1</td><td>1</td></tr>
<tr><td>5.8.3</td><td>year of construction</td><td>1</td><td>1</td></tr>
<tr><td>5.8.4</td><td>pipe diameter</td><td>1</td><td>1</td></tr>
<tr><td>5.8.5</td><td>type of pipe (transportation or distribution main, service connection)</td><td>1</td><td>1</td></tr>
<tr><td>5.8.6</td><td>pipe material</td><td>1</td><td>1</td></tr>
<tr><td>5.8.7</td><td>pipe connection</td><td>1</td><td>1</td></tr>
<tr><td>5.8.8</td><td>corrosion protection</td><td>1</td><td>1</td></tr>
<tr><td>5.8.9</td><td>affected part (pipe, fitting, connection)</td><td>1</td><td>1</td></tr>
<tr><td>5.8.10</td><td>condition of pipe and bedding</td><td>1</td><td>1</td></tr>
<tr><td>5.8.11</td><td>type of failure (burst, fitting…)</td><td>1</td><td>1</td></tr>
<tr><td>5.8.12</td><td>cause of failure (e.g. corrosion)</td><td>1</td><td>1</td></tr>
<tr><td>5.8.13</td><td>sketch of position, photo documentation</td><td>1</td><td>1</td></tr>
<tr><td>5.8.14</td><td>process of failure elimination</td><td>1</td><td>1</td></tr>
<tr><td>5.8.15</td><td>type of repair / maintenance</td><td>1</td><td>1</td></tr>
<tr><td>5.8.16</td><td>costs of repair</td><td>1</td><td>1</td></tr>
</table>

The “product” quality of the repair itself (quality of material used and working quality) is not considered because no serious and comparable data can be expected due to an “internal” data collection system. To evaluate these aspects a more detailed process analysis of the repair process (which could be supported by external audits of construction sites) would be necessary.

#### 5.4.7.6. QI of staff qualification supporting process

A comparable quantification of the staff qualification concerning skills in water loss management is difficult, because it is not possible to quantify the effective experience of individual employees.

Within the 2007 OVGW process benchmarking this part was not solved satisfactorily. It was asked what number of the active employees in water loss management had certain qualifications, e.g. an OVGW certificate for water engineers, and what number was experienced in working with different leak detection equipment or experienced in analyses like the evaluation of night minimum consumptions or failure statistics.

This approach failed due to the fact that larger companies, in general, are handicapped in the comparison because they often employ a larger number of persons for the tasks of water loss management, not all of them highly qualified. Some of them may “only” be unskilled workers. In small companies all the tasks of water loss management are in “one hand” and one or only some qualified persons are responsible for this work. When ratios of employees qualified for a certain task as percentage of all the employees in water loss management are calculated, in general the smaller companies reach higher ratios than the larger companies. But it is clear that in larger utilities it is possible to employ unskilled workers for simple duties, whereas in smaller companies the qualified staffs also do the basic work. But that does not mean that larger companies have lower know-how in water loss management – in general the opposite is the case! Concerning leak detection, a small team of “real” experts is often much more effective and efficient than a larger team of employees who also have to fulfil many other tasks.

Therefore the following approach for the evaluation of staff qualifications is suggested: it is just asked whether there are qualified employees for different criteria (possible answer: yes or no) irrespective of the total number of employees working in the field of water loss management (Table 36).

However, we have to keep in mind that the comparison of staff qualifications is still on a weak basis because the personal experiences and know-how of individual employees are not quantifiable.

**Table 36: Quality index of staff qualification supporting process**

| A | B | C | D | E | F | G | H |
|---|---|---|---|---|---|---|---|
| sub or supporting process | Code | Criteria | maximum points for single criteria | weighting within sub or supporting process | max. points of sub or supporting process | reached points | quality index of sub or supporting process |
| qualification of staff | 6.1 | employees who are proved water engineers (y/n) | 1 | 2 | 26<br><br>Σ (D * E) | No. of points<br><br>(points of single critera * weighting) | G / F * 100 |
| | 6.2 | employees with special training course an water loss management (y/n) | 1 | 2 | | | |
| | 6.3 | employees with experience in using listening sticks and stethoscopes (y/n) | 1 | 2 | | | |
| | 6.4 | employees with experience in using ground microphones (y/n) | 1 | 2 | | | |
| | 6.5 | employees with experience in using leak noise correlators (y/n) | 1 | 2 | | | |
| | 6.6 | employees with experience in using noise loggers (y/n) | 1 | 2 | | | |
| | 6.7 | employees with experience in using tracer gas (y/n) | 1 | 2 | | | |
| | 6.8 | employees with experience in evaluation of zonal (or DMA) measurements (y/n) | 1 | 2 | | | |
| | 6.9 | employees with experience in evaluation of night minimum consumption (y/n) | 1 | 2 | | | |
| | 6.10 | employees with experience in pipe group based failure statistics (y/n) | 1 | 2 | | | |
| | 6.11 | operation of hydraulic modelling with own staff (y/n) | 1 | 2 | | | |
| | 6.12 | procedure in advanced staff training | 4 | 1 | | | |

#### 5.4.7.7. QI of the main process

The quality index of the main process is calculated by weighting the single quality indices of the sub and supporting processes. Of course this “overall quality performance” has to be seen critically, because a lot of (sometimes) soft single criteria, which are weighted within the sub quality indices, are behind this value. These sub indices are then weighted for the calculation of the main process quality index. Anyone who has ever worked with weightings knows that weightings are not always 100% objective and others may define other weightings.

The experiences with the 2007 OVGW process benchmarking show that the weightings used and the criteria considered may not lead to the full truth (Table 37). In chapter 6.3, the problems that occurred with the quality index are described. The missing consideration of water loss PIs was identified as the main problem. For some utilities, the quality performance did not correlate with their water loss PIs, which means that although the water losses are of a medium or high level, a high level in process quality is reached. Therefore it can be disputed that the right questions were asked for the quality assessment and the weightings for the quality index calculation were correct. Further, the consideration of water loss PIs also seems to be necessary.

The quality index in Table 38 represents an adapted version with adjusted weighting but also with the consideration of the amount of water losses in form of the ILI. Nevertheless it is recommended to be cautious in using the main process quality index. Instead of the main process quality index only the single quality indices of the sub and supporting processes should be used for quality assessment.

**Table 37: Quality index of 2007 OVGW process benchmarking**

| A | B | C | D | E | F |
|---|---|---|---|---|---|
| sub or supporting process | type of process | quality index of sub or supporting process (PI No.) | weighting of sub or supporting process | max. points of sub or supporting process | reached points of sub or supporting process |
| leakage monitoring | sub process | S111 | 2 | 2 | C * D |
| leak detection | | S211 | 2 | 2 | C * D |
| analyses & planning | | S311 | 2 | 2 | C * D |
| infrastructure management | supporting process | H001 | 1 | 1 | C * D |
| leak repair | | H002 | 2 | 2 | C * D |
| qualification of staff | | H003 | 1 | 1 | C * D |
| sum | | | | ∑E (max. 10) | ∑F |
| **quality index main process M11** | **∑F / ∑E** | | | | |

**Table 38: Quality index main process (adapted)**

| A | B | C | D | E | F |
|---|---|---|---|---|---|
| sub or supporting process | type of process | quality index of sub or supporting process (PI No.) | weighting of sub or supporting process | max. points of sub or supporting process | reached points of sub or supporting process |
| leakage monitoring | sub process | S111 | 4 | 4 | C * D |
| leak detection | | S211 | 4 | 4 | C * D |
| analyses & planning | | S311 | 3 | 3 | C * D |
| infrastructure management | supporting process | H001 | 3 | 3 | C * D |
| leak repair | | H002 | 2 | 2 | C * D |
| qualification of staff | | H003 | 1 | 1 | C * D |
| ILI categories A (3 points) - D (0 points) | | WI05 | 3 | 9 | C * D |
| sum | | | | ∑E (max. 26) | ∑F |
| **quality index main process M11** | **∑F / ∑E** | | | | |

## 5.5. *The Process Quality Matrix*

The quality indices described in the previous chapter represent highly aggregated indices which are not very transparent on a first view. Therefore the derivation of measures directly on the basis of these indices is not possible. For the purposes of transparency regarding the individual criteria which lay behind the indices, but more for obtaining an overview about strengths and weaknesses in process operation, a process quality matrix was developed.

The idea of this quality matrix is to give a fast overview of optimisation potentials. Therefore each of the single criteria of the matrix is categorised into five different performance levels (from low to high). The different performance levels are indicated by different colours within the matrix (Table 39). Some questions are answered by “yes” (light blue) or “no” (red), and some questions enable more than one answer (e.g. leak detection equipment, 2.6 in Table 41). In these cases those fields which are accepted as “true” are indicated by a dark green colour.

**Table 39: Indication of performance levels in the quality matrix**

| performance level | | colour |
|---|---|---|
| 1 | low performance | red |
| 2 | | orange |
| 3 | medium performance | yellow |
| 4 | | green |
| 5 | high performance | light blue |

| | |
|---|---|
| equivalent answers (for questions with more than one possible answer) | dark green (answer: true or yes) |

The whole quality matrix is split into six tables (Table 40 to Table 45) due to the lack of space. The individual criteria are equal to the criteria for the quality indices in Table 31 to Table 36, but here also the possible answers (of the participating water supply utilities) are shown in detail.

**Table 40: Quality matrix for leakage monitoring sub process (part 1)**

| | topic question | performance level low red 1 | orange 2 | medium yellow 3 | green 4 | high light blue 5 |
|---|---|---|---|---|---|---|
| **1** | **sub process leakage monitoring (part 1)** | | | | | |
| 1.1 | **system input metering** | Most of our system input is not metered | Not all, but > 50% of our system input is metered | Our system input is metered but we are not sure about the accuracy of these (partly old) meters | Our system input is metered with mechanical and/or magnetic flow meters that are rarely calibrated | Our system input is metered with magnetic flow meters that are regularly calibrated |
| 1.2 | **district metered areas (DMA)** | We have no DMAs and have no plans to establish DMAs | We plan to install DMAs and have started to establish the first DMAs | The first DMAs are established and we have already the first results | We have several DMAs and check and analyse inflow data sporadically | We have several DMAs and monitor flow and pressure on a regular basis |
| 1.3 | **evaluation of night minimum consumption** | Up to now we did not evaluate the night minimum consumption | The night minimum consumption is metered and analysed sporadically with external instruments | The night minimum consumption is metered daily but evaluated only in larger intervalls (e.g. once in a week or month) | We analyse the night minimum consumption of the whole system every day | We analyse the night minimum consumption of each DMA every day |
| 1.4 | **SCADA system (SCADA)** | We do not have a SCADA system | We have started to plan (or install) a SCADA system | We have a SCADA system but not all of our system input meters or zonal meters are implemented | All of our system input meter data or zonal meter data are transmitted to a control room permanently | All of our system input meter data or zonal meter data are transmitted to a control room permanently and there are automatic alarms if limits are exceeded |
| 1.4.1 | **functions of SCADA system (more than 1 answer possible)** | Transmission of system input data (springs, wells) | Transmission of zonal input data (DMA inputs) | Transmission of pressure measurements | Transmission of water levels in reservoirs | Transmission of flows of pumping stations |
| 1.4.1.1 | **data transmission interval system input data** | once a day or less | >15 min. | 1-15 min. | each minute | permanent |
| 1.4.1.2 | **data transmission interval DMA input data** | once a day or less | >15 min. | 1-15 min. | each minute | permanent |
| 1.4.1.3 | **data transmission interval pressure data** | once a day or less | >15 min. | 1-15 min. | each minute | permanent |
| 1.4.1.4 | **data transmission interval reservoir level** | once a day or less | >15 min. | 1-15 min. | each minute | permanent |
| 1.4.1.5 | **data transmission interval pumping station data** | once a day or less | >15 min. | 1-15 min. | each minute | permanent |
| 1.4.2 | **automated evaluation of night minimum consumption** | | no | | yes | |
| 1.4.3 | **automated alarm when tresholds exceeded** (e.g. increase in system input or decrease of service pressure) | | no | | yes | |

**Table 40 continued: Quality matrix for leakage monitoring sub process (part 2)**

| | topic<br>question | performance level<br>low<br>red<br>1 | orange<br>2 | medium<br>yellow<br>3 | green<br>4 | high<br>light blue<br>5 |
|---|---|---|---|---|---|---|
| 1 | **sub process leakage monitoring (part 2)** | | | | | |
| 1.5 | **pressure monitoring** | We do not have any pressure monitoring systems installed | We have a few pressure monitoring systems at pumping stations and treatment plants | We have a few pressure monitoring systems at pumping stations and treatment plants and sporadically we measure the pressure within the distribution system (with mobile manometers) | We have a few pressure monitoring systems at pumping stations and treatment plants and sporadically we measure the pressure within the distribution system with pressure loggers | We have permanent installed pressure loggers and record the pressure within the distribution system continuously |
| 1.6 | **permanent noise loggers** | We do not have any permanent noise loggers and we will not use such loggers in the future | At the moment we do not have any permanent noise loggers but may be we will use such loggers in the future | We have a few permanent noise loggers but we do not think about an area-wide use | We have started with an area-wide use of permanent noise loggers in some districts of our supply system and aim for a coverage of the whole distribution system | We have an area-wide use of permanent noise loggers in our distribution system and evaluate noise data regularly (several times a year) |
| 1.7 | **virtual measuring zones** | We do not have a leakage monitoring in large zones | In parts of our supply system we started to implement virtual measirung zones (by flow measurements only) | In parts of our supply system we started to implement virtual measirung zones using mulitparameter measurements | We have an area-wide system of virtual measuring zones but we use only flow measurements | We have an area-wide use of multiparameter measurements in our distribution system with an automatical leak detection software |
| 1.8 | **recognition of leakage** | We only get aware of bursts when the reservoir is suddenly empty, single small leak are not recognised | Existing leaks which do not come to the surface are only recognised in the course of leak detection campaigns | Existing leaks which do not come to the surface are recognised on basis of monthly evaluations of the system input volume | Existing leaks which do not come to the surface are recognised on basis of weekly evaluations of the system input volume | Because of daily night minimum consumption evaluations also smaller leaks are recognised within 24 hours |
| 1.9 | **first information about leak location** | With the existing leakage monitoring system it is not possible to get any information about the location of a leak | Just a rough estimation in what district of the supply system the leak is located is available | With our leakage monitoring system bursts can be spatialised to single DMAs | With our leakage monitoring system bursts can be spatialised to pipe sections with less than 1.000 m lenght (without additional leak detection measures) | With our leakage monitoring system bursts can be spatialised to pipe sections with less than 300 m lenght (without additional leak detection measures) |
| 1.10 | **accuracy of system input metering** | +/- >100% | +/- 25-100% | +/- 5-25% | +/- 2-5% | +/- 2% |
| 1.11 | **max. zone size (according mains length)** | > 500 km | 100-500 km | 50-100 km | 25-50 km | < 25 km |
| 1.12 | **max. zone size (according No. of service connections)** | > 50.000 service connections | 10.000-50.000 service connections | 3.000-10.000 service connections | 1.000-3.000 service connections | < 1.000 service connections |
| 1.13 | **average zone size (weighted onto No. of service connections)** | > 10.000 service connections | 3.000-10.000 service connections | 1.000-3.000 service connections | 500-1.000 service connections | < 500 service connections |
| 1.14 | **average zone size (weighted onto mains length)** | > 200 km | 100-200 km | 50-100 km | 25-50 km | < 25 km |
| 1.15 | **portion of DMA of whole supply system (according mains length)** | 0% | 0% to 30% | 30% to 70% | 70% to 100% | 100% |

**Table 41: Quality matrix for leak detection sub process**

| | topic<br>question | performance level<br>low<br>red<br>**1** | orange<br>**2** | medium<br>yellow<br>**3** | green<br>**4** | high<br>light blue<br>**5** |
|---|---|---|---|---|---|---|
| **2** | **sub process leak detection** | | | | | |
| 2.1 | **general procedure in leak detection (strategy)** | We make routine leak detection campaigns in intervals of more than 5 years | We make routine leak detection campaigns in intervals of 3 to 5 years | We make routine leak detection campaigns in intervals of 2 years | We make annual routine leak detection campaigns | In general we make a cause based leak detection on basis of information of leakage monitoring (e.g. increase in night minimum consumption). Additional we make routine leak detection campaigns in larger time intervals |
| 2.2 | **leak location time** | We do not have any documentation about that and do not know how it takes to locate a leak | The average location time is higher than 5 days | The average location time is between 2 and 5 days | The average location time is between 1 and 2 days | The average location time is less than 1 day |
| 2.3 | **hit rate<br>(success in leak detection)** | During leak detection only very few leaks were localised. The decrease of water losses was very small | During leak detection some leaks were localised. The water losses could be decreased but are still on a high level | During leak detection many leaks were localised. The water losses could be decreased significantly but further reductions are possible | During leak detection all relevant leaks were localised. The water losses could be decreased significantly and further reductions are not possible | In general all detectable leak are found in course of leak detection campaigns and selective inspections. After leak repair the night minimum consumption is in the range of the long-term minimum |
| 2.4 | **accuracy in pinpointing leaks** | A bigger part of leaks is localised imprecisely and therefore often larger pipe sections (more than 20 m) need to be excavated | The average accuracy of leak location is about +/- 2 metre | The average accuracy of leak location is about +/- 1 m | In general the accuracy of leak location is about +/- 50 cm | With the used technology usually an exact pinpointing (+/- 20 cm) of leaks is possible |
| 2.5 | **documentation of leak detection** | We do not document leak detection activities | The inspected pipe sections are documented, but there is no documentation of the used technology and of the costs for leak detection (personnel and equipment) | It is documented at which pipe sections cause related leak detection or routine surveys are done, but there is no documentation of the used technology and of the costs for leak detection (personnel and equipment) | It is documented at which pipe sections cause related leak detection or routine surveys are done and also the used technology and the costs for leak detection (personnel and equipment) are documented | All leak detection activities (routine and cause related) are exactly documented (pipe section, technology, costs) and there is a documentation of location, type etc. of found leaks (eventually in GIS) |
| 2.6 | **existing leak detection equipment<br>(more than 1 answer possible)** | listening stick, stethoscope | ground microphone | leak noise correlator | temporary noise loggers | equipment for tacer gas ($H_2$) |
| 2.7 | **Is there a standardised routine leak detection at service connections in course of meter replacements or meter reading?** | | no | | yes | |

**Table 42: Quality matrix for analyses & planning sub process (part 1)**

| | topic question | performance level low red 1 | orange 2 | medium yellow 3 | green 4 | high light blue 5 |
|---|---|---|---|---|---|---|
| **3** | **sub process analyses & planning (part 1)** | | | | | |
| 3.1 | **general procedure in analyses and planning** | We do not make any analyses according water loss management | The analyses are limited to the calculation of an annual water balance | The analyses are limited to the calculation of an annual water balance and of various water loss PIs | We calculate a water balance and various water loss PIs annualy. Analyses of the water loss management itself with derivation of optimisation measures are done in larger time intervals | Beside calculation of a water balance and water loss PIs we analyse the process of water loss management (cost-benefit analyses, rehabilitation planning etc.) and if necessary optimisations are implemented |
| 3.2 | **general procedure in calculating a water balance** | Up to now we did not calculate a water balance | We tried to calculate a water balance but had to give up, because we do not measure the system input | Up to now we calculated a water balance of an other scheme than the IWA water balance | We already use the IWA water balance for an annual calculation | We already use the IWA water balance for an annual calculation and use confidence intervals to estimate the accuracy of water balance data |
| 3.3 | **general procedure in calculating water loss PIs** | Up to now we did not calculate water loss PIs | The only PI we calculate is the water loss ratio (%) | We calculate various technical water loss PIs regularly | We calculate various technical and economical water loss PIs regularly (e.g. real losses per mains length, ILI, real losses per connection per day, non-revenue water) | We calculate various technical and economical water loss PIs regularly (e.g. ILI, real losses per connection per day, non-revenue water) and publish the results e.g. in an annual report |
| 3.4 | **time interval in which different criteria are analysed or planned** | | | | | |
| 3.4.1 | **calculation of water loss PIs for whole supply system** | never done | more than 5 years | 2-5 years | every six month or annual | monthly or quaterly |
| 3.4.2 | **calculation of water loss PIs for single DMAs** | never done | more than 5 years | 2-5 years | every six month or annual | monthly or quaterly |
| 3.4.3 | **analyses to trends in night minimum consumption of single zones** | never done | more than 5 years | 2-5 years | every six month or annual | monthly or quaterly |
| 3.4.4 | **investigations if existing measuring systems (flow, pressure etc.) and SCADA systems are sufficient** | never done | more than 5 years | 2-5 years | every six month or annual | monthly or quaterly |
| 3.4.5 | **internal analyses of costs (efficiency) and success (affectivity) of water loss management** | never done | more than 5 years | 2-5 years | every six month or annual | monthly or quaterly |

**Table 42 continued: Quality matrix for analyses & planning sub process (part 2)**

| | topic<br>question | performance level<br>low<br>red<br>1 | orange<br>2 | medium<br>yellow<br>3 | green<br>4 | high<br>light blue<br>5 |
|---|---|---|---|---|---|---|
| 3 | **sub process analyses & planning (part 2)** | | | | | |
| 3.4.6 | **derivation of measures for improvement of process operation (e.g. working instructions)** | never done | more than 5 years | 2-5 years | every six month or annual | monthly or quaterly |
| 3.4.7 | **generation of failure statistics for whole supply system without analyses of single pipe-groups** | never done | more than 5 years | 2-5 years | every six month or annual | monthly or quaterly |
| 3.4.8 | **generation of failure statistics for single DMAs without analyses of single pipe-groups** | never done | more than 5 years | 2-5 years | every six month or annual | monthly or quaterly |
| 3.4.9 | **generation of failure statistics for whole supply system with analyses of single pipe-groups** | never done | more than 5 years | 2-5 years | every six month or annual | monthly or quaterly |
| 3.4.10 | **generation of failure statistics for single DMAs with analyses of single pipe-groups** | never done | more than 5 years | 2-5 years | every six month or annual | monthly or quaterly |
| 3.4.11 | **derivation of measures for improvement in maintenance (e.g. for critical pipe groups)** | never done | more than 5 years | 2-5 years | every six month or annual | monthly or quaterly |
| 3.4.12 | **provision of pipe-group based failure statistics for rehabilitation planning** | never done | more than 5 years | 2-5 years | every six month or annual | monthly or quaterly |
| 3.5 | **PIs calculated for internal purposes (more than 1 answer possible)** | | | water loss ratio (%) | real losses per connection per day | real losses per conn. per day per metre pressure |
| | | | | real losses per mains length | ILI | Non-revenue water (NRW) (%) |
| 3.6 | **PIs published in annual report (e.g. for stake-holders) (more than 1 answer possible)** | | | water loss ratio (%) | real losses per connection per day | real losses per conn. per day per metre pressure |
| | | | | real losses per mains length | ILI | Non-revenue water (NRW) (%) |
| 3.7 | **accuracy of unbilled consumption** | +/- 100% | +/- 50 bis 100% | +/- 25 bis 50% | +/- 10 bis 25% | +/- <=10% |
| 3.8 | **accuracy of apparent losses** | +/- 100% | +/- 50 bis 100% | +/- 25 bis 50% | +/- 10 bis 25% | +/- <=10% |
| 3.9 | **Are overflows of springs returned directly at the spring collection shaft or at other points within the supply system (e.g. returned water at reservoirs or power stations)?** | | returned at point within the transport or distribution system | | returned at spring collection shaft | |

**Table 43: Quality matrix for infrastructure management supporting process (part 1)**

| | topic<br>question | performance level<br>**low**<br>red<br>1 | orange<br>2 | **medium**<br>yellow<br>3 | green<br>4 | **high**<br>light blue<br>5 |
|---|---|---|---|---|---|---|
| **4** | **supporting process infrastructure management (part 1)** | | | | | |
| 4.1 | **mapping / GIS** | We do not have maps of our water supply system | The existing maps are not updated | Our maps are updated but not implemented into a GIS | Our maps are updated but up to now only a part of it is implemented into a GIS | We have a GIS based mapping which is regularly updated |
| 4.2 | **network inspection** | | | | | |
| 4.2.1 | **inspection interval closing valves** | no inspection (or calibration) planed | 6 to 10 years | 3 to 5 years | 1 to 2 years | every six month or more often |
| 4.2.2 | **inspection interval hydrants** | no inspection (or calibration) planed | 6 to 10 years | 3 to 5 years | 1 to 2 years | every six month or more often |
| 4.2.3 | **inspection interval pressure reduction valves** | no inspection (or calibration) planed | 6 to 10 years | 3 to 5 years | 1 to 2 years | every six month or more often |
| 4.2.4 | **calibration interval system input meters** | no inspection (or calibration) planed | 6 to 10 years | 3 to 5 years | 1 to 2 years | every six month or more often |
| 4.2.5 | **calibration interval DMA meters** | no inspection (or calibration) planed | 6 to 10 years | 3 to 5 years | 1 to 2 years | every six month or more often |
| 4.3 | **accomplishment of hydraulic modelling** | Up to now no hydraulic modelling was carried out | Many years ago a hydraulic modelling was carried out | We plan to carry out a hydraulic modelling soon | We have an actual hydraulic modell (max. some years old), larger rehabilitations and expansions are modelled before realisation | We do hydraulic modelling continuously (e.g. expansions, rehabilitation, hydraulic optimisations) and our model is updated continuously |
| 4.4 | **Were optimisation potentials in pressure management investigated by hydraulic modelling?** | | no | | yes | |
| 4.5 | **general procedure in pressure management** | We are unconcerned about the pressure conditions within are supply system | The maximum service pressures are more than 10 bar but pressure reductions are not planned | The maximum service pressures are between 7 and 10 bar, eventually we will reduce the pressure in future | We know about the pressure conditions within our supply system, optimisations are planned but not fully implemented yet | We know about the pressure conditions within our supply system (e.g. due to permanent or temporary pressure measurements and/or hydraulic modelling), we have reduced the service pressure to an acceptable minimum |
| 4.6 | **average service pressure head** | > 75 m | 55-75 m | 45-55 m | 35-45 m | < 35 m |
| 4.7 | **maximal service pressure head** | > 90 m | 70-90 m | 50-70 m | 40-50 m | < 40 m |

