Costs and Cost-Effectiveness Analysis for Waste Water Services

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Abstract
Whenever the implementation of legal requirements for waste water treatment is discussed on a political level economic consequences have to be evaluated. These consequences comprise investment costs as well as the operational costs. There are two main factors which get most attention in this respect. The first is the influence of the treatment efficiency requirements on investment and operational costs, the second is related to the organisational aspects of treatment plant management. The latter often is discussed within the context of public and/or private responsibility. Full cost recovery from the consumers is aimed at for these services today (WFD 2000). As a consequence the full costs for waste water services are of political relevance, as the majority of the population is directly affected irrespective of the question whether the costs are recovered via fees from the municipalities or collected by private companies.
The international development in regard to cost optimisation for waste water services using process performance indicators was reflected in Austria by the development of a country wide benchmarking system for waste water services. Within a 6 years project a process benchmarking system was developed which enables the calculation of comparable process performance and specific cost indicators for sewerage and waste water treatment. This tool was applied at 76 treatment plants with design capacities ranging from ~2.000 to 1mio p.e. and a great number of sewer systems. The main aim of this benchmarking project was to detect cost reduction and process optimisation potentials and to make use of this information for improvements. The enormous amount of data collected during this project also allows interesting conclusions on absolute costs of waste water collection and treatment and the factors influencing them.

Keywords:
Operating and investment costs for waste water services, performance indicators, benchmarking, cost reduction, data quality assessment

INTRODUCTION

In 2003 the IWA report on „Performance Indicators for Waste Water Services“ (MATOS et al. 2003) was published containing a great variety of performance indicators for utilities providing sewerage and waste water treatment irrespective of public or private ownership. The main aim of this report was to produce information on performance of waste water services which allows a comparison of performance not only within a country but worldwide in order to finally improve cost effectiveness and cost efficiency.
The Austrian Benchmarking system developed from 1999 to 2004 (KROISS et.al. 2001) also comprised sewerage and waste water treatment. The following considerations concentrate on waste water treatment as the observation period of only one year in most of the cases is too short for useful conclusion regarding sewer operation. The main goal of the Austrian project was to detect cost reduction potentials by comparison of costs which are related to well defined specific processes. In this way treatment plant managers are enabled to learn from the "best". In order to achieve this goal it is necessary to have reliable data bases and to organise

the exchange of experience from one utility to the other after the cost analysis and the calculation of performance indicators.
Most of the treatment plants in Austria have public ownership and are also operated by either public or publicly owned private enterprises. Competition between the utilities on the market has no importance up to now. As a consequence the main goal of the Austrian benchmarking system is not to improve competitiveness on the market but to maximise cost-effectiveness for services which have to be delivered in order to fulfil legal requirements for waste water treatment efficiency and those for health and safety at work at the plants. The Austrian benchmarking project has voluntarily been accepted by 76 treatment plant managers. As in Austria the legal requirements for effluent quality are similar for all treatment plants. comparability of specific costs related to clearly defined processes is effective if data quality is assessed and important external parameters like the design capacity are considered correctly.
Process indicators are based on real cost taken from the accounting system for one year (in this project the years 1999 and 2004). These costs are linked with the operational data of the same year as the financial data.

Process indicators related to investment costs are based on a formalised transformation of investment into yearly capital costs. The method applied in this project for yearly capital costs is based on a recovery of the investment cost within the lifetime of the installation. The investment costs in this project represent the capital which would be needed to rebuild the existing plant at actual market prices and cost situation. For the transformation of the capital costs into yearly costs a constant real interest rate for capital of 3,5% p.a. has been assumed. In this way the calculated yearly capital costs are made comparable for different treatment plants irrespective of their construction period. The marked influence of economic cycles on prices at the real construction period was not evaluated in this study. These calculated yearly capital costs can be used for answering questions of more general economic interest in regard to water quality management as e.g.:

- Is there a correlation between high investment costs and low operating costs?
- What is the influence of the design capacity of a treatment plant with equal treatment efficiency requirements on specific construction costs?
- What is the range of variation of specific investment costs for plants with similar design capacity and treatment efficiency requirements?
- What is the influence of the utilization of plant capacity on total yearly costs?
- What is the influence of treatment efficiency requirements on specific costs?

For the treatment plant managers capital costs cannot be influenced any more but the indicators derived from these calculations can help for decision making on future asset management.

