The cost of municipal sewage treatment – structure, origin, minimization – methods of fair cost comparison and allocation

H. Bode* and T. Grünebaum**

*Executive Technical Director, Ruhrverband, Kronprinzenstrße 37, 45128 Essen, Germany

**Head of the wastewater division planning and central activities, Ruhrverband, Kronprinzenstrße 37, 45128 Essen, Germany

Abstract Cost comparison in the field of wastewater treatment is a difficult task, particularly concerning sewages charges in different countries. German wastewater management is, for one thing, known to be very efficient, yet, for another, comparatively costly on an international scale. In this context, the marginal conditions typically prevailing in the field of sewage treatment in Germany should be mentioned: dense population and industrialization with high export-oriented production rates, high-profile purification requirements enforced by law. To establish a valid cost comparison, it is necessary to include both the investment and the operating expenses within the scope of the overall annual costs. The major factors impacting the different cost types are represented. Only if these factors are taken into account and quantified, will cost comparison be fair and lead to useful results. Ten hints for cost minimization are given to serve as a guideline for successful and responsable cost reduction. Cost transparency is the prerequisite for the possibility to develop saving potentials while simultaneously securing the social and political acceptance of the charges levied, and to compare the different plants with one another. Experience from Ruhrverband, a water management association for an entire catchment area, being responsible for planning, building and operation of 94 wastewater treatment plants and other plants for water quantity and water quality management, is reported.

Keywords Charges; cost minimization; cost structures; investment costs; operating costs; wastewater treatment

Introduction

The steadily growing internationalization and globalization of water management has fueled a lively debate on the funds to be spent in many places of the world. Involved are not only techno-economic, organizational-administrative criteria, but also political issues. Recent investigations (Rudolph, 1998; Firk *et al.*, 1998; Kraemer *et al.*, 1998) show that a direct cost comparison "across country borders" is particularly difficult: the impact of individual treatment targets is too great, patterns of fund granting, and technical and local conditions on the required capital expenditure. Even the level of sewage charges is not always a proper instrument to ensure cost transparency of the actual costs, because of, e.g., cross or covered subsidization in the form of public-sector subsidies and loans at low interest rates or political takeover prices in the case of privatization of public enterprises. In addition, the pressure of national taxation varies significantly (in particular with regard to the prevailing VAT rates), *and* labour and energy expenses affect the cost of operation. For example: the hourly labour rate in Germany is significantly higher than in France or Italy, with a significantly lower overall yearly working time (due to paid vacation and public holidays). Further, the current costs of energy are still at a comparatively high level in Germany, though a marked downward trend in pricing has been observed since the liberalization of the power supply market in April 1998. The advanced level of performance in sewage treatment achieved in Germany – compared with the requirements of the European Urban Wastewater Directive (NN, 1991) – is another factor enormously impacting on the costs. In

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conclusion it can be stated that with charges exceeding DM 200 per inhabitant and per annum and a percentage of 0.5 of its GNP, Germany has been and is still facing the highest cost burden, compared with other first-world countries like Denmark, Great Britain, France, Italy and Austria (Kraemer *et al.*, 1998; Rudolph, 1998). It must be pointed out, that the responsibility for wastewater treatment and water quality is a rather hard one in a densely populated and industrialized country. These imbalances are not likely to make the discussion on comparable locational conditions any easier, nor are they likely to facilitate the situation of sewage works operators when seen against the background of globalization and Europeanization – and the advent of the European monetary union. It should be mentioned that by the year 2005 the estimated volume of investments required in the field of public sewage treatment plants in Germany amounts to DM 3 to 5 billion/a, and in the decade to follow the capital to be earmarked for the purpose will be on an equally high scale (Dohmann *et al.*, 1997).