**Table 43 continued: Quality matrix for infrastructure management supporting process (part 2)**

| | topic<br>question | performance level<br>low<br>red<br>1 | orange<br>2 | medium<br>yellow<br>3 | green<br>4 | high<br>light blue<br>5 |
|---|---|---|---|---|---|---|
| **4** | **supporting process infrastructure management (part 2)** | | | | | |
| 4.8 | **general procedure in rehabilitation planning** | We do not have a real rehabilitation planning in our utility, rehabiltations of pipes and armartures are carried out due to recent occurrences and if the necessary money is available | The main rehabilitation criteria is the pipe age | Rehabilitation planning is done on basis of failure rates and under consideration of the experience of the network engineer (or water master) | Rehabilitation planning is done on basis of failure rates and under consideration of the experience of the network engineer (or water master), the hydraulic performance of pipes and we try to use synergies with combined construction sites (e.g. gas pipes) | Rehabilitation planning is supported by special software and is done on basis of failure rates and under consideration of the experience of the network engineer (or water master), the hydraulic performance of pipes and we try to use synergies with combined construction sites |
| 4.9 | **rehabilitation criteria**<br><br>**(more than 1 answer possible)** | experience of network engineer (or water master) | failure rates | developement of water losses | other construction sites (e.g. gas pipes, streets) | special pipe rehabilitation software |
| | **customer meter management (customer metering)** | | | | | |
| 4.10 | **customer metering equipment** | we do not have customer meters | Only large customers are metered | We have started to meter all customers but have not completed this process yet | Nearly all customers are metered, public tapping points are not metered | 100% of our customers are metered |
| 4.11 | **meter age and replacement interval** | We do not have reliable information about the age of customer meters | We only change meters if they are obviously defect | A lot of the customer meters are older than 10 years, up to now we did not work out a customer meter replacement programme | We have a customer meter replacement programme but we were not able to replace all meters older than 10 years yet | We replace all customer meters in 5 years intervals |
| 4.12 | **time frame for meter readings** | Meter readings are undertaken over the whole year (several seperated time periods), therefore the consumption data can not be refered exact to a specific validation date | Meter readings are undertaken over the whole year (uniformly distributed), therefore the consumption data can not be refered exact to a specific validation date | Meter readings are undertaken over a short time period, which is the same each year | All customer meters are equipped with a data logger which logs the annual consumption data at a specific validation date | All customer meters are equipped with a data logger which logs the consumption data at various specific validation dates |
| 4.13 | **theft of water, illegal connections, bypasses, manipulations** | We did not make any investigation about these topic and have no programmes again theft of water | Occassionally illegal connections are found | Occassionally illegal connections or other frauds (e.g. theft out of hydrants) are found | We have a systematic programe against illegal connections | We have a systematic programe against illegal connections, for finding bypasses and to avoid theft of water |

**Table 44: Quality matrix for leak repair supporting process (part 1)**

| | topic<br>question | performance level<br>low<br>red<br>**1** | orange<br>**2** | medium<br>yellow<br>**3** | green<br>**4** | high<br>light blue<br>**5** |
|---|---|---|---|---|---|---|
| **5** | **supporting process leak repair (part 1)** | | | | | |
| 5.1 | **repair time for reported leaks at distribution mains (time from locating a leak to the recovery of the functionality of the pipe)** | We do not have any documentation of leak repair, therefore we do not know how long it takes to repair the leak | The average repair time is more than 24 hours | The average repair time is between 12 and 24 hours | The average repair time is between 6 and 12 hours | The average repair time is less than 6 hours |
| 5.2 | **repair time for unreported leaks at distribution mains** | We do not have any documentation of leak repair, therefore we do not know how long it takes to repair the leak | The average repair time is more than 7 days | The average repair time is between 3 and 7 days | The average repair time is between 1.5 and 3 days | The average repair time is less than 1.5 days |
| 5.3 | **repair time for reported leaks at service connections** | We do not have any documentation of leak repair, therefore we do not know how long it takes to repair the leak | The average repair time is more than 48 hours | The average repair time is between 24 and 48 hours | The average repair time is between 12 and 24 hours | The average repair time is less than 12 hours |
| 5.4 | **repair time for unreported leaks at service connections** | We do not have any documentation of leak repair, therefore we do not know how long it takes to repair the leak | The average repair time is more than 14 days | The average repair time is between 7 and 14 days | The average repair time is between 2 and 7 days | The average repair time is less than 2 days |
| 5.5 | **Does it happen that leaks are located but repaired weeks or month later?** | | yes | | no | |

**Table 44 continued: Quality matrix for leak repair supporting process (part 2)**

| | topic<br>question | performance level<br>low<br>red<br>1 | <br>orange<br>2 | <br>medium<br>yellow<br>3 | <br>green<br>4 | <br>high<br>light blue<br>5 |
|---|---|---|---|---|---|---|
| **5** | **supporting process leak repair (part 2)** | | | | | |
| 5.6 | **general procedure in of failure documentation** | We do not document failures | The only possibility to evaluate the number of failures is to count the repair orders | We only have a very simple documentation which allows a classification of failures at mains or at service connections | We have a detailed failure documentation (e.g. location, diameter, material, type of failure etc.) | We have a detailed failure documentation (e.g. location, diameter, material, type of failure etc.) and the failures are implemented into a GIS |
| 5.7 | **information for maintenance and rehabilitation planning** | The information about failures is not considered in maintenance and rehabilitation planning | The information about failures is only partwise considered in maintenance and rehabilitation planning | In general the information about failures is used in rehabilitation and maintenance planning, but sometmes the information is not considered | The information about failures is very important for our rehabilitation and maintenance planning. | The information about failures is very important for our rehabilitation and maintenance planning. With standardised procedures the information is considered regularly in rehabilitation and maintenance planning |
| 5.8 | **criteria of failure documentation**<br><br>**(according to OVGW guideline W 100)** | | name of documenting person | place and time of failure | year of construction | pipe diameter |
| | | | type of pipe (transportation or distribution main, service connection) | pipe material | pipe connection | corrosion protection |
| | | | affected part (pipe, fitting, connection) | condition of pipe and bedding | type of failure (burst, fitting…) | cause of failure (e.g. corrosion) |
| | | | sketch of position, photo documentation | process of failure elimination | type of repair / maintenance | costs of repair |

**Table 45: Quality matrix for staff qualification supporting process**

| | topic question | performance level low red 1 | orange 2 | medium yellow 3 | green 4 | high light blue 5 |
|---|---|---|---|---|---|---|
| **6** | **supporting process qualification of staff** | | | | | |
| 6.1 | **employees who are proved water engineers** | | no | | yes | |
| 6.2 | **employees with special training course an water loss management** | | no | | yes | |
| 6.3 | **employees with experience in using listening sticks and stethoscopes** | | no | | yes | |
| 6.4 | **employees with experience in using ground microphones** | | no | | yes | |
| 6.5 | **employees with experience in using leak noise correlators** | | no | | yes | |
| 6.6 | **employees with experience in using noise loggers** | | no | | yes | |
| 6.7 | **employees with experience in using tracer gas** | | no | | yes | |
| 6.8 | **employees with experience in evaluation of zonal (or DMA) measurements** | | no | | yes | |
| 6.9 | **employees with experience in evaluation of night minimum consumption** | | no | | yes | |
| 6.10 | **employees with experience in pipe group based failure statistics** | | no | | yes | |
| 6.11 | **Is hydraulic modelling operated with own personnel or by external companies?** | | external company | | own personnel | |
| 6.12 | **procedure in advanced staff training** | We do not train our staff | Once in a while our employees attend seminars, internal staff training do not take place often | Some of our employees have attended several courses and seminars, in future all of our employess should attend further education seminars | The level of education of our staff is high. At least once a year each of our employess attends at courses, seminars or conferences (e.g. of the Association for Gas and Water). At least once a year internal staff trainings are organised | The level of education of our staff is very high. To hold this high level our employees attend several courses, semiars etc. each year and additional internal trainings are organised several times |

## 5.6. *Verbal descriptions*

Beside the “hard facts” in the form of variables and performance indicators, additional verbal descriptions about the process operation of single sub and supporting processes can provide useful information. Of course, it is not possible to build up each single activity of the process operation in a fixed process scheme, and such a fixed process can not claim to be the one and only truth.

Therefore verbal descriptions are useful for two aspects:

- to enable a better illustration of the process operation and to support deriving measures for improvements
- to identify common practises which should be implemented into the process benchmarking system

Such verbal descriptions were missing in the OVGW field test, but it was seen that this is essential information which has to be used in later projects.

## 5.7. *Exchange of experiences and derivation of measures for improvement*

The objectives of process benchmarking are improvements in the performance of process operation. These improvements can be increases in efficiency but also increases in the quality of the process operation.

The process benchmarking described in the previous chapters does not represent the whole solution to achieve these objectives. In fact, this performance indicators and quality criteria system represents the basis for further analyses and for the exchange of experiences with other utilities. Of course, the performance indicators give an overview about strengths and weaknesses of a single utility in operating the process of water loss management. But to derive measures for improvement it is necessary to analyse these results.

Therefore the first step after the performance comparison should be utility internal analyses of the results to obtain an overview about their own performance and to identify performance gaps. A plausibility check of the (basis) data should also be done at this stage. Questionable data have to be critically analysed before discussions with other utilities.

“Best-in-class” workshops can be a good start for the exchange of experiences with other utilities. The results of the process comparison can be presented to all the participating utilities at these workshops and first analyses not only within the whole field of utilities but also within groups with comparable frame conditions can be carried out.

The depth of analyses will vary, depending on the duration of the workshops. Experience within the OVGW project shows that one single workshop day is a good start for exchanging views, but following workshops or discussions and analyses, maybe in smaller groups, or even between two utilities, are often necessary to derive concrete measures for improvement.

# 6. Field test - the 2007 OVGW process benchmarking

Between February 2007 and April 2008 the OVGW organised a process benchmarking project for the Austrian water supply sector which was initiated and operated by Graz University of Technology and by University of Natural Resources and Applied Life Sciences Vienna. In fact it was the first process benchmarking in the Austrian water supply sector this project also had the character of a field test.

Benchmarking the process of water loss management in that form also represents a worldwide innovation. The successful development of a process benchmarking system and an interesting field test with many important experiences was possible with the support of eleven participating water utilities.

But the first trial on benchmarking the process of water loss management was more than just a field test: according to the participants' feedback the project succeeded in comparing the different procedural methods in water loss management for different structures and sizes of utilities and it was possible to derive measures for improvement.

## 6.1. *Frame conditions*

The process benchmarking system used in the field test differs in some points from the system described within this thesis. The improvements which were implemented to the system were described in the chapters about the process benchmarking system and are described in chapter 6.3.

An assessment period of three years (2004, 2005 and 2006) was used for most of the data to give better comparability. The PIs calculated represent average values of the three years which are broken down on a single year. The water balance and water loss PIs were calculated for the single year 2006.

Table 46 gives an overview about the frame conditions and the different strategies in water loss management used by the participating utilities of the 2007 OVGW process benchmarking. The utilities with the numbers 1, 3 and 11 represent rural structures. Utilities 5, 7, 9 and 10 are smaller cities with about 2000 to about 15000 inhabitants. The utilities 2, 4, 6 and 8 are larger cities with about 50000 to 200000 inhabitants.

**Table 46: Frame conditions and strategies of participating utilities in 2007 OVGW process benchmarking (part 1)**

| utility nr. | urbanity | grouping system input volume | strategy in leak detection | existing DMAs | night minimum monitoring | use of noise loggers |
|---|---|---|---|---|---|---|
| 1 | rural | > 5 Mio. m³/a | cause based | yes | yes | no |
| 2 | large city | > 5 Mio. m³/a | mixed | yes | yes | no |
| 3 | rural | < 5 Mio. m³/a | cause based | yes | yes | no |
| 4 | large city | > 5 Mio. m³/a | routine surveys | yes | yes | no |
| 5 | small city | < 5 Mio. m³/a | mixed | yes | yes | no |
| 6 | large city | > 5 Mio. m³/a | routine surveys | planned | no | no |
| 7 | small city | < 5 Mio. m³/a | no strategy yet | planned | no | no |
| 8 | large city | > 5 Mio. m³/a | mixed | yes | yes | yes |
| 9 | small city | < 5 Mio. m³/a | mixed | yes | yes | yes |
| 10 | small city | < 5 Mio. m³/a | mixed | no | yes | no |
| 11 | rural | < 5 Mio. m³/a | cause based | planned | yes | no |

**Table 46 continued: Frame conditions and strategies of participating utilities in 2007 OVGW process benchmarking (part 2)**

| utility nr. | routine leak detection at service connections | dominating pipe material at service connections | hydraulic modelling | own measuring vehicle | proportion of distribution mains annually inspected by leak detection methodologies | service connection density (conn./km) | average service pressure head (m) |
|---|---|---|---|---|---|---|---|
| 1 | no | plastic | planned | no | 0.4% (using DMAs) | 27.3 | 52 |
| 2 | yes | plastic | planned | yes | 17% | 31.4 | 49 |
| 3 | no | plastic | old | no | 7.6% (using DMAs) | 21.3 | 54 |
| 4 | no | plastic & metal | planned | no | 107% | 30.4 | 40 |
| 5 | no | plastic & metal | actual | no | 36% | 28.7 | 50 |
| 6 | yes | plastic | actual | yes | 27% | 29.9 | 40 |
| 7 | no | plastic | planned | no | 9.5% | 36.3 | 50 |
| 8 | yes | plastic | actual | yes | 101% | 38.3 | 44 |
| 9 | no | metal | actual | no | 117% | 21.4 | 60 |
| 10 | yes | plastic | old | no | 53% | 23.3 | 50 |
| 11 | yes | plastic | actual | no | 1.8% (using DMAs) | 34.7 | 55 |

The urbanity as an indicator for the structure of the water supply system is one of the most important grouping criteria beside the strategy in leak detection (whether this is done cause-based or in form of routine surveys, compare chapter 4.5.3).

## 6.2. *Summary of results*

In this chapter the most important and most significant results of the 2007 OVGW process benchmarking project in Austria are described. The focus is on project results, which are important from a methodological point of view. The description follows the structure of the PI system, starting with water loss PI, next the results of the main process and afterwards the results of the sub- and supporting processes. Last but not least, results about quality indices and outcomes of the best-practice workshop are explained.

**Please note that all results shown for the 2007 OVGW process benchmarking are results based on the process benchmarking system used in this OVGW 2007 project. Some adaptations of this process benchmarking system, in particular of the process structure, are described in this thesis (compare chapters 5 and 6.3). These improvements in the process benchmarking system are not reflected within the project results shown!**

**Those results which represent the adapted process benchmarking system with the implemented improvements are indicated clearly.**

### 6.2.1. Water Loss PIs

The performance within the water loss PIs shows how successful a water utility operates its water loss management. It also has to be mentioned that it is very important to watch the trend of water loss PIs and not only data of a single year in order to evaluate the success in water loss management.

The importance of considering data accuracy of water balance data should also be mentioned. The “min.” and “max.” values in Figure 40 to Figure 44 represent confidence intervals in the form of maximal possible error margins. These error margins are calculated on the basis of the error margins of each single water balance data and the error margins of basic data like mains length, number of service connections or average service pressure head. For the “min.” and “max.” values the best and the worst case for each water loss PI was calculated. Therefore, except for the ILI, the “min.” and “max.” values are symmetric under and above the “directly calculated" value, which is calculated directly from the input data. Experience shows that the "right" value usually is anywhere between the directly calculated value and the maximum value because over registration normally does not occur at system input meters. Therefore the system input volume tends to be underestimated what leads to an underestimation of real losses.

Small error margins for the system input volume can also lead to high error margins for the volume of real water losses when the real losses are at a low level, some of values of single utilities have error margins of about 100 % or even more: e.g., utility number 3 and utility number 8.

The water loss ratio (Figure 40) represents the percentages of the real losses of the system input. This PI is still very common although it is definitely not qualified for the assessment of water losses (compare chapter 4.4.1). But this PI is calculated within the process benchmarking project to show the unserviceableness in comparison with other PIs.

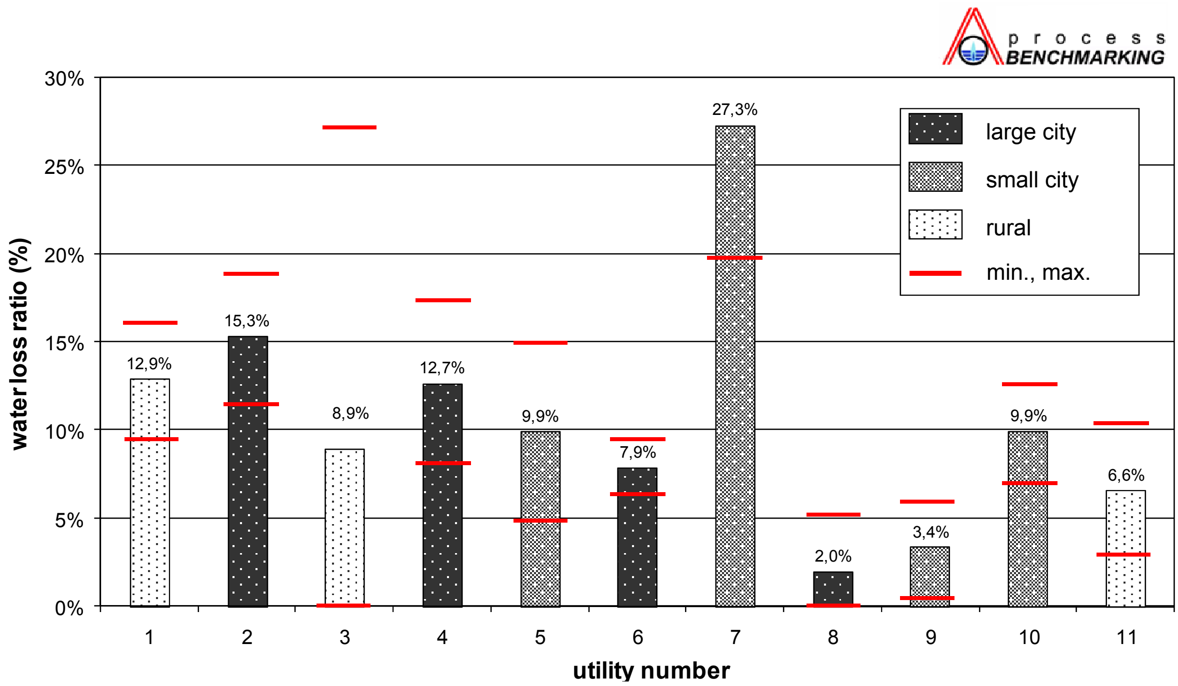


**Figure 40: Water loss ratio (source: 2007 OVGW process benchmarking in KOELBL et al. 2008a)**

For the technical assessment of water losses it is necessary to use PIs which consider structural parameters like the mains length, the number of service connections or the average service pressure.

In DVGW W 392 (2003), real losses per mains length are the decisive PI whereby an assessment subject to the structure of the distribution network (rural, urban or metropolitan) can be made (Figure 41 and Table 12). On the basis of Table 12, the following classification on basis of the different structures can be made:

| | | |
|---|---|---|
| high level of water losses: | utility number: | 2, 4, 6, 7 |
| medium level of water losses: | utility number: | 1, 3, 5, 10, 11 |
| low level of water losses: | utility number: | 8, 9 |

As mentioned in chapter 4.4.2 it is recommended to use this PI for supply systems with service connection densities smaller than 20 per kilometre. But all eleven participating water utilities have a service connection density of more than 20. Only the utilities number 3, 9 and 10 are in that range with service connection densities of 21 to about 23 (see Table 46).

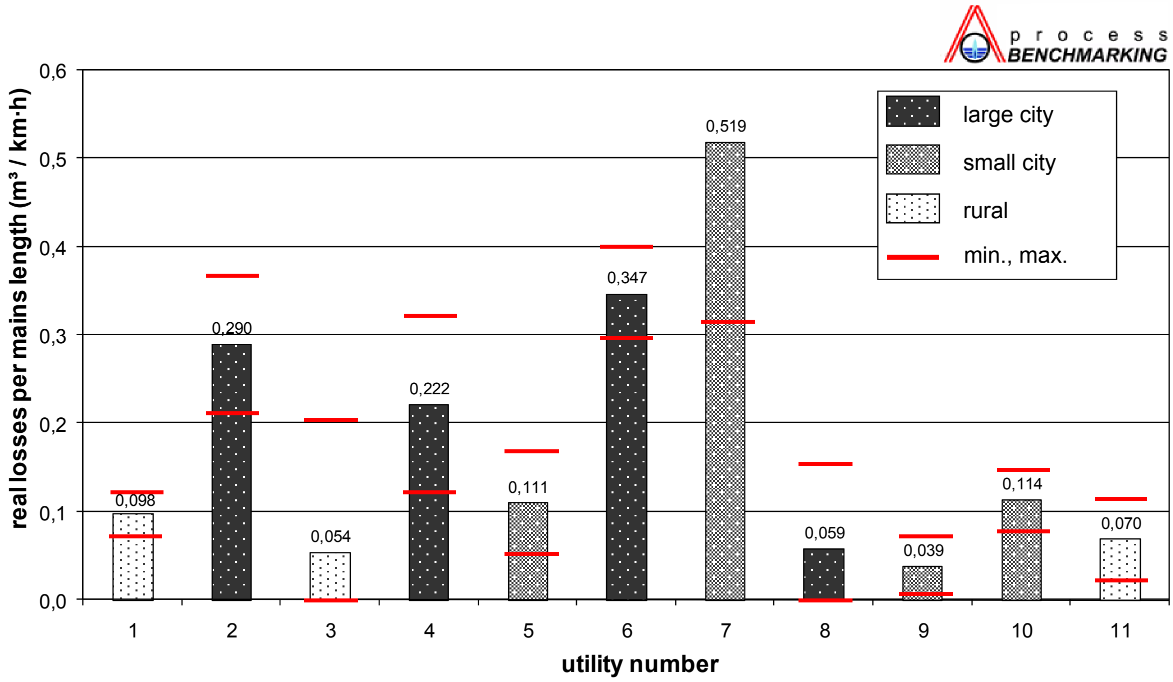


**Figure 41: Real losses per mains length (source: 2007 OVGW process benchmarking in KOELBL et al. 2008a, amended)**

For supply systems with a service connection density higher than 20 connections per kilometre the IWA WLTF (LIEMBERGER 2007) and ALEGRE et al. (2006) recommend using the PI "real losses per connection per day" (Figure 42).

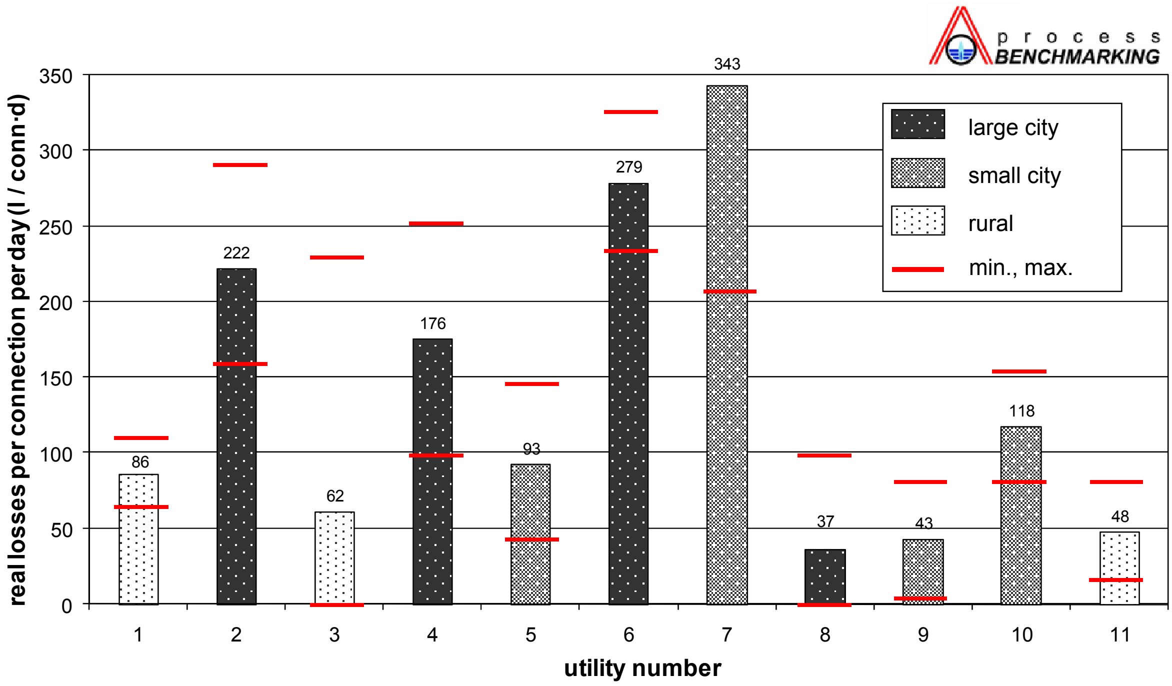


**Figure 42: Real losses per connection per day (source: 2007 OVGW process benchmarking)**

According to the scheme for real losses per connection per day (Table 17), which was developed within this work, it is possible to classify the utilities for this PI into four possible categories: A to D (compare Table 16). Table 47 gives an overview of this classification for the data of the 2007 OVGW process benchmarking. Due to the fact that Table 17 is calculated for an average length of service connections (from property boundary to measurement point) of 5 m, the classification is only significant for the utilities 4, 5, 7 and 8 (bold text in Table 47). The other utilities should preferably calculate the ILI directly and use the classification for ILI.