THE AUSTRIAN BENCHMARKING SYSTEM

The Austrian benchmarking system was developed within a six years project from 1999 to 2005 and is now available to all treatment plants using a internet platform located at the Austrian Water and Waste Association and operated by a team of economical (Quantum company) and technical-scientific (Vienna University of Technology, Institute for Water Quality, Resource and Waste Management) experts (KROISS et.al. 2001, LINDTNER 2004, KROISS and LINDTNER 2005). The benchmarking system has been applied at 76 treatment plants of different size from 2000 to 1 million p.e., spread all over the country. These plants represent about 30% auf the Austrian treatment plant capacity and the results are representative for more than 70% of it. All the following statements and conclusions are based on the data collected from these treatment plants. As the data are related to one year of operation there is still some uncertainty in regard to the absolute values of performance indicators. It is less relevant for the best performance values (“benchmarks”) than for the variation of the values. It is assumed that due to the voluntary participation at this project mainly managers with high willingness to optimise cost effectiveness were attracted. As a consequence the variability of process indicators for all treatment plants might be higher than derived from the project, or that medians of specific costs for all Austrian treatment plants are higher than shown in this paper. It is probable that the study results are at least representative for well operated plants.

In order to relate costs to processes it is important to clearly define the processes. In this project 4 different main processes as well as 2 support processes were defined.
Main processes:

1. mechanical pre-treatment (influent pumping, screening and grit removal)
2. mechanical-biological treatment (primary sedimentation if existing, biological treatment)
3. sludge thickening and stabilisation (digestion)
4. further sludge treatment and disposal (dewatering, storage, incineration, composting etc. transport and disposal)

Support processes:

1. obligatory processes comprising laboratory and monitoring, administration, operation building and infrastructure
2. optional processes as workshops, motor pool, etc.

Each main process is described by defined input and output data. In such a way it is possible to make mass and energy balances for each process and for the treatment plant as a whole. This methodology is extensively used for quality assessment of technical data.

For the benchmarking procedure it is necessary to introduce a accounting system at each treatment plant which enables a clear attribution of all the different costs to the defined processes. This needs thorough investigations and sometimes a complete review of the existing accounting system. Once the new system is installed there is no additional effort necessary for the following years.

RELATING COST TO TECHNICAL PARAMETERS

An extensive sensitivity analysis (LINDTNER 2004) showed that the best technical parameter for the analysis of the following costs is the mean yearly organic load (MYL-COD) expressed as population equivalents (pe) defined as 110g of COD/d in the influent of the treatment plant:

- total yearly costs,
- total operating costs and
- operating costs for the 4 main processes

This specific pollution load corresponds to 60g of BOD_5/p.e./d, commonly agreed worldwide and used by IWA report (MATOS et al. 2003). COD was used because of better data reliability and the fact that data quality control by mass balances can only be applied for COD and not on BOD_5.
Capital costs for process 2 (mechanical biological treatment) are related to a “standard design load” (SDL-COD) for better comparability. SDL-COD represents the maximum load of the treatment plant at which the Austrian effluent standards (Table 1) for municipal waste water treatment can be met.
The calculation of this “standard design load” is based on the ATV design guideline A 131 (ATV 2000). For the Processes 1, 3 and 4 the capital costs were related to the real design load (RDL-COD) of the treatment plant expressed in p.e. of organic loading as indicated in the

project documents of the treatment plant.

Size (pe_{60})		50 to 500	500 to 5,000	5.000 to 50.000	>50.000
BOD_5	mg/l	25	20	20	15
COD	mg/l	90	75	75	75
NH_4-N (T>8°C)	mg/l	10	5	5	5
TotN-removal*	%	-	-	70*	70*
TotP**	mg/l		1,5 (>1000pe)	1,0	1,0

Table 1: *Austrian effluent standards for municipal waste water treatment (1996)*

*Temperature >12°C yearly mean, ** yearly mean. All other standards are 95%iles based on daily flow proportional composite samples, self monitoring and external monitoring results have to meet these requirements. Maximum values 150% of standard (200% for ammonia) must never be exceeded, no minimum value for N-removal.