Already during the last decade in Germany the charges for sewage disposal increased to a high level. The reasons are manifold, some of them are discussed below:

- Stringent safety requirements to be met by the operating companies of sewage works: non-compliance resulting in consequences based particularly on criminal and charges law, leading to very low contamination concentrations in the final effluent;
- Stringent requirements for sewage treatment efficiency by extending the treatment spectrum to the nutrients (almost always nitrogen *and* phosphorus) and more difficult to break down substances (COD), with modified monitoring methods ("four out of five rule", "qualified random sampling");
- Stringent requirements for stormwater treatment;
- Stringent standards for residue and sludge disposal;
- Increased expenditure for planning and monitoring tasks due to administrative requirements by e.g.: in-depth preliminary planning with a higher level of detail already prior to the definite approval of the project by the authorities, and comprehensive and costly standards for plant monitoring;
- High specific costs required for the connection of rural areas not yet connected to the public sewerage systems;
- Misdirecting of money raised for sewerage and wastewater treatment in public households caused by lack of cost transparency which facilitates employment of this money for other purposes;
- High public demand with regard to sewage treatment as compared to the past, finding its response quite often in high-profile legal and regulatory targets, as e.g.: nature and landscape conservation, limitation of noise and odor emissions, industrial safety, traffic safety, comfort in the workplace and design of work environment, architecture;
- Special technical, economic and environmental problems caused by density of population and industrialization.

Ruhrverband is a water management association for an entire catchment area based on a special act. Its work today focusses on sophisticated water quantity and quality management for more than five million people, using raw water taken from the Ruhr. At the present time the Ruhrverband operates 94 wastewater treatment plants, more than 450 stormwater treatment plants, eight reservoirs and some other plants for water management. The experience gained in the field of cost structures with these plants is described.

Cost structures in sewage treatment

The overall expenditure for wastewater disposal consists in principle of the cost of operation and the cost of capital spent on the discharge of wastewater and the treatment of stormwater, *plus* the cost of wastewater purification. According to experience gained in

Germany it is known that wastewater *discharge*, compared to wastewater *treatment*, accounts for approximately two thirds of the total charges for wastewater disposal. The amount of capital cost for the required investments varies widely as a function of the different specific reference variables (purchase/manufacturing cost or current replacement value). With a share of 60%, they absorb the greatest portion of the collected sewage charges as imputed depreciation allowance if combined with the calculated interest costs. In general, the overall investments for the sewerage systems are several times higher than those needed for the sewage treatment plants.

Operation of sewage treatment plants entails regular maintenance costs. These are preferably broken down as costs for labor, energy, materials and supplies, maintenance, disposal and other operationals. From a strictly monetary point of view, the operating costs do not depend on the investments involved (design and construction). Yet if seen from a technical point of view it becomes evident that the operating costs are virtually predetermined by the type of plant and equipment used. Consequently, careful consideration should be given during the planning phase as to whether and how far a shifting of investment costs toward operating costs might be advisable and reasonable. Shifting of costs in the early planning phase can be illustrated as follows:

- Centralization in the field of sewage treatment by combination or linkup of sewage plants: here the reduced investment costs compared to smaller sewage treatment plants must be set against, among others, the operating cost for the transfer of the wastewaters (sewerage maintenance, and, if required, pumping costs), but on the other hand also against decreasing operating cost for the large sewage treatment plant.
- Replacement of bubble aeration by less effective surface aeration in activated sludge plants: here lower investment cost (e.g. for the blower room in the basement otherwise necessary) compare with additional energy cost.
- Substituting simultaneous aerobic sludge stabilization for anaerobic processes: here the savings for sludge digestion (minus the investment for the larger aeration tank) have to be compared e.g. with additional energy cost for the biological sewage purification.
- No "in-house" sludge treatment, but contracting out certain tasks by employing the services of another sewage works located not too far away or of external providers: here the savings in investment costs compare with additional transport and co-treatment expenses in the neighborhood plant or by external providers (mobile sludge dewatering, utilization of sludge as material or for incineration).
- No implementation of a more effective sludge dewatering or drying stage: here the lower investment costs compare with an increased expenditure for sludge transport, sludge utilization and/or disposal.

It becomes evident from the above that it is hardly possible to judge the economic success of a new plant by looking only either at the investment costs or at the operating costs. Both technical and economic criteria must be weighted as equivalent decision variables. All changes in these items occurring during the forecast period must be considered, implying a dynamic cost structure. Hence a cost comparison method is obviously a suitable instrument to be applied in the decision finding process.