The utilities number 5 and 8 are classified with “low water losses”, utility number 4 has a medium level of water losses and utility 7 is classified with “high water losses”.

**Table 47: Classification of real losses per connection per day on basis of Table 17**

| **utility number** | **service connection density (conn./km)** | **average service pressure head (m)** | **average length of service connections** (from property boundary to measurement point) **(m)** | **real losses per connection per day (l/conn.d)** | **classification on basis of Table 17** |
|---|---|---|---|---|---|
| 1 | 27.3 | 52 | 10.0 | 86 | A |
| 2 | 31.4 | 49 | 10.0 | 222 | B |
| 3 | 21.3 | 54 | 20.8 | 62 | A |
| **4** | **30.4** | **40** | **5.0** | **176** | **B** |
| **5** | **28.7** | **50** | **5.0** | **93** | **A** |
| 6 | 29.9 | 40 | 11.6 | 279 | C |
| **7** | **36.3** | **50** | **5.0** | **343** | **C** |
| **8** | **38.3** | **44** | **6.2** | **37** | **A** |
| 9 | 21.4 | 60 | 15.0 | 43 | A |
| 10 | 23.3 | 50 | 20.0 | 118 | A |
| 11 | 34.7 | 55 | 10.5 | 48 | A |

According to Table 16: A…low water losses B…medium level of water losses C…high water losses D…very high water losses

Figure 43 shows the results for the Infrastructure Leakage Index (ILI). According to the definition of this PI, the ILI should only be calculated for water utilities with more than 3000 service connections. Therefore the utilities with less than 3000 service connections are marked within the figure.

The ILI is the preferable performance indicator for a classification of water losses because this PI considers many structural criteria like length of mains, number and length of service connections and the average service pressure.

On the basis of Table 16, the following classification for the ILI’s of the OVGW process benchmarking 2007 can be made:

| | | |
|---|---|---|
| C | high water losses: | utility number: 6, 7 |
| B | medium level of water losses: | utility number: 2, 4 |
| A | low water losses: | utility number: 1, 3, 5, 8, 9, 10, 11 |

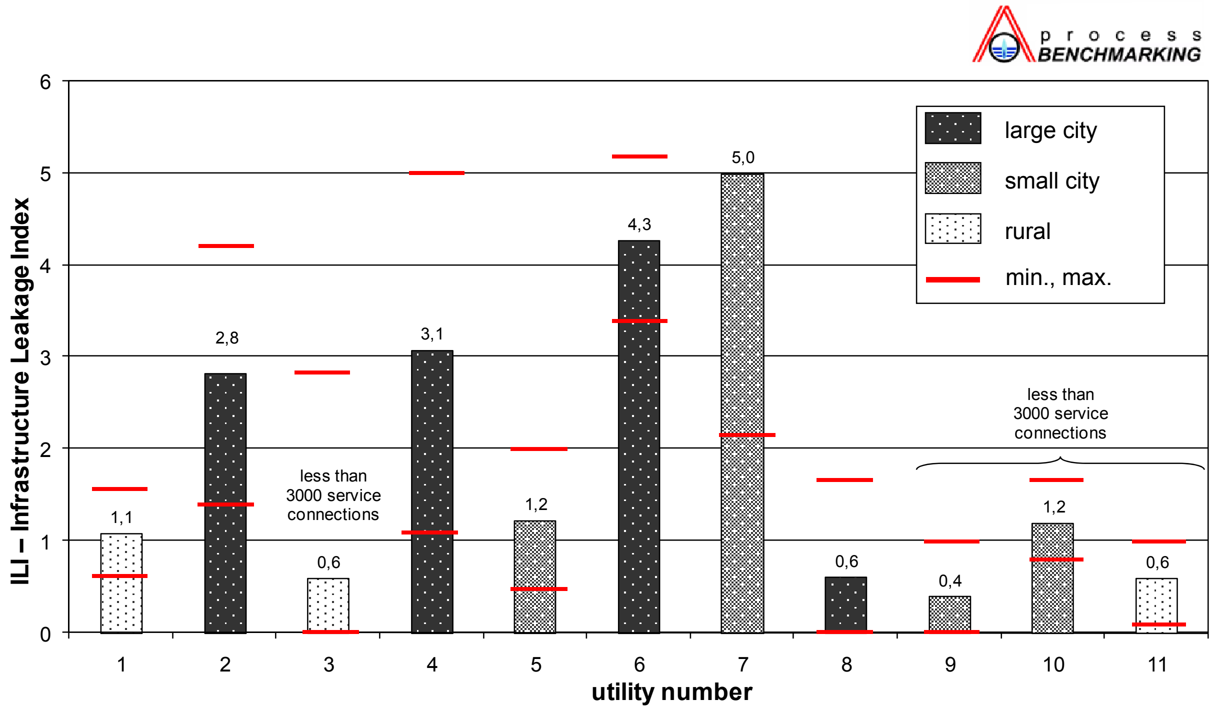


**Figure 43: ILI (source: 2007OVGW process benchmarking in Koelbl et al. 2008a, amended)**

Figure 44 gives an overview of the non-revenue water expressed in percentages of the system input volume.

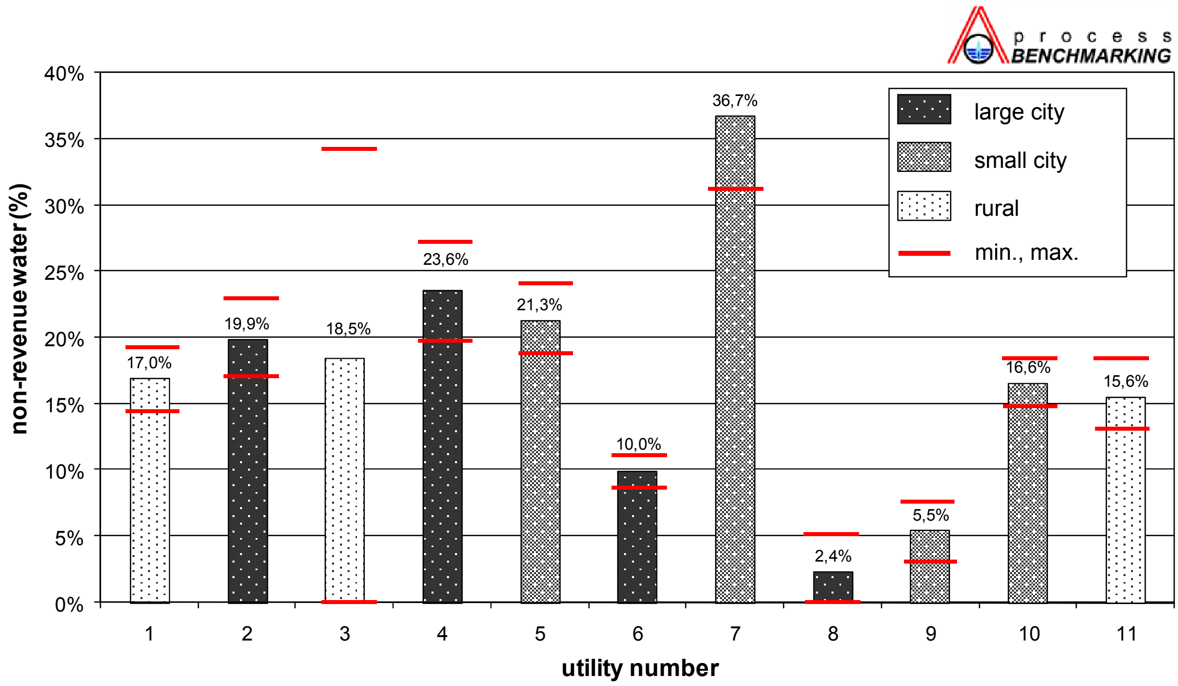


**Figure 44: Non-revenue water (source: OVGW process benchmarking 2007)**

A comparison of the different classification schemes in Table 48 shows that the DVGW W 392 (2003) classification for real losses per connection per day is stricter than the ILI classification, which is based on the World Bank Institute classification scheme. According to the classification for real losses per connection per day the utilities 1, 3, 5, 10 and 11 have a medium level of water losses. But on basis of the ILI classification these utilities are in the range of low water losses. The utilities 2 and 4, which are classified as systems with high water losses on basis of losses per mains length, have a medium level of losses according to the ILI scheme. The utilities 6 and 7 are classified as systems with high water losses in both classification schemes, and the systems with low water losses according to losses per mains length (utilities number 8 and 9) also have low losses according to the ILI scheme.

The classification for real losses per connection per day is based on the ILI classification scheme, but as Table 17 is calculated for an average length of service connections (from property boundary to measurement point) of 5 m this scheme only enables an estimation of the classification, especially for utilities with service connection lengths other than 5 m.

However, Table 48 shows that the influence of the length of service connection is not that high. For the eleven values of 2007 OVGW process benchmarking the classifications are all the same as those of the classification for the ILI. Nevertheless, for values near categories' borders a more exact classification on basis of ILI is recommended.

**Table 48: Comparison of different classifications**

| | Classification | | | |
|---|---|---|---|---|
| **utility number** | **water loss ratio** | **real losses per mains length** | **real losses per connection per day** | **ILI** |
| 1 | 12.9% | medium | A low | A low |
| 2 | 15.3% | high | B medium | B medium |
| 3 | 8.9% | medium | A low | A low |
| 4 | 12.7% | high | B medium | B medium |
| 5 | 9.9% | medium | A low | A low |
| 6 | 7.9% | high | C high | C high |
| 7 | 27.3% | high | C high | C high |
| 8 | 2.0% | low | A low | A low |
| 9 | 3.4% | low | A low | A low |
| 10 | 9.9% | medium | A low | A low |
| 11 | 6.6% | medium | A low | A low |

The aspect of misleading interpretations of water loss ratios expressed in percentages of the system input volume becomes clear with utility number 6. Comparing the performance of water utility number 6 on the basis of the classifications of the other three PIs in Table 48, it becomes clear that the water loss ratio leads to a completely wrong interpretation of the situation. With only about 8 % of water losses this utility would probably be classified as a system with low water losses, but on the basis of the indicators which consider the structure of the supply system (real losses per mains length, real losses per connection per day and ILI) this utility is classified as a system with high water losses. Therefore the water loss ratio should not be used for technical assessment.

### 6.2.2. Main process results

Beside evaluations of all sub processes the overall performance of the main process is also analysed. Therefore the costs and also the effort in working time per kilometre of distribution mains and per 100 service connections are calculated. These values are compared with an overall quality index which is calculated from the single quality indices of all the sub processes and supporting processes.

Figure 45 shows the overall performance of the whole process of water loss management. The range of costs per kilometre mains is very broad, from about 50 € per km up to about 360 € per km. This broad range shows that there may be a large potential to increase the efficiency at some utilities which has to be analysed to identify the right strategy for leakage monitoring and leak detection for each utility. For example, water utility number 4 does a lot of leak detection on a rotational basis (compare Figure 50) but the ILI of this utility is about 3 (compare Figure 43), which is not that bad in comparison with international examples. However, for the Austrian situation there is room for improvement.

On the left side of Figure 45 are the water utilities 1 and 11, which use DMAs for leakage monitoring (note: The costs for installing the monitoring system are not included in Figure 45).

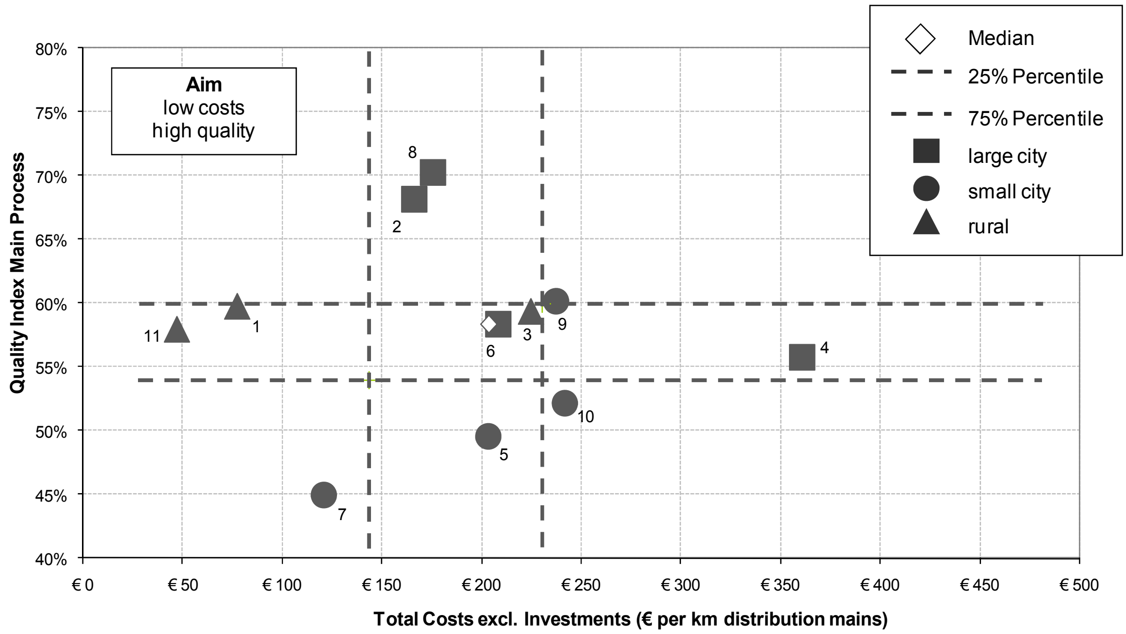


**Figure 45: Total costs (excl. investment cost for leakage monitoring) and quality index of main process (the numbers represent the participating water works), (source: 2007 OVGW process benchmarking in KOELBL et al. 2008a)**

Investment costs for leakage monitoring systems are an essential aspect for discussing the efficiency of water loss management. Often it is difficult to allocate investment costs for leakage monitoring systems because in general these systems are used also for other purposes like controlling pumps and valves. This was one reason for excluding the investment costs in the 2007 OVGW project. Nevertheless, these costs need to be considered for an objective discussion.

Figure 46 shows the total costs of the main process inclusive of investment costs for leakage monitoring systems, where that proportion of costs for measurement systems and SCADA systems which can be attributed to leakage monitoring is considered. The investment costs are considered as depreciation costs (depreciation period: 10 years). Because the investment costs have been collected as context information (note: no accuracy considered) in the 2007 OVGW project, the results in Figure 46 have to be seen as a first trial to test the methodology but the data are not proved to be reliable.

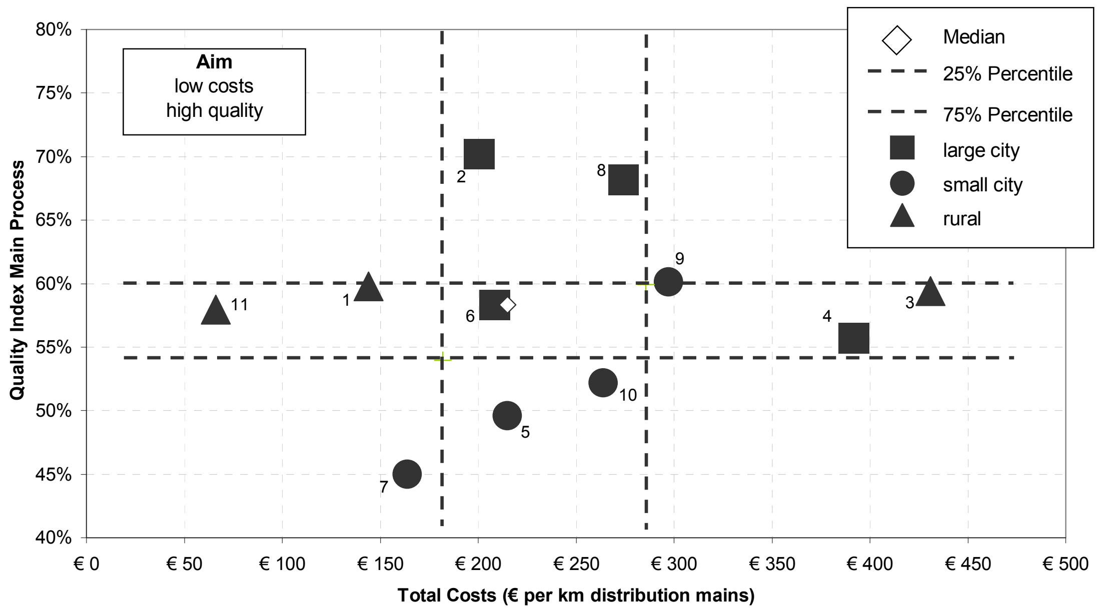


**Figure 46: Total costs (incl. investment costs for leakage monitoring) and quality index of main process (source: 2007 OVGW process benchmarking)**

Figure 47 gives an example for the evaluation of working hours. In this case the denominator is 100 service connections. The effort in working hours is, as with the costs, quite different and varies over a huge range. Especially utility number 4 spends more than double the time of the other participants.

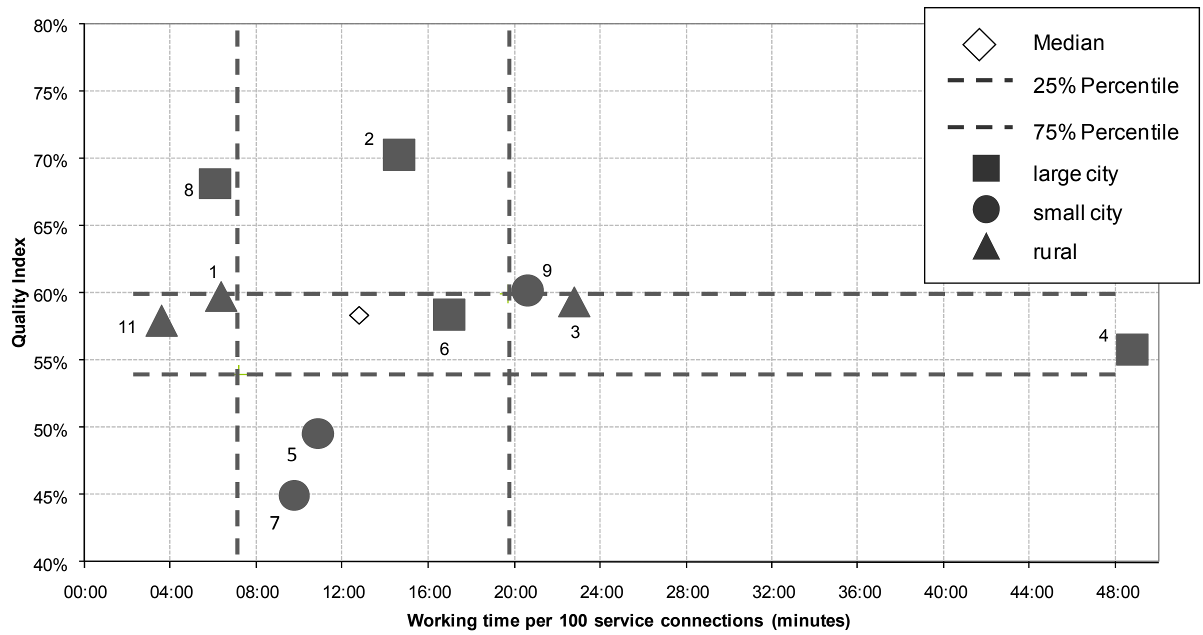


**Figure 47: Working time per 100 service connections and quality index of main process (source: 2007 OVGW process benchmarking)**

The interpretation of the main process results needs to be done cautiously because the frame conditions of the participating eleven utilities of the 2007 OVGW process benchmarking are very heterogeneous and a multi-criteria clustering is not possible due to the low number of participants. Therefore the comparability is much better on the level of sub processes. Nevertheless the background knowledge about the utilities frame conditions (also from previous corporate benchmarking projects) allows an interpretation on the level of the overall process.

The lowest main process costs per km distribution mains (excl. investment costs) have the utilities 1 and 11. Both of them achieve a moderate quality index level. Utility 1 is a supra-regional supplier with many DMAs. Of course the geographical frame conditions of utility 1 for installing DMAs are favourable and are therefore not comparable with the frame conditions of large cities. Nevertheless the DMA system of utility 1 is probably the largest and one of the best DMA systems in Austria.

Utility 11 is a relatively small rural water supply system which has only one system input point (a well with a storage tank). Therefore the leakage monitoring is very simple (low depreciation costs). Due to the relatively low average age of the pipe network, the failure rates are quite low (6.8 per 100 km distribution mains) and therefore the effort in leak detection is also very low.

On the other side of the spectrum, utility 4 has the highest main process costs. This utility is a large city with a high average network age. The reason for the high costs might be the rotational leak detection strategy. Experiences in other cities show that recent technologies like noise loggers are much more cost efficient than common sounding campaigns like it is practiced by utility 4.

Although the quality index for the main process is not very reliable and significant, it becomes clear that utility 7 achieves the lowest quality index on the main process level. This corresponds with the high leakage level (ILI of 5). The low total costs of utility 7 are due to less effort in leak detection and in leakage monitoring. This utility has large potential for improvements but needs to build up a water loss management strategy first of all.

The utilities 2 and 8 which use mixed leak detection strategies (DMAs and rotational leak detection) achieve the highest quality indices at a moderate cost level (160 to 170 €/km).

Considering the investment costs (Figure 46) the utilities 1, 7 and 11 have the lowest total costs (under 160 €/km). Most of the utilities have costs between 200 €/km and 300 €/km (utilities 2, 5, 6, 8, 9 and 10). The highest total costs have the utilities 4 (about 390 €/km) and 3 (about 430 €/km). Utility 3 is a small, rural structured water supply system with several system input point (some springs) and several zones. Therefore the investment costs but also the running costs are higher than in other larger and less complex structured utilities.

For more significant interpretations more accurate data about investment costs would be necessary. But also the number of participants with similar frame conditions should be higher to enable a clustering of utilities with same frame conditions. As already mentioned, the interpretation of quality indices should be done on the sub process level. Also for the economic performance indicators the comparability is much better on the level of sub processes.

### 6.2.3. Leakage monitoring sub process results

The effort in working hours for leakage monitoring strongly depends on the leakage monitoring systems installed and on the size of the utility. Small utilities with complex systems (e.g. many system input points and several measurement zones) have higher costs per kilometre distribution mains or per 100 service connections than larger utilities and utilities with less complex systems. Depending on the functionality of the monitoring system (e.g. analyses software), the daily effort in working hours is variable.

Figure 48 shows the running costs for the leakage monitoring sub process (exclusive of investment costs for leakage monitoring systems) and the quality index, and Figure 49 shows the monitoring cost inclusive investment costs (consideration of depreciation costs of leakage monitoring systems) and the ILI. The unit of the cost data is € per kilometre of distribution mains per year.

The two figures not only give a good overview of the water loss situation, the leak detection strategies (cause related or on rotational basis, compare chapter 4.5.3) and the quality in operating the sub process of water loss monitoring but also of the influence of the urbanity. As shown in Figure 48 the utilities 6 and 7 have a significant lower quality index than the other utilities. This might results from an almost missing leakage monitoring at utility 6 and an (up to now) missing strategy in water loss monitoring at utility 7. Figure 49 shows that these results correspond with the performance in ILI, which is the highest for those two utilities in the whole field of participants.

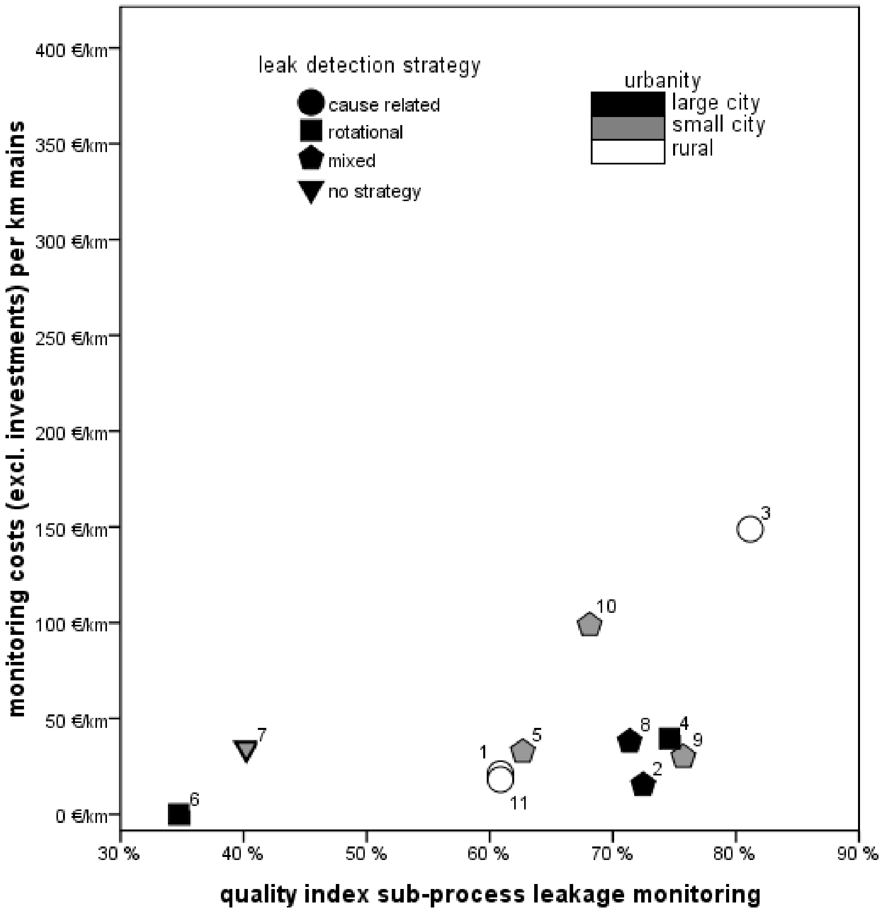


**Figure 48: Running costs for leakage monitoring (source: 2007 OVGW process benchmarking)**

Concerning running costs, eight of the eleven utilities are almost on the same level of about 20-30 € per kilometre of distribution mains per year. Utility 6 has no costs, whereas the utilities 3 and 10 have higher running costs of about 100 €/km (utility 10) and 150 €/km (utility 3). On the one hand, the higher costs per km result from the system size (both between 60 and 75 km distribution mains) and, on the other hand, from a relatively complex water supply system with some system input points, several assets (storage tanks, bulk delivery points etc.), several DMAs and the fact that the monitoring system is not fully completed (utility 3).