Classification of treatment plants according to their size (MYL) in "groups"

The investigation of the very heterogeneous sample of 76 treatment plants spread all over the country clearly showed that there is a strong influence of the size of the treatment plants on the specific costs. In order to obtain comparable financial indicators it was necessary to group the plants according to their size (expressed as the actual MYL-COD). The range of size for the "groups" was chosen in a way that the influence of the size on the financial process indicators was in the same range as the accuracy of the data. The investigation of 76 municipal treatment plants (5000 to 100.000 p.e.) showed that the influence of the size of treatment plants on specific costs is increasing with decreasing size, especially below 20.000 p.e. The costs for the introduction of the benchmarking procedure are much less depending on the size of the plant than the absolute cost reduction potential. At very small plants (< 5000 p.e.) this fact becomes crucial for the application of the benchmarking procedure.

Relevance of the project results for Austrian situation

LINDTNER (2003) showed that the results from 76 municipal plants are representative for ~ 90% of the Austrian municipal treatment plant capacity if the Main Treatment Plant of Vienna (4 mio p.e.) is not taken into account. Only the very small plants (<5.000 p.e.) are not well represented in the investigation results.

Definition of Benchmark bands, Benchmarks, and Benchmark plants

Benchmark bands are defined for each "group" and represent the lowest specific total yearly costs achieved in a benchmark plant increased by a percentage which has been fixed on the basis of experience in regard to data quality and inaccuracies. Benchmark bands are only interesting for scientific or political evaluation but not for optimisation of treatment plant operation.

Benchmark plants have to meet the following criteria:

- The effluent quality must comply with the legal requirements laid down in the respective Austrian regulation (Tab. 1)
- Compliance with technical data quality criteria (mass balance check, etc.).
- Waste water characteristics have to be municipal (no dominant influence of industrial waste water).
- Lowest specific overall operating costs in a "group"

A *benchmark* is defined as the lowest specific operating costs for one of the processes (process performance indicator) within a "group" of treatment plants. Data uncertainty is not considered as an issue at the stipulation of the benchmarks, as special data quality assessment is applied. Benchmarks for capital costs of processes were not calculated as they do not allow accurate comparison.

BENCHMARKING RESULTS

Process performance indicators like Benchmark bands and Benchmarks without reference to any specific plant are made publicly available on the web (KROISS et al. 2001) or for all participants. The detailed results of the treatment plant analysis are contained in an "individual report" which is confidential.

Benchmark bands are shown in figure 1. The specific costs shown in this figure represent the minimum achievable operational and total yearly cost for waste water treatment plants meeting the legal requirements in the year of investigation. This figure also shows the great influence of the size of the treatment on the specific costs for plants below 50.000 p.e.. Recent investigations at plants >100.000 p.e. showed that the benchmark band values are only about 10% below those for 50.000 p.e..

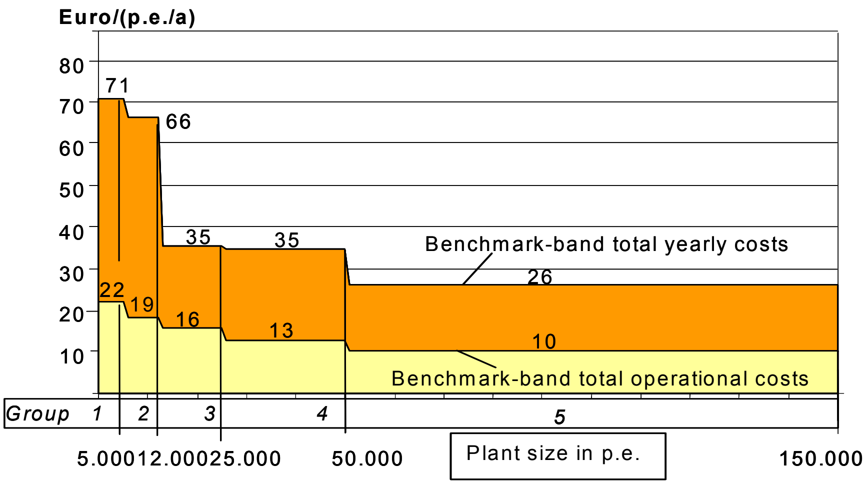


Figure 1: *Benchmark-bands for operating and total yearly costs for 5 size groups*

WEB BASED BENCHMARKING PLATFORM

In order to facilitate the access to the benchmarking process for all treatment plants a web-based Benchmarking Platform at the Austrian Water and Waste Management Association was developed and is now in operation. The platform (www.abwasserbenchmarking.at) reduces the costs for the benchmarking procedure by making optimal use of automated data management and easy accessibility not only in Austria but also worldwide in principle. Adequate professional control of the system and quality assurance is provided by a team of experts derived from the benchmark development team.