To improve cost transparency and comparability, a uniform classification and level of detail should be upheld during the entire term of a project and maintained right from the beginning of the planning work up to the establishment of the final account (ATV, 1998). Here again reference to the known interrelationship of impacting factors may be appropriate: the best method to exert an influence on the initial expenditure as well as on the operating cost of the running plant is to use the manouvering room available when the project is still in its infancy, i.e. when the basic elements are being determined and the preliminary planning still is under way (Bode, 1998c).

The cost of sewage treatment plants

Investment cost

Design and construction costs of sewage treatment plants fall into three major cost categories: civil engineering, mechanical engineering, and electrical engineering including instrumentation and control. Pro rata assignment of these segments within the individual process stages may vary a lot; in Germany it is estimated that a statistical mean of 35% of the total investment falls upon mechanical engineering plus control and instrumentation, whereby a trend toward a declining proportion for civil engineering is being observed. This trend may well originate from the fact that a great number of projects to optimize sewage purification is being realized by adding (high tech) extensions to existing plants. For example, in a filter plant, the machinery-based cost accounts for about 40%, while the cost for electrical engineering, instrumentation and control amounts to about 10% of the total expenditure. The remaining 50% are to be assigned to civil engineering, which, e.g., compares with a share of up to 80% needed to build a primary-sedimentation tank.

The above cost center pattern for investments, divided into costs for civil, mechanical and electrical plus instrumentation and control engineering is transferred to the relevant depreciation periods to determine the yearly capital cost and is also used to compute the mixed index to allow adaptation of cost data from different years to a uniform level of a reference year.

To establish a cost comparison it is necessary to exactly predefine the frame of investigations and the scope of data compilation. For example, earlier surveys show that costs relating to the planning work, building lot, influent pump station, stormwater tank and sludge treatment are often not contained in the acquired cost data. It is further important that always gross prices – i.e. inclusive of all taxes – are being reviewed.

Essential factors impacting on the investment expenditure are:

- Plant size;
- Process selection and definition of sewage treatment targets (purification requirements);
- Special sewage-specific features;
- Special site-specific features;
- Market situation in the sectors of civil engineering and equipment manufacture.

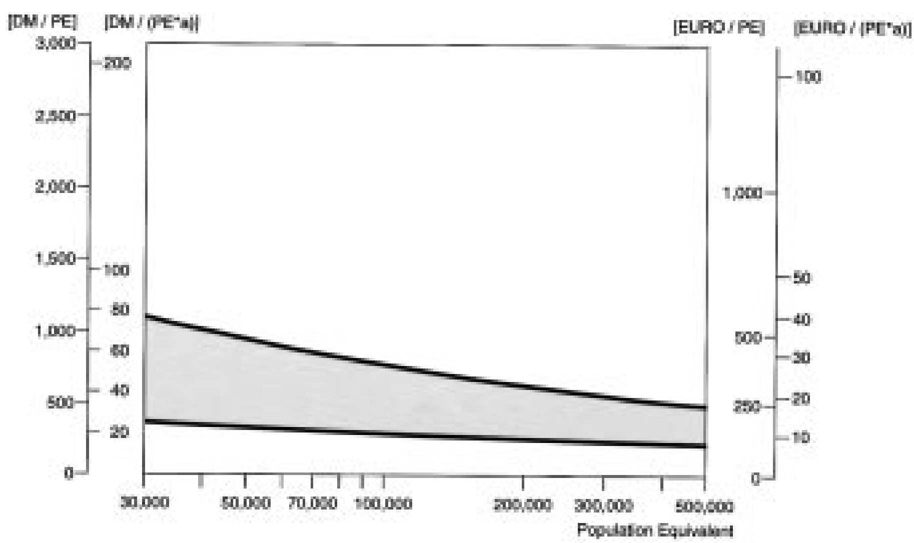

Figure 1 Capital spend for sewage treatment plants in Germany

The really decisive cost determinants like current annual expenses arising as debt service with depreciation and interest, are practically fixed and apply to many years to follow. There will hardly be any opportunity to influence these in the course of the useful economic and operational life of the plant, except for the minor chance to implement financial measures such as debt refunding, conversion in the ratio of owned to borrowed capital, and interest payment for the latter and employment of leasing models.

Operating costs

Operating expenses are incurred in conducting the ordinary major activities of the "on stream" facilities. Thus, any decision in favor of a specific technical solution in the early planning phase will essentially predetermine the level of operating cost. This underlines the need for a holistic approach in the planning work.