Some of the utilities use DMAs (utilities 1, 3, 8 and utilities 9, 10 and 11 partly). Utility number 1 probably has the most diligent DMA system of all the participants with more than 60 DMAs and practicable analysis software. The running costs are quite low and the investment costs for this system are not out of range.

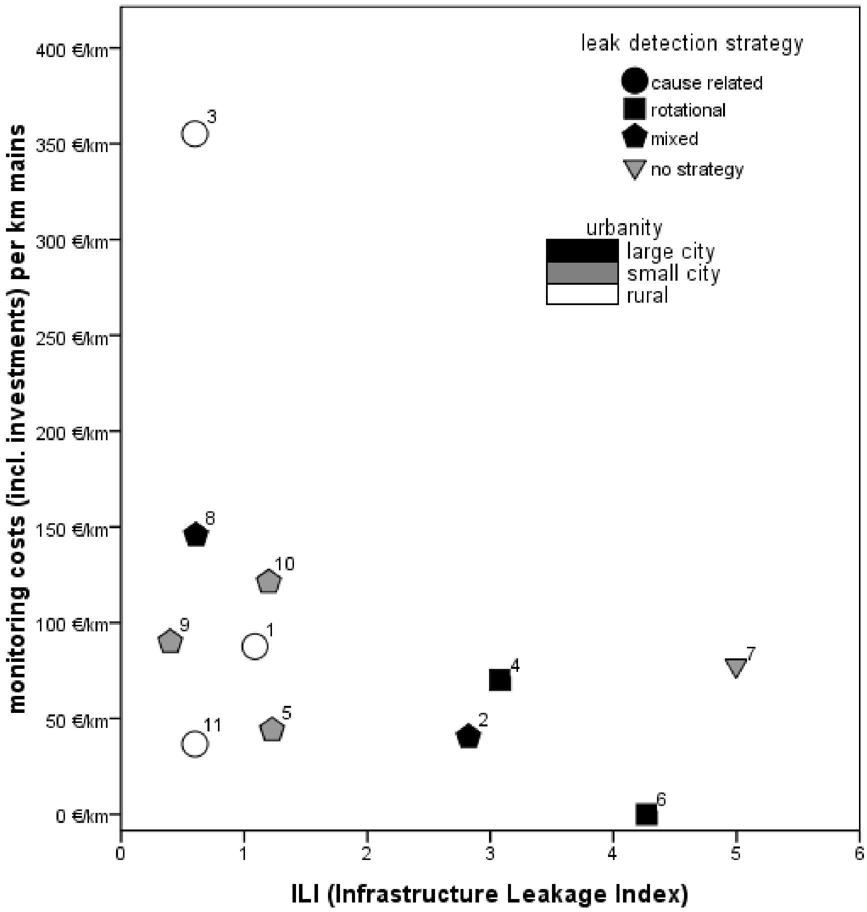


**Figure 49: Leakage monitoring costs inclusive investment costs for leakage monitoring systems (source: 2007 OVGW process benchmarking)**

One of the larger cities (utility 8) uses a mixed strategy (with some DMAs) and has therefore higher costs for leakage monitoring. This can be seen in Figure 49 where the investment costs are considered, and which are higher than those of the other three large cities (utilities 2, 4 and 6). As we can see in Figure 48, the running costs for leakage monitoring are nearly the same for utilities 2, 4 and 8 but the level of leakage is quite different between utility 8 and the other large cities. This difference is probably not just a result of a more advanced leakage monitoring. In fact the leak detection and the infrastructure management also have a large influence.

### 6.2.4. Leak detection sub process results

The main criteria for the sub process of leak detection are the leak detection strategy (cause related or on a rotational basis, compare chapter 4.5.3), the leak detection technology used and the amount of leak detection.

Some of the participating water utilities use DMAs (see chapter 6.2.3) while other utilities do leak detection on a rotational basis (some of them have mixed strategies with some DMAs and some larger zones).

Figure 50 shows how much leak detection is done by the water utilities per year (within the assessment period of three years). The costs related to the amount of leak detection also vary with the leak detection technology used. For example, water utility number 4 has relatively high costs using mainly common sounding methodology like listening sticks and leak noise correlators (Figure 51). On the other hand, utilities 8 and 9 use noise loggers and therefore have much lower costs for leak detection. Utilities 8 and 9 have a much better performance than utility number 4 when comparing the water loss PIs (Figure 52). Concerning failure rates, the three utilities are in a comparable range of about 15 to 18 failures per 100 km of distribution mains per year (compare Figure 55). Therefore utilities 8 and 9 have a comparable effort to utility 4 in pinpointing but due to their cause based leak detection strategy the run times of leaks might be shorter than at utility 4.

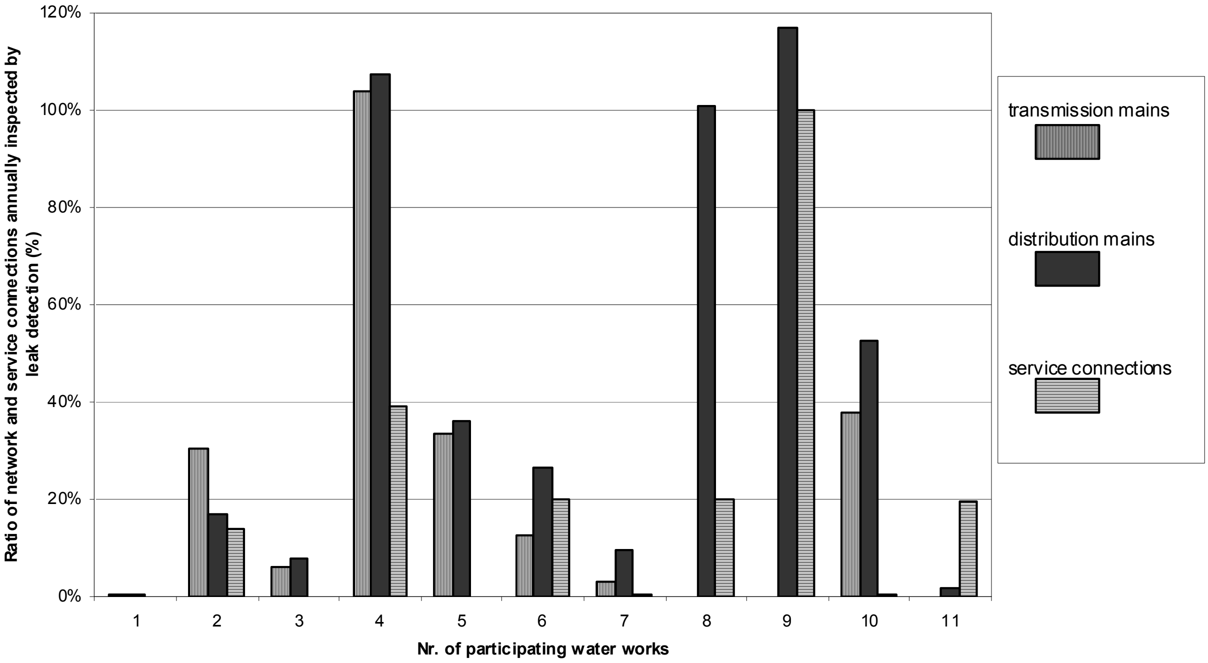


**Figure 50: Ratio of network and service connections annually inspected by leak detection (source: 2007 OVGW process benchmarking in KOELBL et al. 2008a)**

Another outcome of this analysis is the fact that those utilities which use DMAs have a significant lower effort in leak detection. Utilities 1, 3 and 11 only do cause related leak detection which is less (or much less) than 10 % of the distribution mains per year. Therefore the leak detection costs of these utilities are only a 1/4 to 1/3 of the costs of the utilities 2, 5, 6, 8, 9 and 10. Utility 7 has quite low costs because there is a lack of leak detection measures, which becomes clearer when comparing the level of water losses.

Figure 52 compares the level of water losses with the ratio of annual leak detection. Utility number 7 has the highest water losses but one of the lowest ratios of leak detection. It is obvious that a first measure for reducing water losses has to be an increase in leak detection. Increasing the amount of leak detection is also recommended for utility number 6. But utility 6 should also improve its leak detection strategy.

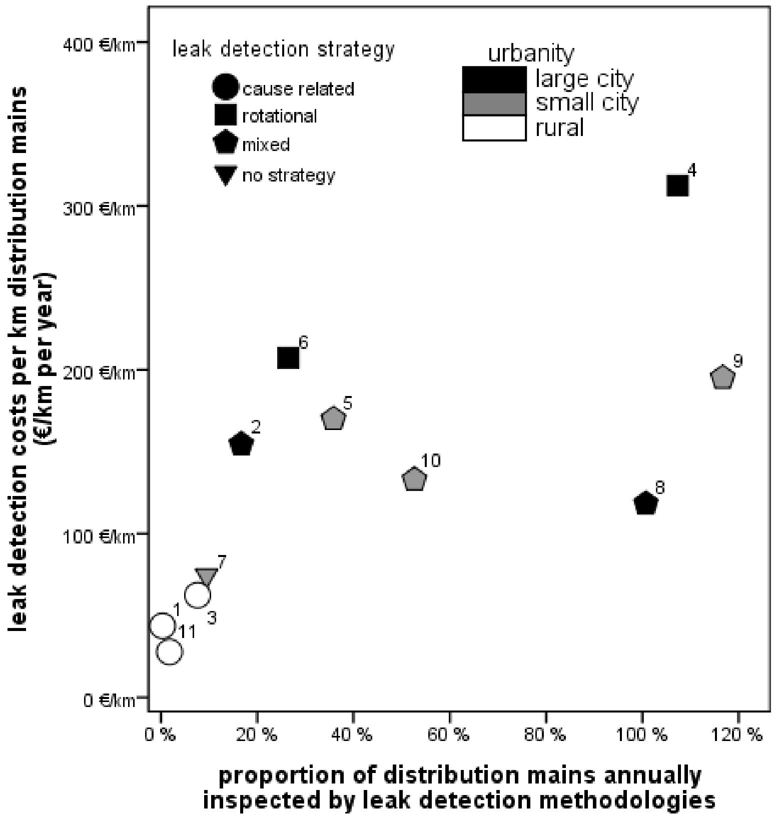


**Figure 51: Costs of leak detection and ratio of network and service connections annually inspected by leak detection (source: 2007 OVGW process benchmarking)**

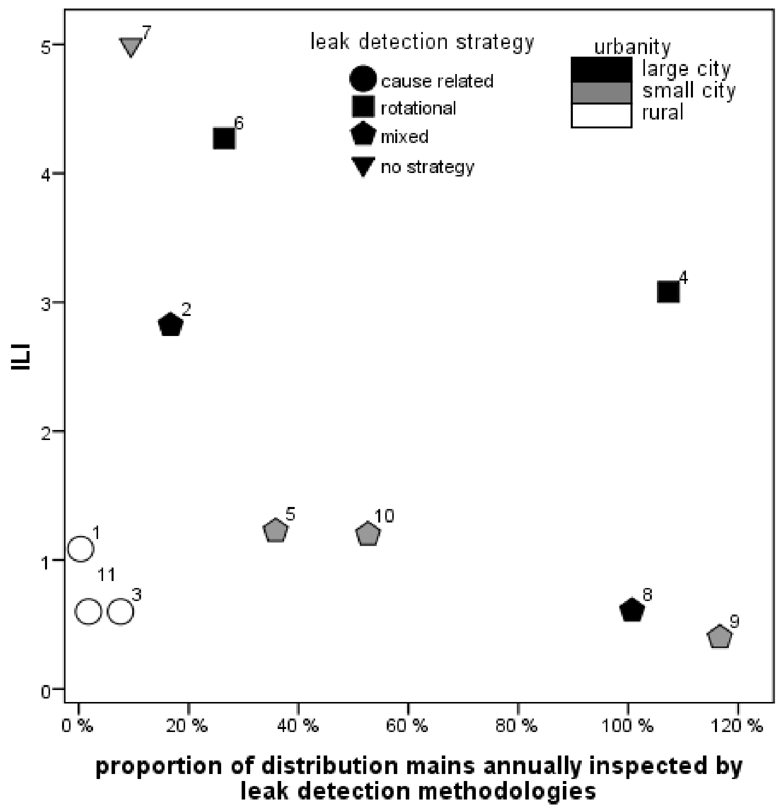


**Figure 52: ILI and proportion of distribution mains annually inspected by leak detection (source: 2007 OVGW process benchmarking)**

Another aspect that needs to be considered is the average network age. The average network age was not assessed in the 2007 OVGW process benchmarking project but information from the OVGW corporate benchmarking has been available for most participating utilities. Following (qualitative) classifications of the network age can be done for the utilities:

| | |
|---|---|
| young network: | utilities 2, 11 |
| medium network age: | utilities 1, 3, 5 (?), 6, 8, 9, 10 |
| old network: | utilities 4, 7 (?) |

(?)...no detailed information available

Considering the network age it becomes clear, that (especially) the utilities 4 and 7 need to focus on infrastructure management (beside increasing the leak detection) to decrease the average network age. The utilities 2 and 6 need to analyse, if “critical” pipe groups are responsible for background losses which are difficult (or impossible) to detect (e.g. problems with corrosions or with seals at pipe couplings).

### 6.2.5. Analyses & planning sub process results

The efficiency assessment of analyses & planning sub process is quite difficult because most of the utilities can only estimate the annual working time spent on these purposes. Therefore a higher possible error margin (data accuracy) needs to be considers for the interpretation of these results. Nevertheless, more than the half of the participants of the 2007 OVGW process benchmarking have the same range of annual costs per kilometre (9-14 €/km) whereas three utilities specify their costs at less than 2 €/km (Figure 53).

An increase with the utility size becomes evident concerning the quality in sub process operations (Figure 53). All the larger cities and a large rural utility (all of them have a system input volume of more than 5 million m³ per year) reach a higher quality performance than the smaller cities and the two smaller rurally structured utilities.

The main criteria for the quality of analyses & planning sub process are the regularity of different analyses (night minimum consumption, failure rates etc.) and the calculation of a water balance and different water loss PIs (see chapter 5.4.7.3). Larger utilities obviously have more personnel resources but also more know-how and routine in doing analyses and planning activities. In general the larger utilities use the information of the water loss management more intensive for other purposes like rehabilitation and maintenance planning. This might also be a reason for the higher quality index.

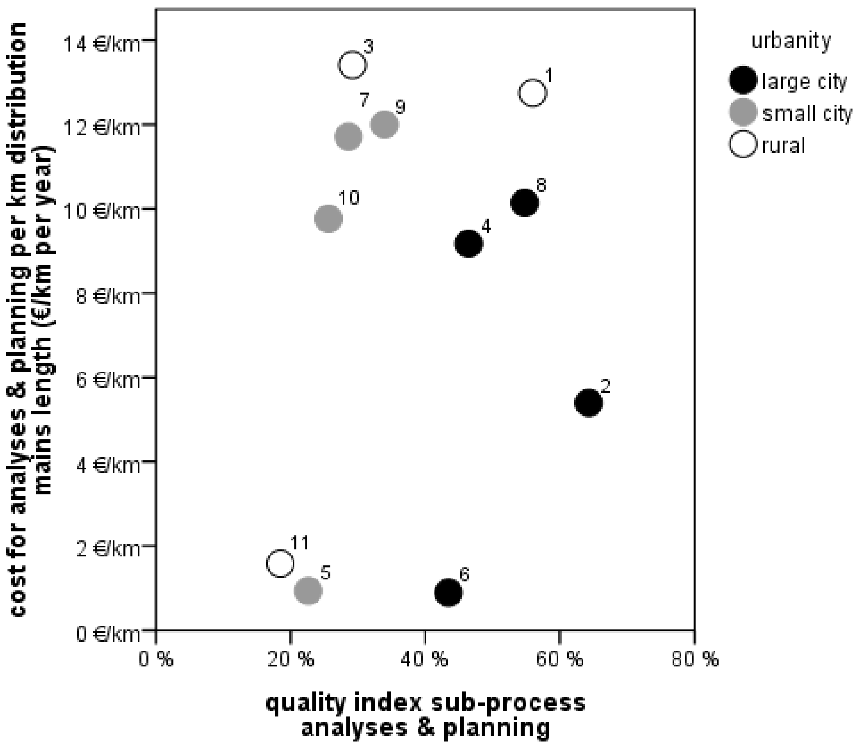


**Figure 53: Costs per km distribution mains for analyses & planning (source: 2007 OVGW process benchmarking)**

### 6.2.6. Leak repair supporting process results

Due to its status as a "former" sub process and its special role within infrastructure management, some performance indicators are calculated for the leak repair supporting process.

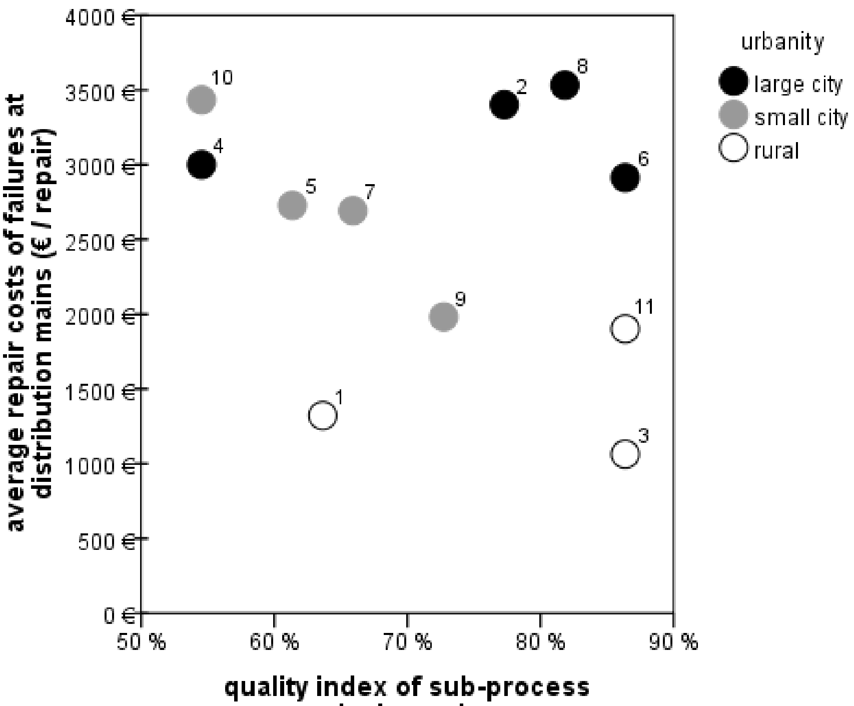


**Figure 54: Average repair costs for leak repair at distribution mains (source: 2007 OVGW process benchmarking)**

One aspect is the assessment of average repair costs at distribution mains (for failures with leakage). Whereas the rural utilities have average repair costs of less than 2000 € per failure, larger cities have higher repair costs of about 3000 to 3500 € per failure due to the usually more complex situations in larger cities (e.g. pipes of other media e.g. gas; traffic, etc.). Therefore the construction costs are lower in rural regions (note: also the rebuilding of the road surface is in general more expensive in urban situations). Two of the smaller cities lie between these two groups; one of them has higher costs and one of them has costs comparable with rural systems (Figure 54).

Another interesting aspect is the correlation of failure rates with the level of water losses. Figure 55 allows a bold interpretation of the situation within the utilities regarding the condition of infrastructure, strategy in leakage monitoring and leak detection and also regarding the effectiveness of water loss management.

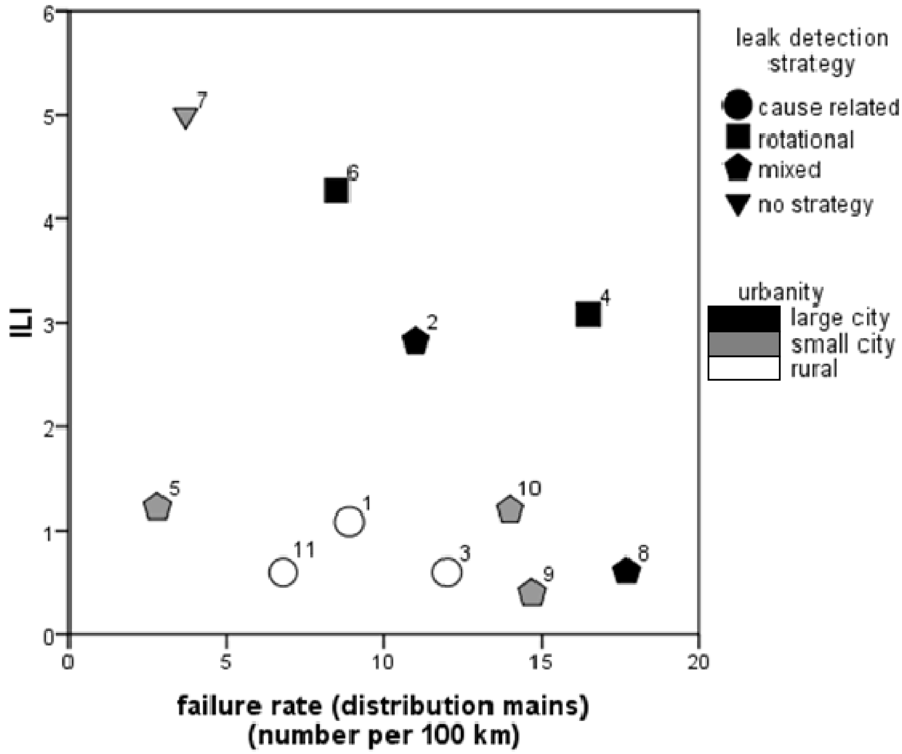


**Figure 55: Failure rates and ILI (source: 2007 OVGW process benchmarking)**

There are four utilities with significantly higher water losses than the other utilities, which have ILIs around 1. The utilities with higher losses are 2, 4, 6 and 7, which use a leak detection strategy on a rotational basis (except utility 2 which uses a mixed strategy) and do not have intensive leakage monitoring.

Utility number 7 has high water losses but a very low failure rate. The low failure rate is probably due to a lack of leak detection (compare Figure 52). There may be many undetected leaks within this supply system. A decrease in leakage can be expected with an increase in leak detection.

Utilities 2 and 6 have medium failure rates and a medium to high level of water losses. The ratio of mains annually inspected by leak detection of these two utilities is about 20-25 %. Beside an increase in leak detection, optimisations of leakage monitoring and of the leak detection (strategy and technology) are also recommended.

Utility number 4 seems to be in a more difficult situation (higher average age of network). Although a lot of leak detection is done and many failures are repaired, the amount of water losses is relatively high. Beside intensive leak detection measures, other infrastructure measures like an effective rehabilitation planning, should also be taken into consideration.

All the utilities with lower water losses use a cause based or mixed leak detection strategy. It is evident that intensive leakage monitoring enables short awareness times and, combined with cause based leak detection, the run times of leaks are kept short. Of course, it has to be taken into consideration that most of these systems (except utility number 8) are small cities or rural water supply systems, which makes the situation easier. Nevertheless, the example of utility number 8 shows that it is possible to achieve a good level of leakage even in large and historic cities.

### 6.2.7. Quality indices results

The problems in assessing process quality and calculating quality indices has already been discussed in chapter 5.4.7. Figure 56 shows the quality indices of all the sub and supporting processes and also of the main process (overall process), as calculated in the 2007 OVGW process benchmarking.

The results of the quality indices are plausible regarding their performance in water loss management for almost all the utilities. E.g., utility number 6 has high quality indices in leak repair (e.g. good documentation of failures) and in infrastructure management (e.g. good rehabilitation planning) and, on the other hand, a weak performance in leakage monitoring. This corresponds with the results discussed in the previous chapters. There is also good (or quite good) correlation for the utilities 3, 4, 5, 7, 8, 9, 10 and 11.

For the utilities 1 and 2 it seems that the quality indices do not reflect their “real” performance in water loss management. Utility number 1 probably has one of the most diligent monitoring systems of all the participants and a quite low level of water losses but attains only an average quality level. Utility 2 has the highest quality index for the main process but has higher water losses than utility 8.

Therefore the quality indices were adapted on the basis of these experiences. Following adaptations have been implemented (compare chapter 5.4.7):

- consideration of water losses (ILI)
- adaptation of assessment of qualification of staff
- adaptation of weightings for the main process quality index

Figure 57 shows a comparison of the quality index for the qualification of staff calculated within the 2007 OVGW process benchmarking with the adapted index described in chapter 5.4.7. Larger utilities (e.g. utilities 1, 2, 6, 8) especially benefit from this adaptation and reach higher quality indices for this supporting process because it is not the proportion of staff that fulfils various qualification criteria. There is only an evaluation if there is staff with these qualifications (but not the proportion of staff).