The web based benchmarking process is included in a 4 phase procedure, repeated every year:

- Input of technical and economical data (by the treatment plant operator/manager) and automated evaluation of the data quality
- Data quality check using mass balances, determination of benchmarks and other process performance indicators, quality check of the results by an expert before release and development of individual reports
- Exchange of experience between the treatment plant operators/managers at workshops for each group of treatment plants

The whole data transfer as well as the complete communication between all stakeholders is accomplished via internet. This system fulfils all the requirements for data security and for the different rights to access the results. The software for the platform can easily be adapted to foreign languages in the future for international application.

COST EFFICIENCY CONSIDERATIONS

For treatment plants > 100.000 p.e. the following distribution of costs to the 4 main processes and the support processes is shown in figure 2.

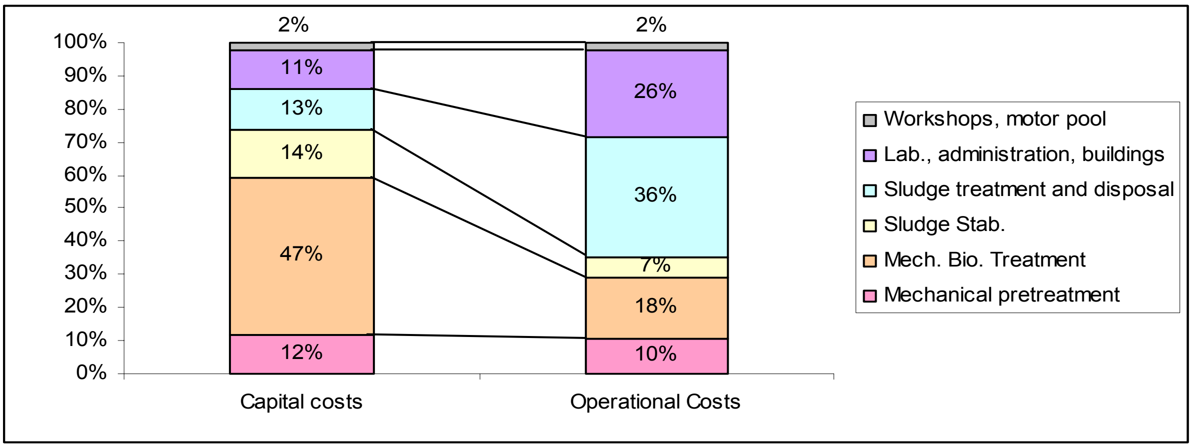


Figure 2: *Costs attributed to different processes for plants > 100.000 p.e.*

The most important process for water protection, i.e. mechanical-biological treatment (with nutrient removal), only contributes to about 20% of the operating costs but about 50% of the capital costs. The share of capital costs for this process is nearly equal for construction and for mechanical-electrical equipments. For the operating costs the most relevant cost factors are sludge treatment and disposal (without sludge stabilization) and support processes like administration, laboratory and infrastructure operation.
The influence of treatment efficiency on total yearly costs can be estimated from these data. A reduction of treatment efficiency from BNR to BOD-removal only (e.g. EU municipal waste water guideline 271/91 for normal areas) will result in a reduction of the aeration tank volume by about 65%, secondary clarifier volume would not be affected, as it is for all the other processes. The aeration capacity and ICA will result in a reduction of investment of about 30%. This results in a capital cost reduction for process 2 by ~50 % corresponding to a total capital cost reduction of ~25. The operating costs for process 2 will be reduced by about 30%, corresponding to a total operating cost reduction of ~7%. Applying this to a benchmark band plant with 15€/p.e.yearly capital and 10€/p.e. yearly operating costs this results in a total cost reduction of ~4,5€/p.e./year. This is markedly lower than the variability of the total cost for the treatment plants investigated.
Common waste water fees in Austria are in the range of 60 to 80€/p.e./a. It can be concluded from this that the increase in cost for the consumer by changing from EU minimum requirements for normal areas to sensitive areas (full nitrification and nutrient removal) is in the range of 7% of actual total yearly cost while the pollution discharge is reduced by a factor of 3 to 5.