Cost impacting factors are, in principle, similar to those on the investment side. Hence the size of plant, sewage-specific and site-specific characteristics and the current market situation are to be considered as well. However, it should be pointed out that the degree of utilization of the plant in relation to its design capacity is of much greater importance, so that preferably the actual load of the plant should be used as population-specific value. This applies to an optimized use of both processes and units *and* required supplies.

Measures geared to reduce or minimize the operating expenses have an either direct or indirect effect on the technical processes or organizational relationships typically found in sewage treatment plants. Consequently, they are closely linked to the result of sewage treatment.

Figure 2 gives the evaluation of operating cost rates and population-specific sizes of sewage treatment plants of the Ruhrverband. However, in the light of the impacting factors discribed above and relationships, a generally applicable "absolute" statement is hardly possible.

These figures from Ruhrverband (Figure 2) fit into the results of a survey which was recently conducted on 34 European sewage treatment plants (Table l.; [Bode, 1999]. All plants were designed for nutrient removal. The cost data came from real cases which formed an average of some representative nature for their country. The evaluation shows that the originating annual costs of recently built plants do not differ by a factor of more than 1.2 within the first four countries. It becomes obvious, that plant related costs and charges might differ a lot from each other (see introduction).

Table 1 Cost of wastewater treatment in six european countries – related to the design capacity

		Capital costs		Operating costs		Annual costs	
	Number of anaerobic plants	DM/p.e..a	Part of annual costs [%]	DM/p.e..a	Part of annual costs [%]	DM/p.e..a	Part of annual costs of Switzerland [%]
CH	4 to 6	65	59	46	41	111	100
D	3 of 6	57	55	46	45	103	93
DK	1 of 6	34	35	63	65	97	88
F	0 of 5	23	25	69	75	92	83
NL	3 of 6	40	50	40	50	80	72
I	2 of 5	21	34	41	66	62	58
arithmetical average of each part							

*all data of larger wastewater treatment plants. Size of plants from 800–300,000 p.e., a representative mixture of wastewatre treatment plants of each country

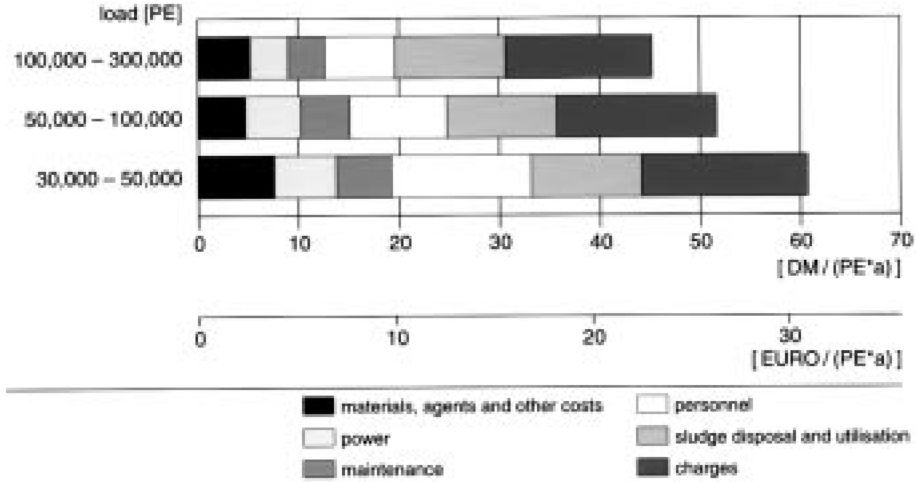

Figure 2 Annual operating costs of 22 sewage treatment plants of Ruhrverband classified according to the plant loads

Environmental aspects of the cost of sewage treatment

In view of the rising cost pressure described above it is more than ever necessary to focus on water conservation and earmark any remaining funds for this objective. Application of the maximum principle in sewage treatment means to realize an optimum cost-benefit ratio with limited financial resources. In principle, the most efficient tool to succeed on this route is to manage an entire catchment area and to use the resulting synergy effect (Bode, 1998a; Grünebaum and Nisipeanu, 1998). Against this background it becomes evident that it may be helpful to also evaluate cost aspects in any planned or required effort to reduce emissions. Under average conditions, the expenses for municipal sewage treatment can be assessed as substance-related variables. Accordingly, the costs incurred in German municipal sewage treatment plants may be quantified as follows:

DM 10 to 15 per kg eliminated nitrogen N_{total}
DM 25 to 40 per kg eliminated phosphorus P_{total};
DM 1 to 2 per kg eliminated organics, determined as COD (Grünebaum, 1993).