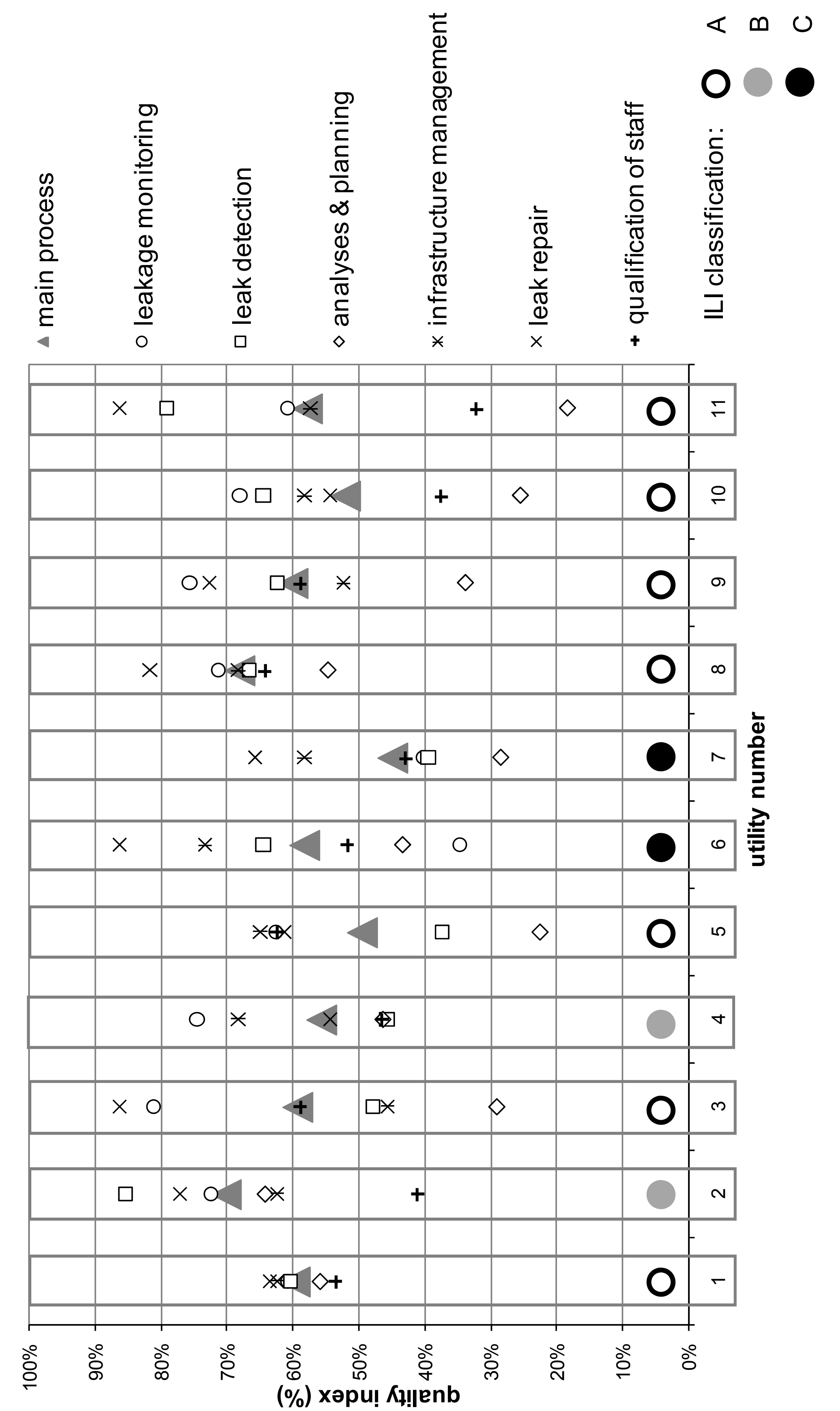


**Figure 56: Summary of quality indices (source: 2007 OVGW process benchmarking)**

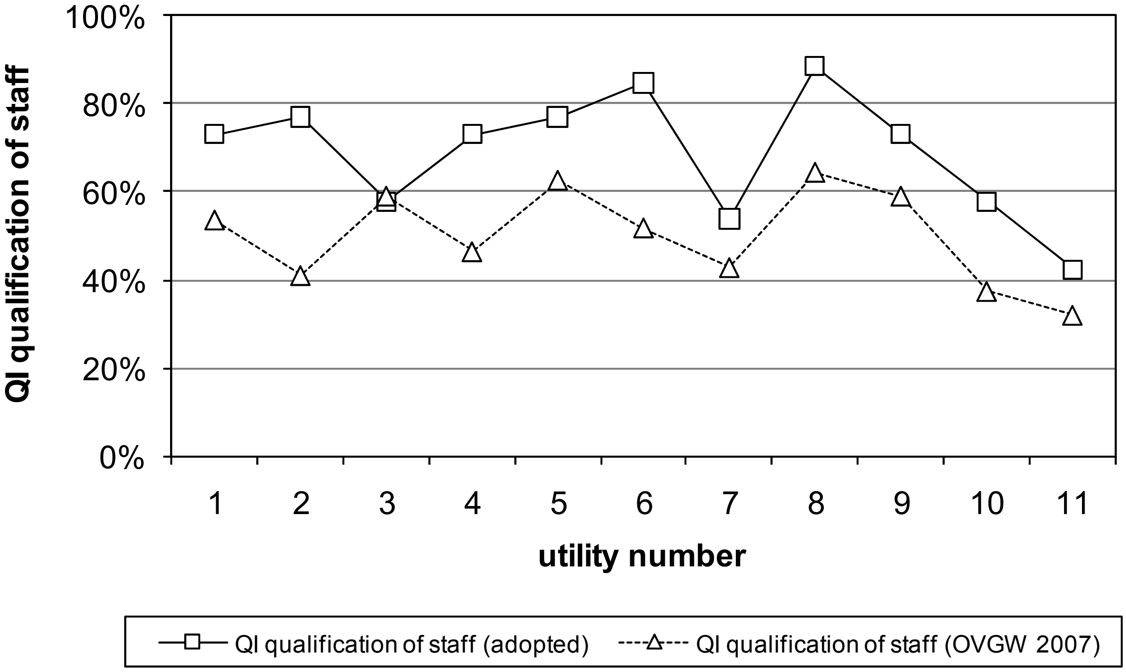


**Figure 57: Comparison of quality indices for qualification of staff**

The adaptation of the quality indices also has an influence on the quality index of the main process. Utilities with low water losses benefit from the consideration of the level of water losses whereas utilities with high water losses achieve a lower main process quality index. In Figure 58 the adapted quality index for the main process is compared with the original one. The utilities with low water losses (utilities 1, 3, 5, 8, 9, 10 and 11) now reach a higher level of main process quality, whereas the utilities number 2, 4, 6 and 7 stay almost at the same quality level. Utility 2 reaches a higher quality index of staff but due to the ILI of about 3 the main process quality index does not change.

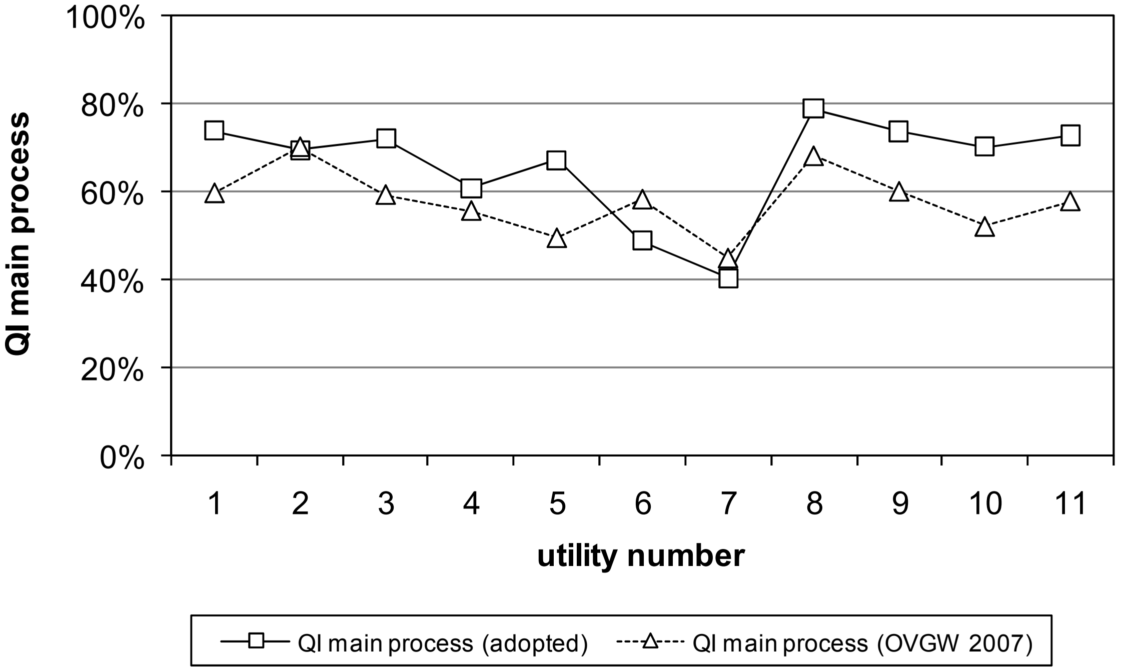


**Figure 58: Comparison of quality indices for main process**

### 6.2.8. Best-practices workshop

A one-day best-practices workshop with the objectives of analysing the results of the process comparison and giving an exchange of experiences to derive measures for improvement was the last “official” step in the field test.

After an introduction of the most important results of the process comparison, three utilities presented different strategies and technologies in water loss monitoring and leak detection:

- utility number 1: leakage monitoring on the basis of DMAs and cause based leak detection
- utility number 6: leak detection on a rotational basis (no DMAs)
- utility number 9: leak detection with noise loggers

The discussion about these different strategies was followed by analyses of the results of single utilities in comparison with the other utilities. The quality matrix was very helpful for this purpose. On the basis of the eleven quality matrixes, which were printed next to each other on large posters (Figure 59), it was very easy to get an overview about the strengths and weaknesses of each utility. The derivation of concrete measures for improvement was also made easier by this matrix.

**Figure 59: Analyses of the quality matrix within the best-practice workshop (source: 2007 OVGW process benchmarking)**

Concerning leakage monitoring following improvements could have been derived (selected examples):

- increasing of accuracy of system input metering
- implementation of DMAs
- implementation or optimisation of minimum night flow analyses

- modernisation of SCADA system (combination with leakage monitoring software)
- implementation of pressure monitoring
- data gathering for first information about leak location

For the sub process of leak detection following optimisation potentials could have been identified (selected examples):

- change of leak detection strategy (e.g. cause based instead of leak detection on rotational basis)
- optimisation of the location time
- documentation of leak detection activities (where, when, what methodology)
- use of temporary noise loggers

Following examples of improvement potentials in analyses & planning have been identified:

- failure statistics for single zones and  for single pipe groups
- internal analyses of efficiency in water loss management (cost – benefit analyses)
- extended publication of water loss performance indicators (several PIs) in annual reports
- improvement of accuracy of unbilled consumption and other water balance input data

Frequently mentioned improvement potentials for the infrastructure management are for example:

- adaptation of inspection intervals (according OeNORM B 2539 - OVGW W 59)
- hydraulic modelling
- optimisation of rehabilitation planning (on basis of failure rates)
- decrease of maximum service pressure (in some cases)
- failure documentation
- optimisation of repair times

Some of the utilities might have potential for increasing staff qualification in water loss management. For the improvement of the qualification of staff e.g. the OVGW offers training courses on leak detection.

Finally experiences about the following topics were exchanged in detailed discussions:

- different aspects of flow metering and customer meter reading
- zone measurements in large networks (permanent and temporary)
- advantages and disadvantages of different leak detection technologies

- $H_2$-tracer gas technology
- use of measuring vehicles
- leak detection at plastic pipes
- pressure monitoring

The feedback of the utilities to the workshop was very positive and all of them said they had benefitted from the process benchmarking project and, in particular, the best-practices workshop.

As an outcome of the project, and on basis of the workshop results, the utilities can optimise their water loss management. Some utilities expressed the wish to change their water loss management strategy due to the experiences from this project.

## 6.3. *Methodical experiences of the field test*

The most important outcome of the field test from the 2007 OVGW process benchmarking is that the process benchmarking system developed for the process of physical water loss management works. Following the feedback of the eleven participating water supply utilities, the field test was more than just a test run. In fact the utilities already had a useful outcome of the project. The process benchmarking system fulfilled most of the requirements for such an instrument and, therefore, the benefit for the utilities was satisfactory.

But, of course, the field test also provided important information about optimisation potentials of the process benchmarking system itself and was therefore essential for the quality of the process benchmarking system described in this PhD thesis.

Concerning data availability, it was found that most of data can be provided from the utilities with an adequate effort, even if some data need to be estimated. Some utilities had problems submitting accurate data about the working hours for several process steps. Therefore it makes sense to implement (or adapt existing) work time documentation systems within the utilities to gather more detailed information about the effort in work time. Concerning cost allocation, adaptations of documentation system within the utilities are useful for making future comparisons and utility internal management easier.

An important adaptation within the process structure was the change of leak repair from a sub process to a supporting process (compare chapter 5.2). The structure of variables and also the structure of performance indicators changed essentially due to this modification.

Regarding comparability, it was found that a comparison at the level of sub processes or even at the level of single tasks works well, whereas a performance comparison of the main process of physical water loss management is difficult. Therefore it is very important to consider the frame conditions of the participating companies. The condition of the infrastructure is very important (age of pipes, level of water losses) but also the general network instrumentation. The average age of the pipe network was not assessed in the 2007 process benchmarking project but this information is essential for the interpretation of water loss management data and should therefore be assessed in future projects (as context information).

On the basis of the results from the single sub processes the question what is the right strategy in leakage monitoring and leak detection can be answered. Under consideration of the frame conditions it is possible to reveal the advantages and disadvantages of each strategy in a qualitative but also from an economic point of view.

For better comparability of leakage monitoring costs and the total costs of the main process it is necessary to consider the investment costs of leakage monitoring systems (e.g. measurement equipment, SCADA systems). The experience in allocating these costs showed that it is difficult to estimate the portion of investment costs which is related to leakage monitoring. The problem is that these systems are not only used for leakage monitoring in general but also for controlling the water supply system (e.g. control of pumps). In chapter 6.2 the influence of investment costs for leakage monitoring systems was discussed on the basis of the results for the main process and the leakage monitoring sub process.

The comparability of highly aggregated quality indices must be valued critically. The quality index for staff qualifications had to be overworked, because larger utilities were disadvantaged due to the consideration of the proportion of staff qualified for different tasks (see chapter 5.4.7 and 6.2.7). The consideration of the level of water losses was implemented for the quality index of the main process. These measures lead to a better comparability of quality indices.

The need for some minor modifications of definitions like the change of the status of a variable to context information (e.g. “ci201a, leak detection during meter reading”) is not discussed here.

The implementation of additional verbal descriptions as a complement to the “hard facts” in form of variables and performance indicators seems to be important from a methodical point of view. These verbal descriptions about the process operation of single sub and supporting processes should provide useful information for two aspects: to enable a better illustration of the process operation and to identify common practises which should be implemented into the process benchmarking system (compare chapter 5.6).

The experience with the quality matrix was very positive. Together with the performance indicators, the structured quality matrix enables a good overview of the strengths and weaknesses in process operation and it is easily possible to derive measures for improvement.

Another very positive experience of the field test was the best-practices workshop in which the results were discussed in detail and the utilities had the opportunity to exchange their experiences. Experiences with the OVGW project show that one single workshop day is a good start for exchanging experience. However, due to the many aspects which have to be considered in water loss management, further workshops and/or discussions and analyses, maybe in smaller groups or even bilaterally between two utilities are useful and sometimes necessary to derive concrete measures for improvement and to reach the aim of benchmarking: learning from each other.

# 7. Summary and conclusions

The objective of this PhD thesis was to create a process benchmarking system for the process of physical water loss management. Aspects of managing non-revenue water (NRW) were not part of this thesis.

The process benchmarking system developed is based on recent developments in performance assessment and covers aspects of modern water loss management. The process benchmarking system enables an assessment of the performance of water supply utilities in physical water loss management from an economic point of view as well as from technical quality aspects.

The system meets the demands made on performance assessment tools (compare chapter 1.2).

- In the course of a mapping the process the process of physical water loss management a diligent, *clear process structure* was worked out. The process structure is easy to understand and all parts of the process (sub processes, supporting processes) are described in detail. Due to the *hierarchical structure* the performance assessment can be done for different process levels: for the main process as well as for sub processes or even single tasks.
- The process benchmarking system has been developed on the basis of *recent developments* in water loss management and benchmarking. Beside information from publications of the IWA Water Loss Task Force and many personnel discussions with international experts in the field of water loss management, the latest developments in benchmarking were also considered. Experts from the Austrian water supply utilities were also involved in the system development. The merging of latest scientific developments with practical experiences guaranties an up-to-date system with a good *practical applicability*.
- The objective of s*imple data gathering* was perhaps not fully fulfilled. Endeavours were made to work out a simple cost allocation system. However, because, in general, the cost data needed are not directly available from common cost documentations within the utilities, more effort in data collection is necessary. The query of context-information happens with selective lists, which keeps the effort as low as possible. The average time for data collection in the field test was about 3 person-days per utility, which can be seen as an arguable expenditure of time.
- A central point in data comparisons is the consideration of *data quality*. Therefore the accuracy and reliability was considered for all the variables and all performance indicators were indicated by a possible error margin (expressed in percentages or by a data quality classification from A-D, see chapter 5.3.1).
- Another important objective was to create a *transparent process benchmarking system* without using “black-box” solutions. Most of the performance indicators are quite simple, e.g., costs per kilometre or working hours per 100 service connections. It is more difficult to give full transparency with the highly aggregated quality indices. The calculation of the quality indices with all its weightings is described in detail within these PhD thesis but it is difficult to provide that information in a “user friendly” way. Nevertheless, it

is possible to understand the criteria behind the indices in combination with the quality matrix.

- The system developed is *applicable for all structures* and all sizes of water supply systems for direct supply – *rural, urban* and *metropolitan* structures. An application of this process benchmarking system for bulk supply systems is not foreseen. Therefore, adaptations would be necessary due to other demands in water loss management of bulk supply systems than in those systems with a direct supply to customers.
- Of course it is necessary to consider the different s*tructural parameters* of different water supply systems in the performance comparison and data interpretation. Therefore a lot of context information is necessary and various *grouping criteria* and *explanatory factors* need to be defined (e.g., urbanity or the strategy in leak detection). A meaningful performance comparison is only possible in "comparable" groups" (clusters) of similarly structured utilities.
- Concerning the demand of creating a v*oluntary and anonymous system,* the experiences of the field test show that it makes sense to use synonyms (e.g. numbers or letters) in data illustration to preserve anonymity (especially for publications), but when exchanging experiences within the workshops all utilities were of the opinion that it makes sense to abolish the restriction of anonymity within the field of participants. Voluntary participation is a must for process benchmarking as it is a fundamental idea of benchmarking in general. It is not possible to attain success by forcing utilities to participate in process benchmarking. Therefore this instrument is not appropriate for regulating water utilities. Other instruments (e.g. yardstick-competitions) are necessary for this purpose (compare chapter 2.6.3).
- The system stood a *field test* in the Austrian water supply sector. Eleven water supply utilities of different sizes and relevant structures (rural, small city, large city) participated in this first project run. The field test was essential for the quality of the process benchmarking system because the field test provided important information about optimisation potentials of the process benchmarking system itself. Nevertheless, the process benchmarking system already fulfilled most of the requirements during the field test and therefore the utilities were satisfied with the benefits they gained.

The process benchmarking system for physical water loss management has many benefits for water supply utilities and can be used for several purposes:

- finding a strategy
- finding a methodology
- improvement in efficiency
- improvement in quality of process operation
- modernisation

The main process results can be helpful for the purpose of finding the right strategy in water loss management. General aspects of economic performance, but also the level of water losses can vary between different strategies. The system enables to determine whether the strategy used in water loss management is effective or not. If not, the system provides decision support to find the best strategy for a utility. E.g., one outcome of the field test is the fact that utilities with a strong focus on leakage monitoring in general achieve a lower level of water losses than utilities without leakage monitoring. The total costs in water loss management of utilities with focus on monitoring are not higher because the effort in leak detection is usually much lower than with leak detection only on a rotational basis.

Another aspect is the use of the process benchmarking system as a decision support system for an optimal mix of methodologies in leakage monitoring (e.g., functions of SCADA systems) and technical equipment for leak detection (e.g., cost and benefit of noise loggers).

Of course the system supports an improvement in efficiency and quality of process operation. The system should show where there is room for improvements within the process operation. This means detecting inefficiencies but also identifying potentials for technical (qualitative) optimisations.

The methodologies of corporate benchmarking and process benchmarking, and hence also the process benchmarking system for physical water loss management, are instruments which support modernisation and an increase of efficiency in the water supply sector, which is an important objective of the European Commission and the European Parliament.

Beside the practical applicability, this PhD thesis provides some interesting input for scientific progress in the field of performance assessment in the water supply sector.

The PhD thesis can be seen as a further developmental step in the methodology of benchmarking at process level. Whereas many process benchmarking activities are based on almost qualitative process comparisons, this thesis describes the approach of a structured process analyses.

Comprehensible performance comparisons are made possible due to the use of “metric” elements in process benchmarking in the form of a hierarchical process structure with performance indicators according to this structure. This is the basis for a process benchmarking with larger groups of participants. It opens the possibility for gathering a larger quantity of process performance data which are the basis for the definition of significant benchmarks.

The use of “metric” elements in process benchmarking leads to a discussion of the definition of process benchmarking. Up to now the IWA terminology has distinguished between “metric” and “process” benchmarking, whereas in Germany the term “corporate” instead of “metric” has been used in recent publications. The approach of this process benchmarking systems is a further argument that supports the term “corporate” instead of “metric” benchmarking.

In addition to these general aspects regarding the methodology of benchmarking, this work represents an innovation concerning a process analysis of physical water loss management on a quantitative basis. Whereas other process benchmarking projects of water loss management (e.g. Canada or the Scandinavian Six-Cities Group project) have used a qualitative approach up to now, the approach developed in this thesis is based on a structured process mapping that enables quantitative process comparisons of the process of physical water loss management.

A further innovation is the quality matrix developed for the assessment of the quality in process operation and for the derivation of concrete measures for improvement. The matrix includes about 100 single criteria of the three sub processes and the supporting processes and was a central element for the exchange of experiences in the best-practices workshop.

The function of the system as a decision support system for the physical water loss management has already been discussed above, but this aspect also seems to be important from the scientific point of view.

# 8. Outlook on future research

As an outlook on future research, an enlargement of the process benchmarking system from physical water loss management to non-revenue water management can be foreseen. In 2007 the IWA Water Loss Task Force, under the leadership of Roland Liemberger, started an initiative on mapping the process of non-revenue water management. The aim of this initiative is the development of a standardised process structure as a basis for future international process comparisons and benchmarking activities. An intermediate result of this work was presented at the IWA World Water Congress 2008 in Vienna (KOELBL et al. 2008c).

For an international use (especially in developing countries) of this process benchmarking system an enlargement of the system for the methodology of pressure management will be necessary. This aspect was not considered in the Austrian OVGW process benchmarking system because the classical pressure management methodologies are not practiced in Austria (compare chapter 4.6).

Another aspect that could be interesting to implement is the analysis of the economic level of leakage (e.g. LAMBERT & FANTOZZI 2005), which was also not considered in this work. The economic level of leakage is reached, when further water loss reductions are uneconomical.

Due to the fast development of new leak detection and leakage monitoring equipment it will be necessary to adapt the existing process benchmarking system after a certain time.

In parallel with the generation of this PhD thesis the Austrian Association for Gas and Water (OVGW) has revised the OVGW W 63 (1993) guideline which deals with water losses in water distribution systems. Parts of this thesis were incorporated into the new OVGW W 63 (in press) like descriptions of performance indicators, the classification scheme for real losses per connection per day and a description of leak detection methodologies.

As a final comment there should be a reminder that the successful operation of process benchmarking projects at a high quality level requires a qualified and experienced project team and, in particular, motivated participants.

I hope that this work gives support in the battle against water losses and will help many water utilities to improve their water loss management.

# References

ACHTIENRIBBE, G.E. (1997): Die Trinkwasserversorgung in den Niederlanden – strukturelle Veränderungen. – gwf Wasser Abwasser 138. Jg., Nr. 11, p. 548-550, Germany.

ALEGRE, H, HIRNER, W, BAPTISTA, J. M. AND PARENA, R (2000): Performance indicators for water supply services. - IWA Manual of Best Practice, IWA Publishing, London, UK. ISBN: 1900222272.

ALEGRE, H., BAPTISTA, J.M., CABRERA, E., CUBILLO, F., DUARTE, P., HIRNER, W., MERKEL, W. & R. PARENA (2006): Performance Indicators for Water Supply Services. - Second Edition, Manual of Best Practice, IWA Publishing, London, UK. ISBN 1843390515.

AWWA (2003): AWWA Water Loss Control Committee Report. - AWWA Journal, **98/8**, Denver, USA.

BROTHERS, K. (2002): DMA Design & Application for Non-Revenue Water Reduction in Canada. - IWA Conference "Leakage Management – A Practical Approach", Conference Proceedings, Cyprus.

CAMP, R. (1989): Benchmarking: The Search for Best Practices that Lead to Superior Performance, ASQC Quality Press, Milwaukee, USA.

CHARALAMBOUS, B. (2008): Bridging the water crisis gap: the role of water loss management. – Water21, October 2008, IWA Publishing, London, UK. ISSN 1561-9508.

CLAUSEN, H. & U. SCHEELE (2001): Benchmarking und Yardstick Competition – Ansätze vergleichenden Wettbewerbs in der Wasserwirtschaft. - Wirtschaftswissenschaftlicher Diskussionsbeitrag V-232-01, Institut für Volkswirtschaftslehre I, Carl von Ossietzky Universität Oldenburg.