Figure 3 shows that there was no correlation between the operating costs of the investigated ~80 treatment plants with treatment efficiency. The “effluent pollution value” used in this figure has been developed in Austria and comprises BOD, ammonia, TN and TP effluent concentration and is based on yearly mean discharges (OWAV 2000). Is this value below 1,8 the legal requirements are met. The “value” is very sensitive to ammonia and TP.

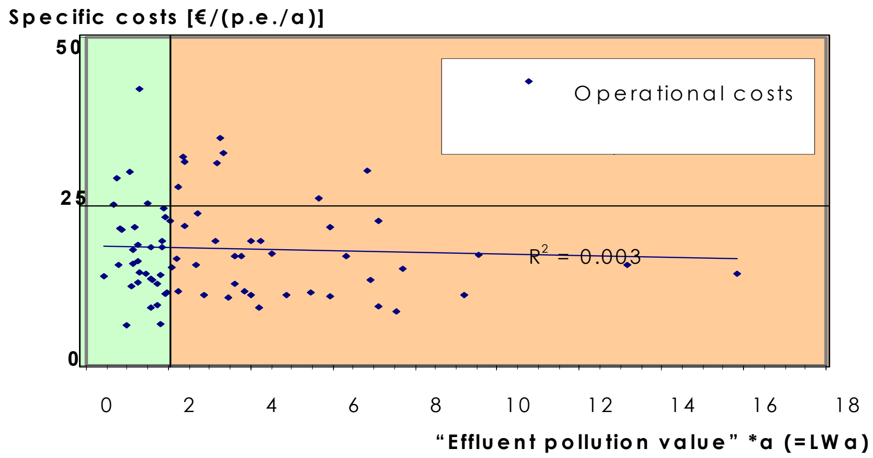
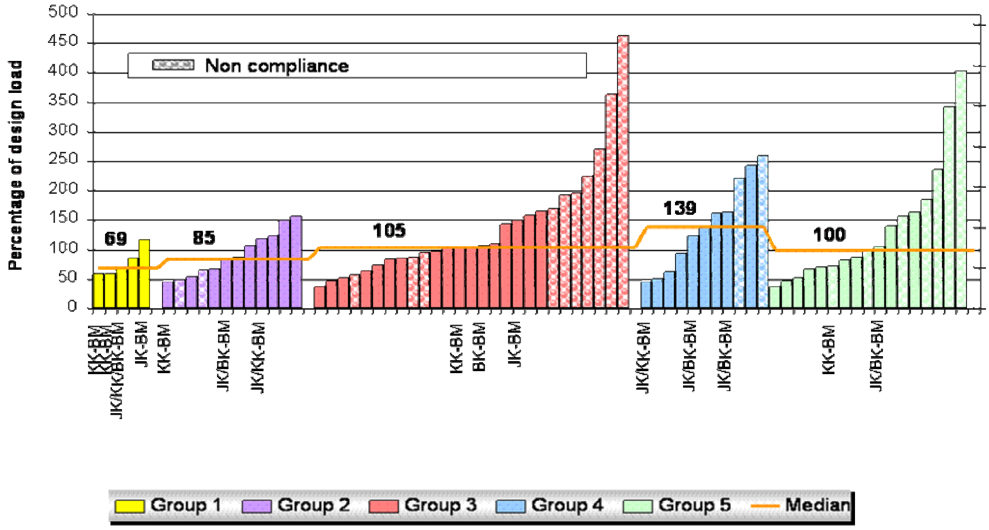


***Figure 3**: Correlation between specific operating costs and "effluent pollution value"*

Looking into details of the results it turned out that benchmark plants do not only have the lowest costs but often the highest treatment efficiency, too. One can conclude from this that the quality of the staff and the competence of the manager are the decisive factors for efficient operation. Minimum operating costs do not coincide with the lowest personal costs, which seems to ascertain the previous statement. There is also no correlation between high capital costs, low operating costs and treatment efficiency.



KK: Capital cost
JK: Yearly costs
BK: Operating cost
BM: Benchmark

***Figure 4:** "Plant Utilization" (100%=design load has occurred during the year of investigation)*

Figure 4 shows the relative "utilisation" of the plant capacity for all the investigated plants. As treatment plants have to fulfil the effluent standards at every time they have to be designed for the most unfavourable loading conditions. "Plant utilisation" in this paper is the ratio between "design loading" during the year of investigation (e.g. the 85%ile of COD load) and the loading capacity of the plant for meeting legal requirements using a standardised design procedure (ATV A 131). In both cases design temperature has to be considered, too. Plants not having complied with legal requirements are indicated. The median "plant utilisation of the larger plants is in the range of 100%. This is not the case for the very small treatment plants. This is an additional reason for the fact that their specific total yearly costs are much higher than for the large plants. Also the benchmark plants are indicated.
Not only the specific capital costs increase with lower "plant utilisation" but also the operating costs for different reasons.