These cost data must be added up so that a genuine monetary comparison of achieved environmental benefits – expressed as load reductions of the above listed pollutants – can be established.

Impacting variables are for one thing the conditions already outlined above, and for another in particular the specified targets with regard to the purification performance of the sewage treatment plant. At this point it should be noted that any effort to eliminate the “very last milligram” of loads would increase the cost disproportionately. The above listed substance-related costs can be used under average German conditions in sewage treatment plants complying with the European Urban Wastewater Directive for sensitive areas.

Thus it will be possible to compare the costs arising from implementing sewage-plant related measures to meet load reductions aimed at or required in surface waters with those arising from alternative water-management measures. It may be particularly helpful to compare the costs arising from actions to reduce load inputs from diffuse sources with those relating to an adaptation of municipal sewage treatment plants. In short, it will often be possible to achieve load reductions with an expenditure similar or below that involved by municipal sewage treatment.

Fair allocation of charges

Both the required cost transparency and a consequent application of the "polluter-pays" principle for new sewage treatment plants with nutrient elimination lead to a separate evaluation of domestic and trade/industrial wastewaters having different constituents. So far normally the consumption figures of potable and industrial water were thought to be the correct yardstick for fixing charges which cover the costs of sewage treatment. But it is now being increasingly realized that *all* expenditures (not only the water consumption related ones) should be assigned to the actual polluters, in order to enhance cost transparency and, thereby, to ensure fair charges. Major criteria to be considered in this connection are:

- Sewage input quantities;
- Organic loads, preferably as COD under consideration of the ratio COD/BOD_5 for the degradability of organics;
- Nitrogen loads referring to both reduced nitrogen and oxidised nitrogen;
- Phosphorus loads;
- Loads of suspended solids, preferably in the form of mineral components to avoid double charging via the COD;
- Other substances, if present (e.g. heavy metals and organic pollutants).

Additional variables should be considered in more severe cases as, for example, intermittent peak loads and extraneous water.

Under the above aspects, the Ruhrverband decided to effect cost assignment for sewage treatment in accordance with a new formula:

$$
\begin{aligned}
E\,[EE] = {} & 0.20 \cdot Q_a\,[m^3/a] \cdot 1/50\,[m^3/(a \cdot EE)] \\
& + 0.20 \cdot (CSB\,[kg/a] \cdot 1/(0{,}120 \cdot 365\,[kg/(a \cdot EE)]) \cdot F\,(COD/BOD_5)) \\
& + 0.20 \cdot (SS_{mineral}\,[kg/a] \cdot 1/(0{,}025 \cdot 365\,[kg/(a \cdot EE)]) \\
& + 0.10 \cdot (P_{total}\,[kg/a] \cdot 1/(0{,}002 \cdot 365\,[kg/(a \cdot EE)]) \\
& + 0.15 \cdot (N_{red}\,[kg/a] \cdot 1/(0{,}011 \cdot 365\,[kg/(a \cdot EE)]) \\
& + 0.15 \cdot [((N_{red} \cdot 0.77 + (NO_x{-}N - (Q_a \cdot 0{,}005))\,[kg/a] \\
& \quad \times 1/(0{,}0085 \cdot 365\,[kg/(a \cdot EE)])]
\end{aligned}
$$

Legend:

E	=	evaluation in the form of evaluation equivalents, roughly corresponding to the load caused by the domestic sewage of one inhabitant (EE)
Q_a	=	sewage quantity (m^3/a)
COD	=	organic substances, fixed as chemical oxygen demand (kg/a)
BOD_5	=	organic substances, fixed as biochemical oxygen demand (kg/a)
SS_{min}	=	mineral proportion of suspended solids (kg/a)
P_{total}	=	phosphorus total (kg/a)
N_{red}	=	reduced nitrogen (kg/a)
NO_x–N	=	nitrate and nitrite nitrogen (kg/a)
$F\,(COD/BOD_5)$	=	correction function:

$1 < COD/BOD_5 < 2$: $F = 0.25\,(COD/BOD_5) + 0.5$

$2 < COD/BOD_5 \leq 3$: $F = 1.00$

$3 < COD/BOD_5 \leq 11$: $F = 0.50\,(COD/BOD_5) - 0.5$

$COD/BOD_5 > 11$: $F = 5.00$

The individual expenditures for sewage and sludge treatment are assigned to the specified treatment targets and to the above given criteria. Prerequisite for this approach is a precise definition and weighting of treatment objectives as well as their conversion into cost-relevant items. To give an example, the expenses incurred by chemical precipitation were assigned to the costs of phosphorus removal. In addition, the resulting elimination of other parameters was considered and allocated pro rata. For other process stages (e.g. preliminary sedimentation, activated sludge process), the same procedure was applied based on the elimination results achieved in the different stages.

Aspects of a comparative evaluation of economic efficiency

When the costs of sewage treatment in the municipal environment are to be validly compared, it will soon become evident how important it is to have unique, clearly defined reference values and to know the exact limits or "interfaces" between sewage treatment and sewage discharge, stormwater treatment and residue disposal. The fact that the data basis, data assignment and data interpretation may vary significantly, adds up to the problem. Recent developments in the field of cost accounting in various branches of industry were also taken up by German sewage plant operators, which reflect the new trend toward benchmarking in water management (Schulz *et al.*, 1998). First experience triggered off a systematic search for benchmarks; these correspond – in some areas – to the above cost specifications, but display on the other hand a better comparability in their systematics. Among the benefits achieved is a uniform data acquisition, providing an essentially improved data transfer. Yet this progress is accompanied by a significantly higher expenditure for data collection.

Other approaches for in-house benchmarking are likely to be feasible when a great number of plants is in the hands of one owner. The "cost accounting and results accounts" method is currently being introduced by the Ruhrverband for its complete range of services, processes, and organizational units, which does also include a cost comparison procedure for all 94 working sewage treatment plants. Prerequisite for the purpose is a precise cost-center/cost-type accounting system according to the generally accepted accounting principles of orderly business, which makes it necessary to define and identify products also in the area of sewage treatment. The population equivalent (PE) normally used to determine the size of sewage treatment plants appears to be relatively unsuitable as it does not include the costly elimination of nutrients. Another possible approach is to refer to the cost-involving processes or parameters given in the evaluation formula (compare chapters before). It must be further ensured that in case of a combination of plants, an appropriate method to assign both cost and products will be found and applied, for example with regard to sludge treatment, joint maintenance and storekeeping operations, or labor (Evers *et al.*, 1999).

Notes on cost minimization for investments

The following guidelines for cost minimization in the field of sewage plant construction may be derived from the above findings and from recent and historical experience of the Ruhrverband, trying hard to reduce the annual costs wherever possible:

1. Thorough and detailed assessment of the project bases (which includes intensive measuring of pollutant loads over longer periods);
2. Investigation of planning variants and consequent assessment of economic efficiency in accordance with techno-economic criteria;
3. Consideration of "slimmed down" expansion measures instead of new plants;
4. Permanent training in cost observation and engineering capabilities of the staff involved in the project;
5. A good eye for gauging the project in its full range (also with regard to redundancy, selection of materials, dimensioning of equipment, demands on architectural structure and comfort);
6. Negotiating and coming to terms with the authorities concerned in case of excessive requirements (with regard to sewage purification targets and relating areas);

7. Streamlining of project management to achieve economic project timetables;
8. Clever tender strategy according to the current market situation;
9. Careful safeguarding of owner's interests on the construction site;
10. Selection of the "best possible" moment for the investment.

Summary and conclusions

In the light of steadily rising sewage charges, the call for cost reduction has also gained momentum in Germany. This is to be seen against the background of the fact that German wastewater management is, for one thing, known to be very efficient, yet, for another, very costly on an international scale. In this context, the marginal conditions typically prevailing in the field of sewage treatment in Germany should be mentioned: dense population and industrialization with high export-oriented production rates, high-profile purification requirements enforced by law. Germany declared itself by almost 100% to be a "sensitive area", which leads to very high requirements being applied in the context of the European Urban Wastewater Directive. However the first salmon are reported to be back in the Rhine after it had been almost a dead river in the seventies.