COST (2008): www.cost.esf.org, 24th of October 2008.

COST C18 (2008): www.costc18.org, 24th of October 2008.

DICKINSON, M. A. (2008): How important is structured training in achieving maximum benefits? Is it overlooked by utilities and is there a need for further development in a continuously changing environment? - Presentation at IWA World Water Congress 2008. Vienna, Austria.

DIJKGRAAF, E., DE JONG, R., VAN DE MORTEL & others (1997): Moeglijkheden tot Marktwerking in de Nederlandse watersector. – Study in order of Ministry of Economic Affairs. Ocfeb Erasmus Universiteit Rotterdam, Netherlands.

DVGW - Guideline W 392 (2003): Network inspection and water losses – activities, procedures and assessment. – DVGW, Bonn, Germany.

DWA-Regelwerk Merkblatt DWA-M 149-4 (Draft Version from November 2007): Zustandserfassung und –beurteilung von Entwässerungssystemen außerhalb von Gebäuden; Teil 4: Detektion von Lagerungsdefekten und Hohlräumen in der Umgebung erdverlegter Leitungen. – DWA, Hennef, Germany.

EUROPEAN COMMISSION (2003): Green Paper on services of general interest. COM (2003) 270. – Brussels, Luxemburg.

EUROPEAN COUNCIL (1998): Directive 98/83/EC of 3 November 1998 on the quality of water intended for human consumption. - Official Journal of the European Communities, Brussels, Belgium.

EUROPEAN PARLIAMENT (2000): Directive 2000/60/EC of the European Parliament and of the Council of 23rd of October 2000 establishing a framework for Community action in the field of water policy, Luxembourg.

EUROPEAN PARLIAMENT (2003): Resolution of the European Parliament on the Green Paper on services of general interest. Plenary session document A5-0484/2003 to COM (2003) 270 – (2003/2152(INI)), Strasbourg, Luxemburg.

FARLEY, M. & S. TROW (2003): Losses in Water Distribution Networks – A Practitioner's Guide to Assessment, Monitoring and Control. – IWA Publishing, London. ISBN 1900222116.

FARLEY, M. (2007): Finding the "difficult" leaks. – Water 21, December 2007, IWA Publishing, London, UK. ISSN 1561-9508.

GANGL, G. & J. KOELBL (2009): Anwendbarkeit des Infrastructure Leakage Index - ILI für kleinere Versorger und Messzonen (DMAs). – gwf Wasser Abwasser 150. Jg., Heft 4/2009, Germany.

GIRSBERGER W. (2003): HACCP – Hazard Analysis and Critical Control Points in Modern Management Systems of Water Suppliers. – SVGW Swiss Association for Gas and Water, Switzerland.

HEIN, A., LÉVAI, P. & W. MERKEL (2008): Process Indicators for drinking water production – a unified approach and its pilot application in Germany. - Performance Assessment of Urban Infrastructure Services. IWA Publishing, London, UK. ISBN 978-18-433-9191-3.

HIRNER, W. & W. MERKEL (2002): Benchmarking als Mittel des organisierten Wettbewerbs. – 26. Wassertechnisches Seminar. Berichte aus Wassergüte- und Abfallwirtschaft, Nr.173/2002, S.1-30, TU München, Germany.

HORVATH, P. & N.R. HERTER (1992): Benchmarking: Vergleich mit den Besten der Besten (Benchmarking: comparison with the best of the best). - Controlling, Vol. 4 No. 1, January-February, pp. 4-11.

ISO 24510 (2007): Activities relating to drinking water and wastewater – Guidelines for the improvement and for assessment of the services to users. – International Organisation for Standardisation, Geneva, Switzerland.

ISO 24511 (2007): Activities relating to drinking water and wastewater – Guidelines for the management of wastewater utilities and for the assessment of wastewater services. – International Organisation for Standardisation, Geneva, Switzerland.

ISO 24512 (2007): Activities relating to drinking water and wastewater – Guidelines for the management of drinking water utilities and for the assessment of drinking water services. – International Organisation for Standardisation, Geneva, Switzerland.

IWA (2008): www.iwahq.org, 24th of October 2008.

IWA/WSAA (2006): Background to the IWA/WSAA process benchmarking project. – Information provided by IWA/WSAA process benchmarking. London, UK.

KIESL H. & J. SCHIELEIN (2002): Effizienz- und Qualitätsuntersuchung der kommunalen Wasserversorgung in Bayern (EffWB), Final Report for year 2000. Rödl & Partner, Nuremberg, Germany.

KIESL H. & J. SCHIELEIN (2005): Effizienz- und Qualitätsuntersuchung der kommunalen Wasserversorgung in Bayern (EffWB) 2004. – Final Public Report on Bavarian project 2004/05). Rödl & Partner, Nuremberg, Germany.

KIESL H. (2008): Effizienz- und Qualitätsuntersuchung der kommunalen Wasserversorgung in Bayern (EffWB) 2007. – Final Public Report on Bavarian project 2007). Rödl & Partner, Nuremberg, Germany.

KINGDOM B., LIEMBERGER R. & P. MARIN (2006): The Challenge of Reducing Non-Revenue Water (NRW) in Developing Countries - How the Private Sector Can Help: A Look at Performance-Based Service Contracting. - Water Supply and Sanitation Sector Board Discussion Paper Series No. 8, The World Bank, Washington, DC, USA.

KLEIN, D., PETERSOHN, D. & B. PAETSCH (2008): Benchmarking Laboratory Processes for Drinking-Water Quality Monitoring. - Performance Assessment of Urban Infrastructure Services. IWA Publishing, London, UK. ISBN 978-18-433-9191-3.

KOELBL, J., LIEMBERGER, R., ROGERS, D., THEURETZBACHER-FRITZ, H., NEUNTEUFEL, R., MAYR, E. & R. PERFLER (2008c): Process Mapping of Non-Revenue Water Management. - Poster at IWA World Water Congress 2008, Vienna, Austria.

KOELBL, J., MARTINEK, D., MARTINEK, P., WALLINGER, CH., FUCHS-HANUSCH, D., ZANGL, H. & A. FUCHS (submitted): Multiparameter Measurements for Network Monitoring and Leak Localising. – Paper submitted for IWA conference Water Loss 2009, Cape Town, South Africa in April 2009.

KOELBL, J., MAYR, E., THEURETZBACHER-FRITZ, H., NEUNTEUFEL, R. & R. PERFLER (2008a): Austrian Case Study on Process Benchmarking of Water Loss Management. - Conference Proceedings Water Loss Management, Telemetry and SCADA in Water Distribution Systems, Ohrid, Macedonia.

KOELBL, J., NEUNTEUFEL, R., THEURETZBACHER-FRITZ, H. & R. PERFLER (2007a): Benchmarking in Österreich – Leistungsverbesserung durch Prozess-Benchmarking. – OVGW Symposium 2007, Conference Proceedings. OVGW, Vienna, Austria.

KOELBL, J., THEURETZBACHER-FRITZ, H., NEUNTEUFEL, R., MAYR, E. & R. PERFLER (2008b): Benchmarking the Processes of Customer Meter Reading and Customer Meter Replacement. – Performance Assessment of Urban Infrastructure Services. IWA Publishing, London, UK. ISBN 978-18-433-9191-3.

KOELBL, J., THEURETZBACHER-FRITZ, H., NEUNTEUFEL, R., PERFLER, R. & R. KRENDELSBERGER (2006): Benchmarking in the Austrian Water Supply Sector: Objectives, Development, Structure and First Results of the 2004 Project. - Water and Environmental Management Series, **12**, 197-204, London, UK. ISBN 1843395134.

KOELBL, J., THEURETZBACHER-FRITZ, H., NEUNTEUFEL, R., PERFLER, R., GANGL, G., KAINZ, H. & R. HABERL (2007b): Experiences with Water Loss PIs in the Austrian Benchmarking Project. - Proceedings Water Loss 2007 Volume I, Bucharest, Romania. ISBN 978-973-7681-25-6.

KOUZMIN, A., LOEFFLER, E., KLAGES, H. & N. KORAC-KAKABADSE (1999): Benchmarking and performance measurement in public sectors - Towards learning for agency effectiveness. - The International Journal of Public Sector Management, Vol. 12 No. 2, 1999, pp. 121-144. MCB University Press, UK.

LAMBERT, A. & R. D. MCKENZIE (2002): Practical Experience in using the Infrastructure Leakage Index. - IWA Conference "Leakage Management – A Practical Approach", Conference Proceedings, Cyprus.

LAMBERT, A. & W. HIRNER (2000): Losses from water supply systems: Standard terminology and recommended performance measures. IWA Blue Pages, London.

LAMBERT, A. (2001): What do we know about pressure:leakage relationships?. - Proceedings IWA Conference "System Approach to Leakage Control and Water Distribution Systems Management", Brno, Czech Republic. ISBN 80-7204-197-5.

LAMBERT, A. (2002): International Report on Water Loss Management and Techniques. – Water Science and Technology: Water Supply, **2**(4) (2002), 1-20, London, UK.

LAMBERT, A. (in press): Ten Years Experience in using the UARL Formula to calculate Infrastructure Leakage Index. – IWA Water Loss 2009 Conference Proceedings, Cape Town, South Africa in April 2009.

LAMBERT, A., BROWN, T.G., TAKIZAWA, M. & D. WEIMER (1999): A Review of Performance Indicators for Real Losses from Water Supply Systems. AQUA, Vol. 48 No 6. ISSN 0003-7214.

LAMBERT, A. & M. FANTOZZI (2005): Recent advances in calculating economic intervention frequency for active leakgage control, and implications for calculation of economic leakage levels. – IWA Conference on Water Economics, Statistics, and Finance, Conference Proccedings, Rethymno, Greece.

LARSSON, M., PARENA, R., SMEETS, E. & I. TROQUET (2002): Process benchmarking in the water industry. - IWA Manual of Best Practice, IWA-Publishing, London, UK. ISBN 1-84339-010-8.

LIEMBERGER, R. & R. MCKENZIE (2005): Accuracy Limitations of the ILI - Is it an Appropriate Indicator for Developing Countries?. - IWA Leakage 2005, Conference Proceedings, Halifax, Canada.

LIEMBERGER, R. (2005): The new German water loss regulations in context with other international applications of the IWA water balance and real loss performance indicators. – Conference Proceedings IWA Conference Efficient 2005, Santiago de Chile, Chile.

LIEMBERGER, R. (2006): Das neue IWA-System zur Beurteilung von Wasserverlusten. - Proceedings Symposium Wasserversorgung 2006, OVGW, Vienna, Austria.

LIEMBERGER, R. (2007): Foreword of Conference Proceedings.- Proceedings Water Loss 2007 Volume I, Bucharest, Romania. ISBN 978-973-7681-25-6.

LIEMBERGER, R., BROTHERS, K., LAMBERT, A., MCKENZIE, R., RIZZO, A. & T. WALDRON (2007): Water Loss Performance Indicators.- Proceedings Water Loss 2007 Volume I, Bucharest, Romania. ISBN 978-973-7681-25-6.

LMSVG (BGBL 13/2006): Lebensmittelsicherheits- und Verbraucherschutzgesetz. – Austrian law, Austria.

MAIN, D. (2008a): How to Use 10 Years of Benchmarking Data to Guide Performance Improvement. – Presentation at IWA Conference PI08 – Performance Assessment of Urban Infrastructure Services, Valencia, Spain.

MAIN, D. (2008b): Personal information to the Canadian benchmarking project. May and June 2008. Canada.

MAIN, D., NG, L. & A NORTH (2008): The Canadian national water and wastewater benchmarking initiative: Using process to drive improvement. Strategic Management of Water in Urban Areas. – Performance Assessment of Urban Infrastructure Services. IWA Publishing, London, UK. ISBN 978-18-433-9191-3.

MCCORMACK, CH. (2005): Canadian Utilities Learn to Fly through Benchmarking of Water Loss Management. - IWA Leakage 2005, Conference Proceedings, Halifax, Canada.

MCKENZIE, R. S., WEGELIN, W., MOHAJANE, P. & S. SHABALALA (2007): Hidden benefits of smale scale performance based public private partnerships. – Proceedings Water Loss 2007 Volume III, Bucharest, Romania. ISBN: 978-973-7681-27-0.

MERKEL, W. (2001): Performance assessment in the water industry. IWA International Report "Kennzahlen und Benchmarking", 2. IWA World Water Congress, Berlin, Germany.

MORRISON, J., TOOMS, S. & D. ROGERS (2007): District Metered Areas Guidance Notes. – Guideline of IWA Water Loss Task Force (free available at www.iwaom.org/wltf/).

NAGY, M., LENZ, K., WINDHOFER, G., FÜRST, J. & B. FRIBOURG-BLANC (2007): Data Collection Manual for the OECD/Eurostat Joint Questionnaire on Inland Waters Tables 1-7 - Concepts, definitions, current practices, evaluations and recommendations. –Eurostat, European Commission.

NEBC (2007): The North European Benchmarking Model. Version 1.2, North European Benchmarking Co-Operation, C/o Vewin, The Netherlands.

NEUNTEUFEL, R., PERFLER, R., THEURETZBACHER-FRITZ, H. & J. KOELBL (2007): Explanatory Factor "Average Network Age Index" (NAX) for Mains Failures and Water Losses. Conference Proceedings of LESAM 2007, 2nd Leading Edge Conference on Strategic Asset Management, Lisbon, Portugal.

NEUNTEUFEL, R., THEURETZBACHER-FRITZ, H., TEIX, P., KOELBL, J. & R. PERFLER (2004): Benchmarking und Best Practices in der österreichischen Wasserversorgung – Stufe A. Final Report of OVGW pilot project 2003/04, OVGW, Vienna, Austria.

OeNorm B 2538 (2002): Transport-, Versorgungs- und Anschlussleitungen von Wasserversorgungsanlagen – Ergänzende Bestimmungen zu ÖNORM EN 805 (engl.: Long-distance, district and supply pipelines of water supply systems – Additional specifications concerning ÖNORM EN 805). - Austrian standard, Österreichisches Normungsinstitut, Vienna, Austria.

OeNorm B 2539 – OVGW W 59 (2005): Technische Überwachung von Trinkwasser-versorgungsanlagen. – Austrian standard for technical inspection of water supply systems, Österreichisches Normungsinstitut, Vienna, Austria.

OTTILINGER, F. (2004): EffWB-Untersuchung – Nutzen der Untersuchung für die interne Kosten-/Leistungsrechnung und Steuerung. – Conference Proceedings Benchmarking Fachsymposium Effizienz- und Qualitätsuntersuchung der Kommunalen Wasserversorgung in Bayern (EffWB), Nuremberg, Germany.

OVERATH, H. & W. MERKEL (2004): Kennzahlen für die Wasserversorgung: Feldtest des Kennzahlensystems der IWA – Nationales Teilprojekt Deutschland. IWW-Rheinisch-Westfälisches Institut für Wasserforschung GmbH, Mühlheim an der Ruhr.

OVGW W 63 (1993): Wasserverluste in Versorgungsnetzen, Anschlussleitungen und Verbrauchsleitungen – Feststellungen, Beurteilungen und Maßnahmen zur Verminderung. – OVGW directive, OVGW, Vienna, Austria.

OVGW W 63 (in progress): Water Losses in Water Supply Systems. – Update of OVGW directive W 63 (1993), OVGW, Vienna, Austria.

OVGW W 85 (2007): Operation manual for water supply companies. - OVGW directive, OVGW, Vienna, Austria.

OVGW W 100 (2007): Water Supply Pipelines – Operation and Service. – OVGW directive, OVGW, Vienna, Austria.

PICCININ C. (2006): From metric benchmarking to process benchmarking. – Presentation on IWA Conference “Benchmarking Water Supply, Waste Management and Water Control” in Amsterdam, Netherlands.

PILCHER, R. (2007): Leak Location and Repair Guidance Notes and…. The Never Ending War against Leakage. - Proceedings Water Loss 2007 Volume II, Bucharest, Romania. ISBN: 978-973-7681-26-3.

PILCHER, R., HAMILTON, S., CHAPMAN, H., FIELD, D., RISTOVSKI, B. & S. STAPELY (2007): Leak Location and Repair Guidance Notes. – Guideline of IWA Water Loss Task Force (free available at www.iwaom.org/wltf/).

PROFILE OF THE GERMAN WATER INDUSTRY (2008). – published by ATT (Association of Drinking Water from Reservoirs), BDEW (German Association of Energy and Water Industries), DBVW (German Alliance of Water Management Associations), DVGW (German Technical and Scientific Association for Gas and Water), DWA (German Association for Water, Wastewater and Waste), VKU (Association of Local Utilities). wvgw Wirtschafts- und Verlagsgesellschaft Gas und Wasser mbH, Bonn, Germany.

SAX, CH. & M. SCHREITMÜLLER (2007): Monitoring System for the close meshed Water-pipe network to the City of CRAILSHEIM - Germany. – Poster at IWA Specialists Conference Water Loss 2007, Bucharest, Romania.

SIEBERT, G. & S. KEMPF (1998): Benchmarking: Leitfaden für die Praxis. Carl Hanser Verlag Munich Vienna. ISBN 3-446-19342-1.

STAHRE P. & J. ADAMSON (2002): Performance benchmarking – a powerful management tool for water and wastewater utilities.- Watermarque 3 (5) [Online-Journal]. <http://www.pbngroup.com/members_area/3.5/3.5-6cities.pdf> on 26nd of November 2003.

STAHRE P. & J. ADAMSON (2005): Performance assessment as a management tool - Experiences from the Scandinavian Six-Cities Group. – Presentation at COST Action C18 Meeting in February 2005, Catania, Italy.

THEURETZBACHER –FRITZ, H., KOELBL, J., KAINZ, H., NEUNTEUFEL, R., PERFLER, R. & R. HABERL (2007): New PI`s and explanatory index factors in the austrian water supply benchmarking system. - EFFICIENT 2007 - The 4th IWA Specialist Conference on Efficient Use and Management of Urban Water Supply, Jeju, Korea.

THEURETZBACHER-FRITZ H. & J. KOELBL (2003). Benchmarking und Best Practices in der österreichischen Wasserversorgung – Methodische Überlegungen zum laufenden Forschungsprojekt. - Schriftenreihe zur Wasserwirtschaft, **41**, 241-248, Graz University of Technology, Austria.

THEURETZBACHER-FRITZ, H., NEUNTEUFEL, R., KOELBL, J., PERFLER, R. & E. MAYR (2008): The Right Choice of Denominators and Grouping Factors in Water Supply Metric Benchmarking. – Performance Assessment of Urban Infrastructure Services. IWA Publishing, London, UK. ISBN 978-18-433-9191-3.

THEURETZBACHER-FRITZ, H., NEUNTEUFEL, R., KOELBL, J., PERFLER, R., UNTERWAINIG, M. & R. KRENDELSBERGER (2006): Benchmarking und Best Practices in der österreichischen Wasserversorgung – Stufe B. – Final Report of OVGW project 2005/06, Graz-Wien-Wiener Neustadt, Austria.

THEURETZBACHER-FRITZ, H.,SCHIELEIN, J., KIESL, H., KOELBL, J., NEUNTEUFEL, R. & R. PERFLER (2005): Trans-National *Water Supply* Benchmarking: The Cross-Border Co-operation of The Bavarian EffWB Project and The Austrian OVGW Project. - Water Science & Technology: Water Supply **6** (2005), 273-280, London, UK.

THORNTON, J. & A. LAMBERT (2005): Progress in practical prediction of pressure:leakage, pressure:burst frequency and pressure:consumption relationships. – Proceedings IWA Konferenz “Leakage 2005”, Halifax, Canada.

THORNTON, J. & A. LAMBERT (2006): Managing pressures to reduce new breaks. – Water 21, December 2006, IWA Publishing, London, UK. ISSN 1561-9508

TWV (BGBl. II Nr. 304/2001 idgF): 304. Verordnung des Bundesministers für soziale Sicherheit und Generationen über die Qualität von Wasser für den menschlichen Gebrauch (Trinkwasserverordnung – TWV). – Austrian Drinking Water Ordinance, Austria.

VEWIN (2001): Reflections of Performance 2000 – Benchmarking in the Dutch Drinking Water Industry. – VEWIN, Rijswijk, Netherlands.

VEWIN (2004): Reflections of Performance 2003 – Benchmarking in the Dutch Drinking Water Industry. – VEWIN, Rijswijk, Netherlands.

VEWIN (2007): Reflections of Performance 2006 – Benchmarking in the Dutch Drinking Water Industry. – VEWIN, Rijswijk, Netherlands.

WIKIPEDIA (2008): www.wikipedia.org, 14th of November 2008.

WRG 1959 (BGBl. Nr. 215/1959 idgF): Wasserrechtsgesetz 1959 - WRG 1959 BGBl 1959/215 (Wv). – Austrian law, Ministry of Agriculture, Forestry, Environment and Water Management and Food, Vienna, Austria.

Web site of OVGW benchmarking project: www.trinkwasserbenchmarking.at

# Appendix

# A1. Data collection system

All the elements of the data collection system (except supporting data) are indicated by codes. If the definitions of data elements are the same as those in the IWA-PI system (ALEGRE et al. 2006) the IWA-codes are also described within the squared brackets.

## A1.1. Contact details

**Table 49: Contact details (context information)**

| | context information | code |
|---|---|---|
| utility contact data | full company name | ci01 |
| | street and house number | ci02 |
| | postal code | ci03 |
| | city | ci04 |
| | county | ci05 |
| | fax number | ci06 |
| contact person | last name | ci07 |
| | first name | ci08 |
| | sex | ci09 |
| | (academic) title | ci10 |
| | telephone number | ci11 |
| | mobile phone number | ci12 |
| | email address | ci13 |
| proxy person | last name | ci14 |
| | first name | ci15 |
| | sex | ci16 |
| | (academic) title | ci17 |
| | telephone number | ci18 |
| | mobile phone number | ci19 |
| | email address | ci20 |

## A1.2. Basis data

**Table 50: Basis data (context information)**

| | context information | code | Definition | value |
|---|---|---|---|---|
| undertaking profile | geographical scope | ci01 [CI1] | [scope of activity of the organisation as a whole] | [nation<br>state<br>region<br>local] |
| | type of activity | ci02 [CI2] | [scope of activity of the organisation as a whole, beyond the water supply] | water supply only<br>water and waste water<br>multi-utility |
| | type of asset ownership | ci03 [CI3] | [ownership of the water supply infrastructure] | [public<br>private<br>mixed] |
| | legal form | ci04 | legal form of the organisation as a whole | municipal utility<br>capital company<br>water association<br>water cooperative |
| | accounting system | ci05 | accounting system used within the organisation | double-entry accounting<br>fiscal accounting<br>cash basis accounting |
| | cost accounting system | ci06 | is there an existing cost accounting system within the organisation | yes<br>no<br>n/a |
| | urbanity | ci07 | structure of the water distribution system | rural<br>small city<br>large city |

[IWA Code], [IWA definition] and [IWA unit]…according to ALEGRE et al. (2006)

**Table 51: Basis data (supporting information)**

| | supporting information | code | definition | unit |
|---|---|---|---|---|
| employees | name or group of employee | no code | name of single employee or name of group of employees with the same hourly rate | - |
| | hourly rate | no code | personnel costs per hour for the employee or employee group | €/h |
| | portion of overhead costs | no code | portion of overhead costs within the hourly rates of employees | % |

## A1.3. Water supply system data

**Table 52: Water supply system data (variables)**

| | variable | code | definition | unit |
|---|---|---|---|---|
| water supply system | measuring zones | v001 | number of measuring zones within the supply system (pressure zones and/or DMAs) | No. |
| | pressure zones | v002 | number of pressure zones within the supply system | No. |
| | DMAs | v003 | number of DMAs within the supply system | No. |
| | mains length | v004 [C8] | [total transmission and distribution mains length (service connections not included)] | [km] |
| | service connections | v005 [C24] | [total number of service connections] | [No.] |
| | maximum service pressure head | v006 [CI17] | [maximum target service pressure at any delivery point of the network] | m [kPa] |
| | average service pressure head | v007 [D34] | [average operating pressure at the delivery points], weighted for service connections | m [kPa] |
| | minimum service pressure head | v008 [CI16] | [minimum target service pressure at any delivery point of the network] | m [kPa] |
| | system input meters | v009 | total number of system input meters within the whole water supply system | No. |
| | system input meters (PCS) | v010 | total number of system input meters within the whole water supply system which are connected to a process control system (PCS) | No. |
| | district meters | v011 [C11] | total number of water metering points permanently equipped for district metering | [No.] |
| | district meters (PCS) | v012 | total number of district meters which are connected to a process control system | No. |
| | pressure meters | v013 | total number of permanent installed pressure meters within the water supply system | No. |
| | pressure meters (PCS) | v014 | total number of permanent installed pressure meters within the water supply system which are connected to a process control system | No. |
| | noise loggers | v015 | total number of permanent installed noise loggers within the water supply system | No. |
| | readout interval of noise loggers | v016 | average readout interval of noise loggers | d |
| | pressure reduction valves | v017 | total number of number of pressure reduction valves within the whole water supply system | No. |
| | transmission mains length | v018 | total transmission mains length | km |
| | distribution mains length | v019 [C9] | [total distribution mains length] | [km] |
| | length of service connections | v020 | distribution length of | km |
| | average service connection length | v020a [C25] | [average length (metres) from the property boundary (delivery point) to the measurement point] | [m] |

[IWA Code], [IWA definition] and [IWA unit]…according to ALEGRE et al. (2006)

## A1.4. Water balance data

The data accuracy is indicated directly by error margins in percentages for all water balance data. The assessment period for water balance data is one year.