CONCLUSIONS

The Austrian benchmarking system developed over the last years has proved in practice to be a powerful tool for cost efficiency optimisation of waste water treatment plants. Special emphasis was given to the data quality assessment and to data security, as especially the economic data is sensible. An internet based Benchmarking Platform (www.abwasserbenchmarking.at*)* is now in operation which enables a reliable and low cost access for all treatment plants. The German version can be adapted to other languages and would also enable a global cost comparison.

The data from benchmarking 76 treatment plants was used for general cost effectiveness and efficiency considerations. The main conclusions in this investigation are:

- The influence of treatment efficiency requirements on waste water fees or costs is often overestimated and is lower than the variation of total yearly costs for different treatment plant with equal requirements.
- There is no correlation between treatment efficiency and operating costs for treatment plants with similar requirements. Excellent treatment efficiency often coincides with low specific costs.
- Low "plant utilisation" results in marked increase in specific capital and operational costs. "Plant utilisation" has been defined using comparable
- Design load (expressed in p.e.), specific local situation and quality of design have a greater influence on specific costs than treatment efficiency. The effect of plant size becomes especially strong at TP with a capacity <50.000 p.e..

REFERENCES

ATV-Arbeitsblatt A 131 (2000): *Bemessung von einstufigen Belebungsanlagen ab 5000 Einwohnerwerten*. Abwassertechnische Vereinigung e.V. (DWA), Hennef, Germany.

Kroiss, H., Haberl, R., Bogensberger, M., Nowak, O., Ertl, T., Josef, Habich, Lindtner,S., Starkl, M., Murnig, F. und Sleytr, K. (2001): *Benchmarking in der Siedlungswasserwirtschaft.* Lebensministerium. Wien, Austria (**htttp://www.k2w.at**; see „Referenzen").

Kroiss H. (ed.) (2002): *Benchmarking in der Abwasserentsorgung*. **Wiener Mitteilungen Bd. 176**. ISSN 0279-5349, ISBN 3-85234-067-5. Ed. Institut für Wassergüte und Abfallwirtschaft der TU-Wien, Karlsplatz 13, 1040 Wien

Lindtner S., Kroiss H., Nowak O (2004*):.Benchmarking of Municipal Waste Water Treatment Plants (an Austrian Project)*. Wat.Sci Tech. **Vol 50 No 7 pp 265-271**

Lindtner S. (2004): *Beitrag zum Benchmarking von Abwasseranlagen*. Thesis. **Wiener Mitteilungen Bd. 189**. ISSN 0279-5349 ISB 3-85234-080-2, Ed. H. Kroiss, Institut für Wassergüte und Abfallwirtschaft der TU-Wien, Karlsplatz 13, 1040 Wien.

Matos, R., Cardoso, A., Ashley, R., Duarte, P., Molinari, A. und Schulz,A.(2003): **IWA Technical report**: *Performance Indicators for Wastewater Services*. 1. Edition, IWA-International Water Association, London UK.

ÖWAV (2000): -Arbeitsbehelf 9: Kennzahlen für Abwasserreinigungsanlagen, Teil 1: Ablaufqualität-Bewertung und Beurteilung. Österreichischer Wasser und Abfallwirtschaftsverband, Wien.

Preißler P. (1995): Controlling – Lehrbuch und Intensivkurs. Oldenburg, München

Schulz A., Schön J., Schauerte H., Graf P., Averkamp W. (1998): *Benchmarking in der Abwasserbehandlung*. **Korrespondenz Abwasser**, **45**, pp 2297 - 2302.

Wibbe S. (1999): *Benchmarking in der Abwasserwirtschaft*. **Korrespondenz Abwasser, 46**, pp 1432 - 1436.

Wiesmann J. (1999): Neue Wege zum Benchmarking für Betreiber. ATV-Bundes- und Landesgruppentagung, 28.-29.9., Mainz. **ATV-Schriftenreihe - Band 17**, 257 - 280.