**Table 53: Water abstraction data**

| name and definition | variable / supporting data | code | unit |
|---|---|---|---|
| point of abstraction (e.g. well, natural spring) | supp. data | no code | - |
| abstracted volume of single point of abstraction | supp. data | no code | $m^3/a$ |
| type of meter of single point of abstraction | supp. data | no code | - |
| diameter of meter of single point of abstraction | supp. data | no code | mm |
| year of meter installation of single point of abstraction | supp. data | no code | - |
| year of last meter calibration of single point of abstraction | supp. data | no code | - |
| error margin of abstracted volume of single point of abstraction | supp. data | no code | % |
| abstracted water (summarised value of annual abstracted volumes of all points of abstraction) | variable | wb01 | $m^3/a$ |

The experience with the OVGW benchmarking showed that there are no imports and exports of raw water in Austria but, for the sake of completeness, these two variables are described in Table 54 and Table 55.

**Table 54: Import of raw water data**

| name and definition | variable / supporting data | code | unit |
|---|---|---|---|
| point of raw water import | supp. data | no code | - |
| imported raw water volume of single point of import | supp. data | no code | m³/a |
| type of meter of single point of raw water import | supp. data | no code | - |
| diameter of meter of single point of raw water import | supp. data | no code | mm |
| year of meter installation of single point of raw water import | supp. data | no code | - |
| year of last meter calibration of single point of raw water import | supp. data | no code | - |
| error margin of abstracted volume of single point of raw water import | supp. data | no code | % |
| imported raw water (summarised value of annual imported raw water volumes of all points of raw water import) | variable | wb02 | m³/a |

**Table 55: Export of raw water data**

| name and definition | variable / supporting data | code | unit |
|---|---|---|---|
| point of raw water export | supp. data | no code | - |
| exported raw water volume of single point of export | supp. data | no code | m³/a |
| type of meter of single point of raw water export | supp. data | no code | - |
| diameter of meter of single point of raw water export | supp. data | no code | mm |
| year of meter installation of single point of raw water export | supp. data | no code | - |
| year of last meter calibration of single point of raw water export | supp. data | no code | - |
| error margin of abstracted volume of single point of raw water export | supp. data | no code | % |
| exported raw water (summarised value of annual exported raw water volumes of all points of raw water export) | variable | wb03 [A5] | m³/a |

[IWA Code], [IWA definition] and [IWA unit]…according to ALEGRE et al. (2006)

**Table 56: Water treatment data**

| | variable | code | Definition | unit |
|---|---|---|---|---|
| water treatment | water without treatment | wb04 | annual volume of water without treatment | m³/a |
| | water with treatment | wb05 | annual volume of water with treatment (disinfection is ranked among treatment) | €/h |
| | backwash water and losses during treatment | wb05a | annual volume of backwash water and losses during water treatment | m³/a |

**Table 57: Import of treated water data**

| name and definition | variable / supporting data | code | unit |
|---|---|---|---|
| point of treated water import | supp. data | no code | - |
| imported treated water volume of single point of import | supp. data | no code | m³/a |
| type of meter of single point of treated water import | supp. data | no code | - |
| diameter of meter of single point of treated water import | supp. data | no code | mm |
| year of meter installation of single point of treated water import | supp. data | no code | - |
| year of last meter calibration of single point of treated water import | supp. data | no code | - |
| error margin of abstracted volume of single point of treated water import | supp. data | no code | % |
| imported treated water (summarised value of annual imported treated water volumes of all points of treated water import) | variable | wb06 | m³/a |

**Table 58: Returned water data**

| name and definition | variable / supporting data | code | unit |
|---|---|---|---|
| point of returned water discharge | supp. data | no code | - |
| returned water volume of single point of returned water discharge | supp. data | no code | m³/a |
| type of meter of single point of returned water discharge | supp. data | no code | - |
| diameter of meter of single point of returned water discharge | supp. data | no code | mm |
| year of meter installation of single point of returned water discharge | supp. data | no code | - |
| year of last meter calibration of single point of returned water discharge | supp. data | no code | - |
| error margin of abstracted volume of single point of returned water discharge | supp. data | no code | % |
| returned water (summarised value of annual returned water volumes of all points of returned water discharge) | variable | wb22 | m³/a |

The system input volume (Table 59) is calculated out the previous described data:

+ total volume of abstracted water (wb01)
+ total volume of imported raw water (wb02)
- volume of exported raw water (wb03)
- backwash water and losses during treatment (wb05a)
+ volume of imported treated water (wb06)
- volume of returned water (wb22)

= system input volume (wb07)

**Table 59: System input data**

| variable | code | Definition | unit |
|---|---|---|---|
| system input volume | wb07 [A3] | annual volume of system input | m³/a |

[IWA Code], [IWA definition] and [IWA unit]…according to ALEGRE et al. (2006)

**Table 60: Billed water consumption data**

| name and definition | variable / supporting data / context information | code | unit |
|---|---|---|---|
| annual volume of unmetered exported treated water | supp. data | no code | m³/a |
| point of treated water export | supp. data | no code | - |
| treated exported water volume of single point of export | supp. data | no code | m³/a |
| type of meter of single point of treated water export | supp. data | no code | - |
| diameter of meter of single point of treated water export | supp. data | no code | mm |
| year of meter installation of single point of treated water export | supp. data | no code | - |
| year of last meter calibration of single point of treated water export | supp. data | no code | - |
| error margin of abstracted volume of single point of treated water export | supp. data | no code | % |
| exported treated water (summarised value of annual exported treated water volumes of all points of treated water export) | variable | wb08 [A7] | m³/a |
| annual billed metered consumption (direct supply) | supp. data | no code | m³/a |
| annual billed unmetered consumption (direct supply) | supp. data | no code | m³/a |
| billed consumption (direct supply), (total amount of annual billed authorised consumption, only direct supply) | variable | wb09 | m³/a |
| billed metered consumption [total amount of annual billed metered authorised consumption (including exported water)] | variable | wb23 [A8] | m³/a |
| billed unmetered consumption [total amount of annual billed unmetered authorised consumption (including exported water)] | variable | wb24 [A9] | m³/a |
| billed authorised consumption [total amount of annual billed authorised consumption (including exported water)] | variable | wb16 [A10] | m³/a |
| bulk water consumption (exported water to other water undertakings) | context information | ci21 [CI69] | [%] |
| direct supply (residential, commercial, public and industrial consumption) | context information | ci22 | % |

[IWA Code], [IWA definition] and [IWA unit]…according to ALEGRE et al. (2006)

**Table 61: Unbilled water consumption data**

| name and definition | variable / supporting data | code | unit |
|---|---|---|---|
| description of each unbilled metered consumption | supp. data | no code | - |
| annual volume of each single unbilled metered consumption | supp. data | no code | m³/a |
| unbilled metered consumption [total amount of annual unbilled metered consumption (including exported water)] | variable | wb25 [A11] | m³/a |
| description of each unbilled unmetered consumption | supp. data | no code | - |
| annual volume of each single unbilled unmetered consumption | supp. data | no code | m³/a |
| unbilled unmetered consumption [total amount of annual unbilled unmetered authorised consumption (including exported water)] | variable | wb26 [A12] | m³/a |
| unbilled authorised consumption [total amount of annual unbilled authorised consumption (including exported water)] | variable | wb17 [A13] | m³/a |

[IWA Code], [IWA definition] and [IWA unit]…according to ALEGRE et al. (2006)

The annual authorised consumption (Table 62) is calculated out the previous described data:

+ billed authorised consumption (wb16)

+ unbilled authorised consumption (wb17)

= authorised consumption (wb15)

**Table 62: Authorised consumption data**

| variable | code | Definition | unit |
|---|---|---|---|
| authorised consumption | wb15 [A14] | annual volume of metered and/or non-metered water that is taken by registered customers, by the water supplier itself or by others who are implicitly or explicitly authorised to do so by the water supplier, for residential, commercial, industrial or public purposes; it includes water exported | m³/a |

[IWA Code], [IWA definition] and [IWA unit]…according to ALEGRE et al. (2006)

The last part of water balance data deals with water losses. The volume of real (physical) water losses is calculated by:

system input volume (wb07)
- authorised consumption (wb15)
- apparent losses (wb19)
= real losses (wb20)

**Table 63: Water loss data**

| name and definition | variable / supporting data | code | unit |
|---|---|---|---|
| possible meter errors of customer meters | supp. data | no code | % |
| description of each type of unauthorised consumption | supp. data | no code | - |
| volume of unauthorised consumption for each type of unauthorised consumption | supp. data | no code | m³/a |
| total volume of authorised consumption (summarised value of authorised consumption volumes of all types of unauthorised consumption) | supp. data | no code | m³/a |
| water losses [difference between system input volume and authorised consumption] | variable | wb18 [A15] | m³/a |
| apparent losses (summarised value of annual volume of authorised consumption and customer meter inaccuracies) | variable | wb19 [A18] | m³/a |
| real losses [total amount of annual physical water losses up to the point of customer metering] | variable | wb20 [A19] | m³/a |
| Non-revenue water [difference between system input volume and authorised consumption] | variable | wb21 [A21] | m³/a |

[IWA Code], [IWA definition] and [IWA unit]…according to ALEGRE et al. (2006)

## *A1.5. Process specific data*

In general, the assessment period for process specific data is three years to avoid pure comparability due to annual variations in process operation.

### A1.5.1. Data of leakage monitoring sub process

**Table 64: Variables of leakage monitoring sub process**

| Variable | Code | Definition | unit |
|---|---|---|---|
| total costs of sub process leakage monitoring | v101 | annual costs (personal and material) including costs for outsourcing in-house and extern and fictive depreciation costs | €/a |
| total working time of sub process leakage monitoring | v102 | annual working time including working time of outsourcing in-house and extern | hours/a |
| working time utility intern of sub process leakage monitoring | v103 | annual working time for sub process excluding outsourcing | hours/a |
| personal costs utility intern of sub process leakage monitoring | v104 | annual utility intern personal costs for sub process excluding outsourcing | €/a |
| other costs utility intern for sub process leakage monitoring | v105 | annual other running costs and material costs utility intern for sub process | €/a |
| costs for outsourcing in-house for sub process leakage monitoring | v106 | annual costs (apportionments) for outsourcing in-house for sub process | €/a |
| working time outsourcing in-house of sub process leakage monitoring | v107 | annual working time of outsourcing in-house for sub process | hours/a |
| personal costs outsourcing in-house of sub process leakage monitoring | v108 | annual personal of costs outsourcing in-house for sub process | €/a |
| material costs outsourcing in-house of sub process leakage monitoring | v109 | annual material costs of outsourcing in-house for sub process | €/a |
| costs for outsourcing extern for sub process leakage monitoring | v110 | annual costs (apportionments) for outsourcing extern for sub process | €/a |
| working time outsourcing extern of sub process leakage monitoring | v111 | annual working time of outsourcing extern for sub process | hours/a |
| personal costs outsourcing extern of sub process leakage monitoring | v112 | annual personal of costs outsourcing extern for sub process | €/a |
| material costs outsourcing extern of sub process leakage monitoring | v113 | annual material costs of outsourcing extern for sub process | €/a |
| investment costs for leakage monitoring equipment | v114 | estimated costs of measurement equipment and SCADA system for those components or those parts of the SCADA system which accord to leakage monitoring | € |
| average age of leakage monitoring system | v115 | estimated average age of leakage monitoring equipment and SCADA system | a (years) |

**Table 65: Context information of leakage monitoring sub process**

| context information | code | definition / possible answer | unit |
|---|---|---|---|
| system input metering | ci101* | 5 possible answers (low to high performance), see chapter 5.5 | - |
| district metered areas (DMA) | ci102* | 5 possible answers (low to high performance), see chapter 5.5 | - |
| evaluation of night minimum consumption | ci103* | 5 possible answers (low to high performance), see chapter 5.5 | - |
| SCADA system | ci104* | 5 possible answers (low to high performance), see chapter 5.5 | - |
| pressure monitoring | ci105* | 5 possible answers (low to high performance), see chapter 5.5 | - |
| permanent noise loggers | ci106* | 5 possible answers (low to high performance), see chapter 5.5 | - |
| virtual measuring zones | ci107* | 5 possible answers (low to high performance), see chapter 5.5 | - |
| recognition of leakage | ci108* | 5 possible answers (low to high performance), see chapter 5.5 | - |
| first information about leak location | ci109* | 5 possible answers (low to high performance), see chapter 5.5 | - |
| function of SCADA system: transmission of system input data | ci110* | yes / no | - |
| function of SCADA system: transmission interval of system input data | ci111* | 5 possible answers (low to high performance), see chapter 5.5 | - |
| function of SCADA system: transmission of DMA input data | ci112* | yes / no | - |
| function of SCADA system: transmission interval of DMA input data | ci113* | 5 possible answers (low to high performance), see chapter 5.5 | - |
| function of SCADA system: transmission of pressure data | ci114* | yes / no | - |
| function of SCADA system: transmission interval of pressure data | ci115* | 5 possible answers (low to high performance), see chapter 5.5 | - |
| function of SCADA system: transmission of reservoir water level | ci116* | yes / no | - |
| function of SCADA system: transmission interval of reservoir water level | ci117* | 5 possible answers (low to high performance), see chapter 5.5 | - |
| function of SCADA system: transmission of pumping station data | ci118* | yes / no | - |
| function of SCADA system: transmission interval of pumping station data | ci119* | 5 possible answers (low to high performance), see chapter 5.5 | - |
| function of SCADA system: evaluation of night minimum consumption | ci120* | yes / no | - |
| function of SCADA system: automatic alarm when threshold values exceeded | ci121* | yes / no | - |

* considered in quality matrix

### A1.5.2. Data of sub process leak detection

**Table 66: Variables to costs and working time of leak detection sub process**

| variable | Code | Definition | unit |
|---|---|---|---|
| total costs of sub process leak detection | v201 | annual costs (personal and material) including costs for outsourcing in-house and extern and fictive depreciation costs for leak detection equipment | €/a |
| total working time of sub process leak detection | v202 | annual working time including working time of outsourcing in-house and extern | hours/a |
| working time utility intern of sub process leak detection | v203 | annual working time for sub process excluding outsourcing | hours/a |
| personal costs utility intern of sub process leak detection | v204 | annual utility intern personal costs for sub process excluding outsourcing | €/a |
| other costs utility intern for sub process leak detection | v205 | annual other running costs and material costs utility intern for sub process | €/a |
| costs for outsourcing in-house for sub process leak detection | v206 | annual costs (apportionments) for outsourcing in-house for sub process | €/a |
| working time outsourcing in-house of sub process leak detection | v207 | annual working time of outsourcing in-house for sub process | hours/a |
| personal costs outsourcing in-house of sub process leak detection | v208 | annual personal of costs outsourcing in-house for sub process | €/a |
| material costs outsourcing in-house of sub process leak detection | v209 | annual material costs of outsourcing in-house for sub process | €/a |
| costs for outsourcing extern for sub process leak detection | v210 | annual costs (apportionments) for outsourcing extern for sub process | €/a |
| working time outsourcing extern of sub process leak detection | v211 | annual working time of outsourcing extern for sub process | hours/a |
| personal costs outsourcing extern of sub process leak detection | v212 | annual personal of costs outsourcing extern for sub process | €/a |
| material costs outsourcing extern of sub process leak detection | v213 | annual material costs of outsourcing extern for sub process | €/a |

**Table 67: Variables for existing leak detection equipment**

| Variable | code | Definition | unit |
|---|---|---|---|
| listening sticks and stethoscopes | v216 | number of leak detection equipment within the utility | - |
| ground microphones | v217 | | - |
| leak noise correlators | v218 | | - |
| temporary noise loggers | v219 | | - |
| equipment for tracer gas | v220 | | - |
| measuring vehicles | v221 | | - |
| other leak detection equipment | v222 | | - |
| description of other leak detection equipment | v223 | - | - |
| investment costs for leak detection equipment | v224 | estimated investment costs of leak detection equipment | € |
| depreciation costs for leak detection equipment | v225 | annual fictive depreciation costs calculated on basis of a depreciation period of 10 years | €/a |

**Table 68: Variables for localised leaks**

| | variable | code | unit |
|---|---|---|---|
| localised leaks in assessment period (3 years) | leaks at transmission mains (routine survey) | v239 | - |
| | leaks at transmission mains (cause based) | v240 | - |
| | leaks at distribution mains (routine survey) | v242 | - |
| | leaks at distribution mains (cause based) | v243 | - |
| | leaks at service connections (routine survey) | v245 | - |
| | leaks at service connections (cause based) | v246 | - |

**Table 69: Variables for leak detection measures in assessment period**

| | variable | code | definition | unit |
|---|---|---|---|---|
| leak detection equipment used in assessment period (3 years) | listening sticks and stethoscopes | v226 | Was this leak detection equipment used in the assessment period? | - |
| | ground microphones | v227 | | - |
| | leak noise correlators | v228 | | - |
| | temporary noise loggers | v229 | | - |
| | equipment for tracer gas | v230 | | - |
| | step testing | v231 | | - |
| | Other leak detection equipment | v232 | | - |
| | description of other leak detection equipment | v233 | - | - |
| leak detection measures in assessment period (3 years) | leak detection on transmission mains (routine survey) | v234a | length of transmission / distribution mains inspected by leak detection measures in routine surveys / cause related during assessment period | km |
| | leak detection on transmission mains (cause related) | v234b | | km |
| | leak detection on distribution mains (routine survey) | v234c | | km |
| | leak detection on distribution mains (cause related) | v234d | | km |
| | cost of routine leak detection survey | v235 | part of sub process running costs (without depreciation costs for leak detection equipment) for routine surveys | € |
| | cost of cause related leak detection | v236 | part of sub process running costs (without depreciation costs for leak detection equipment) for cause related leak detection | € |
| | inspected service connections (routine survey) | v237 | number of service connections inspected for leakage by routine surveys during assessment period | - |
| | inspected service connections (cause related) | v237a | number of service connections inspected for leakage cause related during assessment period | - |

**Table 70: Context information for leak detection sub process**

<table>
<tr><th colspan="2">context information</th><th>code</th><th>definition / possible answer</th><th>unit</th></tr>
<tr><td colspan="2">general procedure in leak detection (strategy)</td><td>ci201*</td><td>5 possible answers (low to high performance), see chapter 5.5</td><td>-</td></tr>
<tr><td colspan="2">routine leak detection at service connections</td><td>ci201a*</td><td>Is routine leak detection at service connections done together with customer meter reading (or meter replacement)?</td><td>-</td></tr>
<tr><td colspan="2">leak location time</td><td>ci202*</td><td>5 possible answers (low to high performance), see chapter 5.5</td><td>-</td></tr>
<tr><td colspan="2">hit rate (success in leak detection)</td><td>ci203*</td><td>5 possible answers (low to high performance), see chapter 5.5</td><td>-</td></tr>
<tr><td colspan="2">accuracy in pinpointing leaks</td><td>ci204*</td><td>5 possible answers (low to high performance), see chapter 5.5</td><td>-</td></tr>
<tr><td colspan="2">documentation of leak detection</td><td>ci205*</td><td>5 possible answers (low to high performance), see chapter 5.5</td><td>-</td></tr>
<tr><td colspan="2">service connection plastic material</td><td>ci206</td><td>service connections of material PVC, Pe or GRP</td><td>%</td></tr>
<tr><td colspan="2">service connection metallic material</td><td>ci207</td><td>service connections of material steel, GG, GGG, (lead)</td><td>%</td></tr>
<tr><td colspan="2">Your personal opinion: Do routine inspections on leakage at service connections together with meter readings (or meter replacement) pay off?</td><td>ci208</td><td>yes / no</td><td>-</td></tr>
<tr><td rowspan="5">Are those materials suitable for detecting leaks?</td><td>PVC</td><td>ci210</td><td rowspan="5"><u>4 possible answers:</u><br>very suitable, high hit rate<br>moderate suitable, average hit rate<br>not very suitable, low hit rate<br>not suitable at all, no leaks found</td><td>-</td></tr>
<tr><td>PE</td><td>ci211</td><td>-</td></tr>
<tr><td>Steel</td><td>ci212</td><td>-</td></tr>
<tr><td>CI</td><td>ci213</td><td>-</td></tr>
<tr><td>others</td><td>ci214</td><td>-</td></tr>
<tr><td colspan="2">name of “other” material</td><td>ci215</td><td>description of “other material” of k214</td><td>-</td></tr>
<tr><td colspan="2">payment criteria for contracted leak detection companies</td><td>ci216</td><td><u>5 possible answers:</u><br>flat sum for whole leak detection<br>inspected mains length<br>working time<br>success of leak detection<br>others</td><td>-</td></tr>
<tr><td rowspan="2">soil conditions</td><td>cohesive (clay, silt)</td><td>ci218</td><td>ratio of mains in cohesive soil</td><td>%</td></tr>
<tr><td>cohesionless (sand, gravel)</td><td>ci219</td><td>ratio of mains in cohesionless soil</td><td>%</td></tr>
<tr><td colspan="2">leaks coming to surface</td><td>ci220</td><td>estimation of percentage of leaks coming to surface due to soil conditions</td><td>%</td></tr>
</table>

* considered in quality matrix

### A1.5.3. Data for analyses and planning sub process

**Table 71: Variables for costs and work time of analyses and planning sub process**

| Variable | code | definition | unit |
|---|---|---|---|
| total costs of sub process analyses and planning | v301 | annual costs (personal and material) including costs for outsourcing in-house and extern for sub process | €/a |
| total working time of sub process analyses and planning | v302 | annual working time including working time of outsourcing in-house and extern | hours/a |
| working time utility intern of sub process analyses and planning | v303 | annual working time for sub process excluding outsourcing | hours/a |
| personal costs utility intern of sub process analyses and planning | v304 | annual utility intern personal costs for sub process excluding outsourcing | €/a |
| other costs utility intern for sub process analyses and planning | v305 | annual other running costs and material costs utility intern for sub process | €/a |
| costs for outsourcing in-house for sub process analyses and planning | v306 | annual costs (apportionments) for outsourcing in-house for sub process | €/a |
| working time outsourcing in-house of sub process analyses and planning | v307 | annual working time of outsourcing in-house for sub process | hours/a |
| personal costs outsourcing in-house of sub process analyses and planning | v308 | annual personal of costs outsourcing in-house for sub process | €/a |
| material costs outsourcing in-house of sub process analyses and planning | v309 | annual material costs of outsourcing in-house for sub process | €/a |
| costs for outsourcing extern for sub process analyses and planning | v310 | annual costs (apportionments) for outsourcing extern for sub process | €/a |
| working time outsourcing extern of sub process analyses and planning | v311 | annual working time of outsourcing extern for sub process | hours/a |
| personal costs outsourcing extern of sub process analyses and planning | v312 | annual personal of costs outsourcing extern for sub process | €/a |
| material costs outsourcing extern of sub process analyses and planning | v313 | annual material costs of outsourcing extern for sub process | €/a |

**Table 72: Context information for analyses and planning (part 1)**

<table>
<tr><th colspan="2">context information</th><th>code</th><th>definition / possible answer</th><th>unit</th></tr>
<tr><td colspan="2">general procedure in analyses and planning</td><td>ci301*</td><td>5 possible answers (low to high performance), see chapter 5.5</td><td>-</td></tr>
<tr><td rowspan="12">time interval in which different criteria are analysed or planned</td><td>calculation of water loss PIs for whole supply system</td><td>ci302*</td><td rowspan="12"><u>5 possible answers:</u><br><br>never done up to now<br>more than 5 years<br>each 2 to 5 years<br>annual or every half year<br>quarterly, monthly or more often</td><td>-</td></tr>
<tr><td>calculation of water loss PIs for single DMAs</td><td>ci303*</td><td>-</td></tr>
<tr><td>analyses to trends in night minimum consumption of single zones</td><td>ci304*</td><td>-</td></tr>
<tr><td>investigations if existing measuring systems (flow, pressure etc.) and SCADA systems are sufficient</td><td>ci305*</td><td>-</td></tr>
<tr><td>internal analyses of costs (efficiency) and success (affectivity) of water loss management</td><td>ci306*</td><td>-</td></tr>
<tr><td>derivation of measures for improvement of process operation (e.g. working instructions)</td><td>ci307*</td><td>-</td></tr>
<tr><td>generation of failure statistics for whole supply system without analyses of single pipe-groups</td><td>ci308*</td><td>-</td></tr>
<tr><td>generation of failure statistics for single DMAs without analyses of single pipe-groups</td><td>ci309*</td><td></td></tr>
<tr><td>generation of failure statistics for whole supply system with analyses of single pipe-groups</td><td>ci310*</td><td>-</td></tr>
<tr><td>generation of failure statistics for single DMAs with analyses of single pipe-groups</td><td>ci311*</td><td>-</td></tr>
<tr><td>derivation of measures for improvement in maintenance (e.g. for critical pipe groups)</td><td>ci312*</td><td>-</td></tr>
<tr><td>provision of pipe-group based failure statistics for rehabilitation planning</td><td>ci313*</td><td>-</td></tr>
</table>

* considered in quality matrix

**Table 73: Context information for analyses and planning (part 2)**

| context information | | code | definition / possible answer | unit |
|---|---|---|---|---|
| calculation of water loss performance indicators | | ci314* | 5 possible answers (low to high performance), see chapter 5.5 | - |
| PIs calculated for internal purposes | water loss ratio (%) | ci315* | yes / no | - |
| | real losses per connection per day | ci316* | yes / no | - |
| | real losses per connection per day per metre pressure | ci317* | yes / no | - |
| | real losses per mains length | ci318* | yes / no | - |
| | ILI | ci319* | yes / no | - |
| | non-revenue water (NRW) (%) | ci320* | yes / no | - |
| PIs published in annual report (e.g. for stakeholders) | water loss ratio (%) | ci321* | yes / no | - |
| | real losses per connection per day | ci322* | yes / no | - |
| | real losses per connection per day per metre pressure | ci323* | yes / no | - |
| | real losses per mains length | ci324* | yes / no | - |
| | ILI | ci325* | yes / no | - |
| | non-revenue water (NRW) (%) | ci326* | yes / no | - |
| calculation of a water balance | | ci327* | 5 possible answers (low to high performance), see chapter 5.5 | - |

* considered in quality matrix

### A1.5.4. Data for infrastructure management supporting process

**Table 74: Context information for infrastructure management supporting process**

| context information | | | code | definition / possible answer | unit |
|---|---|---|---|---|---|
| mapping / GIS | | | ci401* | 5 possible answers (low to high performance), see chapter 5.5 | - |
| network inspection | inspection intervals | closing valves | ci402* | 5 possible answers (low to high performance), see chapter 5.5 | - |
| | | hydrants | ci403* | | - |
| | | pressure reduction valves | ci404* | | - |
| | | calibration interval system input meters | ci405* | | - |
| | | calibration interval DMA meters | ci406* | | - |
| hydraulic modelling | accomplishment of hydraulic modelling | | ci407* | 5 possible answers (low to high performance), see chapter 5.5 | - |
| | Were new leaks found due to results of hydraulic modelling? | | ci408 | yes / no | - |
| | Were optimisation potentials in pressure management investigated by hydraulic modelling? | | ci409* | yes / no | - |
| pressure management | | | ci410* | 5 possible answers (low to high performance), see chapter 5.5 | - |
| rehabilitation | rehabilitation planning | | ci411* | 5 possible answers (low to high performance), see chapter 5.5 | - |
| | rehabili-tation criteria | experience of network engineer | ci412* | yes / no | - |
| | | failure rates | ci413* | yes / no | - |
| | | water losses | ci414* | yes / no | - |
| | | other underground work | ci415* | together with other measures e.g. street renewal | - |
| | | IT support | ci416* | yes / no | - |
| | average age of distribution mains | | ci417 | average age | - |
| | average rehabilitation rate of distribution mains | | ci418 | average rehabilitation rate within the last 10 years | % |
| | average age of service connections | | ci419 | average age | - |
| | average rehabilitation rate of service connections | | ci420 | average rehabilitation rate within the last 10 years | % |
| customer meter management | metering equipment | | ci421* | 5 possible answers (low to high performance), see chapter 5.5 | - |
| | meter age and replacement interval | | ci422* | | - |
| | time frame for meter readings | | ci423* | | - |
| | theft of water, illegal connections, bypasses, manipulations | | ci424* | | - |

* considered in quality matrix

### A1.5.4.1.1. *Data for leak repair supporting process*

**Table 75: Variables about number of repairs and repair costs**

| context information | | code | definition / possible answer | unit |
|---|---|---|---|---|
| number of repairs of pipe failures | at transportation mains | v501 | total number of repairs for failures at pipes or fittings (with leakage) during assessment period | - |
| | at distribution mains | v502 | | - |
| | at service connections | v503 | | - |
| number of repairs of fitting failures | at transportation mains | v504 | | - |
| | at distribution mains | v505 | | - |
| | at service connections | v506 | | - |
| total repair costs of pipe failures | at transportation mains | v507 | total costs (earthwork, installation, material etc.) of repairs of failures at pipes or fittings (with leakage) during assessment period | € |
| | at distribution mains | v508 | | € |
| | at service connections | v509 | | € |
| total repair costs of fitting failures | at transportation mains | v510 | | € |
| | at distribution mains | v511 | | € |
| | at service connections | v512 | | € |

**Table 76: Context information about repair time and information for planning**

| context information | | code | definition / possible answer | unit |
|---|---|---|---|---|
| repair time | reported leaks at distribution mains | ci501* | time from locating a leak to the recovery of the functionality of the pipe<br>5 possible answers (low to high performance), see chapter 5.5 | - |
| | unreported leaks at distribution mains | ci502* | | - |
| | reported leaks at service connections | ci503* | | - |
| | unreported leaks at service connections | ci504* | | - |
| | Does it happen that leaks are located but repaired weeks or month later? | ci505* | yes / no | - |
| information for maintenance and rehabilitation planning | | ci506* | 5 possible answers (low to high performance), see chapter 5.5 | - |

* considered in quality matrix

**Table 77: Context information about failure documentation**

| context information | | code | definition / possible answer | unit |
|---|---|---|---|---|
| modality of failure documentation | | ci507* | 5 possible answers (low to high performance), see chapter 5.5 | - |
| criteria of failure documentation (according to OVGW guideline W 100) | name of documenting person | ci508* | yes / no<br><br>Which of these single criteria are documented for each single repair? | - |
| | place and time of failure | ci509* | | - |
| | year of construction | ci510* | | - |
| | pipe diameter | ci511* | | - |
| | type of pipe (transportation or distribution main, service connection) | ci512* | | - |
| | pipe material | ci513* | | - |
| | pipe connection | ci514* | | - |
| | corrosion protection | ci515* | | - |
| | affected part (pipe, fitting, connection) | ci516* | | - |
| | condition of pipe and bedding | ci517* | | - |
| | type of failure (burst, fitting…) | ci518* | | - |
| | cause of failure (e.g. corrosion) | ci519* | | - |
| | sketch of position, photo documentation | ci520* | | - |
| | process of failure elimination | ci521* | | - |
| | type of repair / maintenance | ci522* | | - |
| | costs of repair | ci523* | | - |

* considered in quality matrix

**Table 78: Context information about type of failures**

| context information | | | code | definition / possible answer | unit |
|---|---|---|---|---|---|
| type of failures (only failures with leakage) | transportation mains | burst | ci524 | percentages for type of failures with leakage at transportation mains (sum has to be 100%) | % |
| | | crack | ci525 | | % |
| | | hole | ci526 | | % |
| | | connection failure | ci527 | | % |
| | | fitting failure | ci528 | | % |
| | | others | ci529 | | % |
| | distribution mains | burst | ci530 | percentages for type of failures with leakage at distribution mains (sum has to be 100%) | % |
| | | crack | ci531 | | % |
| | | hole | ci532 | | % |
| | | connection failure | ci533 | | % |
| | | fitting failure | ci534 | | % |
| | | others | ci535 | | % |
| | service connections | burst | ci536 | percentages for type of failures with leakage at service connections (sum has to be 100%) | % |
| | | crack | ci537 | | % |
| | | hole | ci538 | | % |
| | | connection failure | ci539 | | % |
| | | fitting failure | ci540 | | % |
| | | others | ci541 | | % |

**Table 79: Context information about cause of failures**

| context information | | | code | definition / possible answer | unit |
|---|---|---|---|---|---|
| cause of failure (only failures with leakage) | transportation mains | corrosion | ci542 | percentages of causes for failures with leakage at transportation mains (sum has to be 100%) | % |
| | | settlings | ci543 | | % |
| | | material or installation failure | ci544 | | % |
| | | freezing | ci545 | | % |
| | | fatigue of material | ci546 | | % |
| | | external forces | ci547 | | % |
| | | others | ci548 | | % |
| | distribution mains | corrosion | ci549 | percentages of causes for failures with leakage at distribution mains (sum has to be 100%) | % |
| | | settlings | ci550 | | % |
| | | material or installation failure | ci551 | | % |
| | | freezing | ci552 | | % |
| | | fatigue of material | ci553 | | % |
| | | external forces | ci554 | | % |
| | | others | ci555 | | % |
| | service connections | corrosion | ci556 | percentages of causes for failures with leakage at service connections (sum has to be 100%) | % |
| | | settlings | ci557 | | % |
| | | material or installation failure | ci558 | | % |
| | | freezing | ci559 | | % |
| | | fatigue of material | ci560 | | % |
| | | external forces | ci561 | | % |
| | | others | ci562 | | % |

### A1.5.5. Data for qualification of staff supporting process

**Table 80: Context information about qualification of staff**

| context information | code | definition / possible answer | unit |
|---|---|---|---|
| employees who are proved water masters | ci601* | y/n | - |
| employees with special training course an water loss management | ci602* | | - |
| employees with experience in using listening sticks and stethoscopes | ci603* | | - |
| employees with experience in using ground microphones | ci604* | | - |
| employees with experience in using leak noise correlators | ci605* | | - |
| employees with experience in using noise loggers | ci606* | | - |
| employees with experience in using tracer gas | ci607* | | - |
| employees with experience in evaluation of zonal (or DMA) measurements | ci608* | | - |
| employees with experience in evaluation of night minimum consumption | ci609* | | - |
| employees with experience in pipe group based failure statistics | ci610* | | - |
| operation of hydraulic modelling | ci611* | personnel of utility / external personal | - |
| procedure in advanced staff training | ci612* | 5 possible answers (low to high performance), see chapter 5.5 | - |

* considered in quality matrix

## Mitteilungen des Institutes für Wasserwirtschaft und Konstruktiven Wasserbau der Technischen Universität Graz

**Bisher erschienene Hefte:**

| | | | |
|---|---|---|---|
| Heft | 1 | (1959) | VEDER, Ch.: Neue Verfahren zur Herstellung von untertägigen Wänden und Injektionsschirmen in Lockergesteinen und durchlässigem Fels (vergriffen) |
| Heft | 2 | (1959) | BEER, O.: Hochwasserentlastungsanlagen österreichischer Talsperren |
| Heft | 3 | (1960) | WEHRSCHÜTZ, F.: Wasserentnahme aus alpinen Abflüssen |
| Heft | 4 | (1961) | TSCHADA, H.: Die Spiralenauslässe des Kraftwerkes St.Pantaleon |
| Heft | 5 | (1962) | GRENGG, H.: Funktion, Ordnung und Gestalt im konstruktiven Wasserbau |
| Heft | 6 | (1962) | PIRCHER, W.: Wehreichungen an der Enns |
| Heft | 7 | (1962) | WEHRSCHÜTZ, F.: Füll- und Entleerungssysteme von Schiffsschleusen mit großen Fallhöhen |
| Heft | 8 | (1962) | REITZ, A.: Das Stauwerk im Bogen |
| Heft | 9 | (1963) | PIRCHER, W.: Die Bautypen der Wasserkraft |
| Heft | 10 | (1964) | WEHRSCHÜTZ, F.: Kritische Betrachtung der Modellgesetze |
| Heft | 11 | (1965) | SIMMLER, H.: Das neue Institut für Wasserbau |
| Heft | 12 | (1964) | RADLER, S.: Die Berechnung der Abflüsse im natürlichen Gerinne |
| Heft | 13 | (1965) | ALTENBURGER, H.: Der Spiralauslaß als Hochwasserentlastung bei Donaukraftwerken |
| Heft | 14 | (1965) | KRESNIK, E.: Kunststoffe im wasserbaulichen Versuchswesen und deren rauhigkeitsmäßige Erfassung |
| Heft | 15 | (1970) | SVEE, R.: Untersuchungen über die Stabilität bei Wasserkraftanlagen mit idealer Regelung |
| Heft | 16 | (1971) | DROBIR, H.: Die Registrierung eines zeitlich rasch veränderlichen Wasserspiegels mit kapazitiven Meßsonden |
| | | | ROTH, G.: Meßanlage zum Studium instationärer Vorgänge mit Hilfe eines Digitalcomputers |
| Heft | 17 | (1971) | DROBIR, H.: Der Ausfluß aus einem Speicher beim Bruch einer Talsperre |
| Heft | 18 | (1972) | GRENGG, H.: Wörterbuch der Wasserkraftnutzung; Französisch – Deutsch, Deutsch – Französisch |
| Heft | 19 | (1973) | DRAXLER, A.: Mathematisches Modell für die Zuflußprognose als Hilfsmittel zur Optimierung des KW-Betriebes |
| Heft | 20 | (1974) | GRENGG, H.: Die Technisierung großer Ströme in Verbindung mit der Wasserkraft |
| Heft | 21 | (1975) | GRENGG, H.: Die großen Wasserkraftanlagen des Weltbestandes |
| Heft | 22 | (1977) | GRENGG, H.: Die großen Wasserkraftanlagen des Weltbestandes, 2. Teil |
| | | | KRAUSS, H.: Lufteinzug durch den Wasserabfluß in Vertikalrohren |

| | | | |
|---|---|---|---|
| Heft | 23 | (1979) | LIEBL, A.: Die Lehre aus der Katastrophe beim Aufstau des Tarbela-Dammes in Pakistan aus der Sicht der Stahlwasserbauer |
| | | (1980) | KRÖLL, A.: Die Stabilität von Steinschüttungen bei Sohlen- und Uferbefestigungen in Wasserströmungen |
| Heft | 24 | (1981) | TSCHERNUTTER, P.: Grundsatzüberlegungen zur Rentabilität und zum Ausbau von Kleinwasserkraftwerken |
| Heft | 25 | (1984) | Helmut Simmler – Zur Vollendung seines 65.Lebensjahres gewidmet von seinen ehemaligen und derzeitigen Mitarbeitern an der TU Graz |

## Publikation des Institutes für Hydromechanik, Hydraulik und Hydrologie der Technischen Universität Graz

**Bisher erschienene Bände:**

| | | |
|---|---|---|
| SACKL, B. | (1987) | Ermittlung von Hochwasser - Bemessungsganglinien in beobachteten und unbeobachteten Einzugsgebieten |

## Veröffentlichungen des Institutes für Siedlungs- und Industriewasserwirtschaft, Grundwasserhydraulik, Schutz- und Landwirtschaftlichen Wasserbau der Technischen Universität Graz

**Bisher erschienene Bände:**

| | | | |
|---|---|---|---|
| Band | 1 | (1977) | RENNER, H.: Die Berücksichtigung nichtbindiger überdeckender Schichten bei der Bemessung von Wasserschutzgebieten |
| Band | 2 | (1977) | KAUCH, E.P.: Untersuchung des Bewegungsgesetzes für die Filterströmung, im besonderen bei höheren Geschwindigkeiten einschließlich der teilturbulenten Strömung |
| Band | 3 | (1977) | PONN, J.: Geschwindigkeitsverteilungen in radial durchströmten Nachklärbecken – Verwendung einer neu entwickelten Thermosonde |
| Band | 4 | (1978) | Festschrift zum 60. Geburtstag von E.P. Nemecek |
| Band | 5 | (1979) | RENNER, H.: Die Entwicklung einer biologischen Kläranlage für kleinste Verhältnisse |
| Band | 6 | (1980) | Forschungsberichte 1979/80 |
| Band | 7 | (1980) | KAUCH, E.P.: Der Pumpversuch im ungespannten Grundwasserleiter |
| Band | 8 | (1982) | DITSIOS, M.: Untersuchungen über die erforderliche Tiefe von horizontal durchströmten rechteckigen Nachklärbecken von Belebungsanlagen |
| Band | 9 | (1982) | GEIGER, D.: Einfluß der Schlammräumung im Nachklärbecken auf die erreichbare Feststoffkonzentration im Belebungsbecken |
| Band | 10 | (1984) | Forschungsbericht 1983/84 (vergriffen) |
| Band | 11 | (1984) | Beeinträchtigung der Grundwasservorkommen in qualitativer und quantitativer Hinsicht |
| Band | 12 | (1986) | KOTOULAS, K.: Natürliche Entwicklung der Längen- und Querprofilform der Flüsse - ein Beitrag zum naturnahen Flußbau |

| | | | |
|---|---|---|---|
| Band | 13 | (1987) | KAUCH, E.P., M. DITSIOS: Schlammbilanz in Belebungsanlagen - Einfluß der hydraulischen Betriebsparameter für Trockenwetter- und Regenwetterfall |
| Band | 14 | (1988) | Festschrift zum 70. Geburtstag von Ernst P. Nemecek |
| Band | 15 | (1988) | Vorträge über Siedlungs- und Industriewasserbau |
| Band | 16 | (1991) | KAINZ, H.: Auswirkungen von Stoßbelastungen auf den Feststoffhaushalt einer Belebungsanlage |
| Band | 17 | (1991) | KLAMBAUER, B.: Grundwasserschutz und Landwirtschaft – Situation in Mitteleuropa |

## Schriftenreihe zur Wasserwirtschaft Technische Universität Graz

**Bisher erschienene Bände:**

| | | | |
|---|---|---|---|
| Band | 1 | (1992) | Hermann Grengg – zum 100. Geburtstag [1)] |
| Band | 2 | (1992) | ZITZ, W.: Die Mitbehandlung angefaulter Sammelgrubenabwässer in einer kommunalen, schwach belasteten Belebungsanlage [2)], vergriffen |
| Band | 3 | (1992) | ÜBERWIMMER, F.: Untersuchung der Ressourcen gespannter Grundwassersysteme mit hydraulischen und hydrologischen Modellen [1), 2)] |
| Band | 4 | (1992) | Hochwasserrückhaltebecken – Planung, Bau und Betrieb [1), 2)] |
| Band | 5 | (1992) | MOLNAR, T.: Rechnerunterstütztes Projektieren von Bewässerungssystemen [1), 2)] |
| Band | 6 | (1993) | Klärschlammentsorgung in der Steiermark [2)] |
| Band | 7 | (1993) | FRIEDRICH, Ch., WINDER, O.: Lebensraum Grazer Murböschungen – Zoologisch-botanische Untersuchungen einschließlich Planungsvorschläge [2)] |
| Band | 8 | (1993) | REICHL, W.: Mehrdimensionale Optimierung quantitativ und qualitativ bewertbarer Zielfunktionen in der Wasserwirtschaft [1)] |
| Band | 9 | (1993) | WELLACHER, J.: Instationäre Strömungsvorgänge in Hochwasserrückhaltebecken [1)] |
| Band | 10 | (1993) | STUBENVOLL, H. : Analyse der zeitlichen Struktur von Niederschlagsereignissen auf der Grundlage zeitvariabler Datenaufzeichnung;<br>ZEYRINGER, T.: Untersuchung des räumlichen Verhaltens von Niederschlagsereignissen auf zeitvariabler Datengrundlage [1), 2)] |
| Band | 11 | (1993) | Ingenieurbiologie im Schutzwasserbau [2)] |
| Band | 12 | (1994) | Ländlicher Raum: Abwasserentsorgung in der Sackgasse? [2)] (vergriffen) |
| Band | 13 | (1994) | SACKL, B.: Ermittlung von Hochwasser-Bemessungsganglinien in beobachteten und unbeobachteten Einzugsgebieten [1), 2)] |
| Band | 14 | (1995) | Leben mit dem Hochwasser – Gefahr und Anpassung [2)] |
| Band | 15 | (1995) | Betrieb, Erhaltung und Erneuerung von Talsperren und Hochdruckanlagen – Symposium [1)] |
| Band | 16 | (1995) | RICHTIG, G.: Untersuchungen zur Abflußentstehung bei Hochwasserereignissen in kleinen Einzugsgebieten [2)] |

| | | | |
|---|---|---|---|
| Band | 17 | (1995) | KNOBLAUCH, H.: Dissipationsvorgänge in Rohrleitungssystemen [1)] |
| Band | 18 | (1995) | Fremdwasser in Abwasseranlagen [2)] |
| Band | 19/1 | (1996) | XVIII. Konferenz der Donauländer über hydrologische |
| Band | 19/2 | | Vorhersagen und hydrologisch-wasserwirtschaftliche Grundlagen [1), 2)] |
| Band | 20 | (1996) | STRANNER, H.: Schwallwellen im Unterwasser von Spitzenkraftwerken und deren Reduktion durch flußbauliche Maßnahmen [1)] |
| Band | 21 | (1996) | DUM, T.: Verifikation eines numerischen Strömungsmodells anhand physikalischer Modelle [1)] |
| Band | 22 | (1996) | VASVÁRI, V.: Ein numerisches Modell zur Bewirtschaftung gespannter Grundwasservorkommen am Beispiel des Mittleren Safentales [1), 2)] |
| Band | 23 | (1996) | HYDROLOGISCHE MONOGRAPHIE des Einzugsgebietes der Oberen Raab [1), 2)] |
| Band | 24 | (1997) | Niederwasser [1), 2)] |
| Band | 25 | (1997) | KRALL, E.: Untersuchung der Gesamtwahrscheinlichkeit von Hochwasserereignissen in kleinen, unbeobachteten Einzugsgebieten Österreichs auf der Grundlage von Gebietskennwerten [1), 2)] |
| Band | 26 | (1997) | Abwasserentsorgung bei fehlenden Vorflutern [2)] |
| Band | 27 | (1997) | Festschrift anläßlich des 60. Geburtstages von Herrn O.Univ.-Prof. Dipl.-Ing. Dr. techn. Günther Heigerth [1)] |
| Band | 28 | (1997) | MEDVED, N.: Simulation und systematische Erfassung von Spülvorgängen in verlandeten Flussstauräumen [1)] |
| Band | 29 | (1998) | Festschrift anläßlich des 65. Geburtstages von Herrn O.Univ.-Prof. Dipl.-Ing. Dr. techn. Dr.h.c. Heinz Bergmann [1), 2)] |
| Band | 30 | (1998) | Festschrift anläßlich des 80. Geburtstages von Herrn em.O.Univ.-Prof. Dipl.-Ing. Dr.h.c. Dr. techn. Ernst P. Nemecek [2)] |
| Band | 31 | (1999) | BEUTLE, K.: Untersuchungen zur Schlammstabilisierung bei diskontinuierlich belüfteten Belebungsanlagen [2)] |
| Band | 32 | (1999) | REINHOFER, M.: Klärschlammvererdung mit Schilf [2)] |
| Band | 33 | (1999) | GRUBER, G.: Der biologisch abbaubare Kohlenstoffgehalt in der Abwassertechnik, BTOC und BDOC als Alternative zum BSB [2)] |
| Band | 34 | (2000) | Betrieb und Überwachung wasserbaulicher Anlagen - Symposium [1)] |
| Band | 35 | (2001) | FUCHS, D.: Decision Support Systeme für die Rehabilitationsplanung von Wasserrohrnetzen [2)] |
| Band | 36 | (2001) | Untersuchungen im Einzugsgebiet der Oberen Raab über hydrologische Folgen einer möglichen Klimaänderung [1), 2)] |
| Band | 37 | (2001) | HABLE, O.: Multidimensional probabilistic design concept for the estimation of the overtopping probability of dams [1), 2)] |
| Band | 38 | (2001) | VASVÁRI, V.: Geohydraulische und bohrlochgeophysikalische Untersuchungen in geklüfteten Grundwasserleitern [1), 2)] |
| Band | 39 | (2002) | SCHATZL, R.: Skalenabhängiger Vergleich zwischen Wetterradar-daten und Niederschlagsmessungen [2)] |

| | | | |
|---|---|---|---|
| Band | 40 | (2002) | GUNDACKER, F.: Untersuchungen zur Schlammstabilisierung bei diskontinuierlich belüfteten Belebungsanlagen bei tiefen Temperaturen [2)] |
| Band | 41 | (2003) | Wasserbau neu – Die Wasserbauschule an der Technischen Universität Graz [2)] |
| Band | 42 | (2004) | Innovative Messtechnik in der Wasserwirtschaft – Konzeption und Praxiserfahrungen mit einem modularen Monitoringnetzwerk zur universellen Anwendung in der Wasserwirtschaft [2)] |
| Band | 43 | (2005) | 7. Treffen junger Wissenschaftlerinnen und Wissenschaftler deutschsprachiger Wasserbauinstitute [1)] |
| Band | 44 | (2005) | HOCHEDLINGER, M.: Assessment of Combined Sewer Overflow Emissions [2)] |
| Band | 45 | (2006) | NEMECEK, E.P., H.HAERTL, H.GERNEDEL und H.NICKL: Horizontalfilterbrunnen [2)] |
| Band | 46 | (2006) | WASSERBAUSYMPOSIUM GRAZ 2006<br>Stauhaltungen und Speicher – Von der Tradition zur Moderne [1)] |
| Band | 47 | (2006) | KAN((¦))FUNK – Überprüfung, Bewertung und Sicherstellung der Funktionsfähigkeit von Kanalisationsanlagen in Österreich [2)] |
| Band | 48 | (2007) | PATZIGER, M.: Untersuchung der Schlammbilanz in Belebungsstufen aufbauend auf den Prozessen im Nachklärbecken [2)] |
| Band | 49 | (2007) | Abwassergebührensplitting, ÖWAV – TU Graz Seminar [2)] |
| Band | 50 | (2007) | dex Fachsymposium 2007 – Abwasserableitung, Abwasser- und Klärschlammbehandlung [2)] |
| Band | 51 | (2008) | BADURA, H.: Feststofftransportprozesse während Spülungen von Flussstauräumen am Beispiel der oberen Mur [1)] |
| Band | 52 | (2008) | ARCH, A.: Luftein- und Austragsprozesse bei Anlagen mit Peltonturbinen im Gegendruckbetrieb [1)] |
| Band | 53 | (2008) | GANGL, G.: Rehabilitationsplanung von Trinkwassernetzen [2)] |
| Band | 54 | (2008) | Instandhaltung von Trinkwasser- und Abwasserleitungen; ÖWAV – TU Graz Symposium [2)] |
| Band | 55 | (2009) | Optimierte Bemessung von Mischwasserentlastungsanlagen, Erfahrungen mit der Anwendung des neuen ÖWAV-Regelblattes 19; ÖWAV – TU Graz Seminar [2)] |
| Band | 56 | (2009) | KOELBL, J.: Process Benchmarking in Water Supply Sector: Management of Physical Water Losses [2)] |

**Die Bände sind zu beziehen bei:**

[1)] Institut für Wasserbau und Wasserwirtschaft
Technische Universität Graz, Stremayrgasse 10/II, A-8010 Graz
Tel. +43(0)316/873-8361, Fax +43(0)316/873-8357
E-Mail: hydro@tugraz.at

[2)] Institut für Siedlungswasserwirtschaft und Landschaftswasserbau
Technische Universität Graz, Stremayrgasse 10/I, A-8010 Graz
Tel. +43(0)316/873-8371, Fax +43(0)316/873-8376
E-Mail: office@sww.tugraz.at