To establish a valid cost comparison, it is necessary to include both the investment and the operating expenses within the scope of the overall annual costs. The major factors impacting on the different cost types are represented. Only if these factors are taken into account and quantified, can cost comparison be fair and lead to useful results.

Top objective of any sewage treatment effort is to ensure compliance with specified discharge targets. All measures directed at cost minimization must be seen in this context which excludes savings potentials which might theoretically be possible. Cost cuts can only be realized in a responsible way if all relationships and consequences are transparent and thus calculable. The ten hints for cost minimization given above might serve as a guideline for successful and responsible cost reduction.

Cost transparency is the prerequisite for the possibility to develop saving potentials while simultaneously securing the social and political acceptance of the charges levied, and to compare different plants with one another. Central to this approach are modern systematic methods like benchmarking and cost accounting and results accounts, which might be helpful to determine cost parameters and use them to open up optimization potentials. However, the capability to find optimum technical solutions relying on expert knowledge, skills and experience of people taking account of all marginal circumstances, still is and will be the basis for the economic and technical success and progress in water management.

References

Abwassertechnische Vereinigung (ATV) (1998). Durchgängige Kostenplanung und -steuerung; Report of the ATV-Workinggroup 8.1.1 "Kostenanalyse und -steuerung"; Korrespondenz Abwasser, No. 3, Germany, pp. 565–572.

Balmér, P. and Mattson, B. (1994). Wastewater treatment plant operation costs; Wat. Sci. Tech., 30(4), 7–15, IAWQ.

Barraqué, B. (1998). Europäische Antwort auf John Briscoes Bewertung der deutschen Wasserwirtschaft; gwf-Wasser Abwasser, No. 6, Germany , pp. 360–366.

Bode, H. (1998a). Control of Heavy Metal Emission from Metal Plating Industry in a German River Basin; IAWQ, Pergamon Press, London, Great Britain. *Wat. Sci. Tech.*, **38**(4–5), 121–129.

Bode, H. and Nusch, E.A. (1998b). Advanced River Quality Monitoring: Techniques, Strategy, Costs, Benefits. *8th River Basin Conference "Management of Large River Basins"*, Sept., 14 in Budapest, Hungary.

Bode, H. (1998c). Anmerkungen zu den Kosten der Abwasserreinigung in Deutschland; Korrespondenz Abwasser, Germany. **45**(10), 1937 –1946.

Bode, H. (1995). Produktkosten der deutschen Wasserwirtschaft; gwf Abwasser, No. 4, (1999), 244–252.

Briscoe, J. (1995). Der Sektor Wasser und Abwasser in Deutschland; gwf-Wasser Abwasser, No. 8, Germany, pp. 422–432.

Dohmann, M. *et al.* (1997). Die Entwicklung der Marktnachfage für Abwasserentsorgungsdienstleistungen; published by the Bundesverband der Deutschen Entsorgungswirtschaft e.V. (BDE), merz-Verlag, Berlin, Germany.

Evers, P., Grünebaum, T.; and Wilde, J. (1999). Kennzahlen als Grundlage für vergleichende Wirschaftlichkeitsbetrachtungen in der Siedlungswasserwirtschaft (planned publication 1999).

Firk, W., Mertsch, V. and Pinnekamp, J. (1998). Kosten der Abwasserreinigung im internationalen Vergleich; ATV-Schriftenreihe, Abwassertechnische Vereinigung e.V., Hennef, **12**, 333–354.

Grünebaum, T. and Nisipeanu, P. (1998). The Ruhrverband – a water management association for an entire catchment area based on a special act; *AQUA – Journal of International Water Supply Association IWSA*, **47**(5), 229–238.

Grünebaum, T. (1993). Stoffspezifische Kosten der kommunalen Abwasserreinigung; Gewässerschutz Wasser Abwasser, Aachen, Germany. **139**, 23/1–23/16.

Grünebaum, T., Schmitt, F., Schröter, D. and Weyand, M. (1996). Analyse der Betriebkosten von Kläranlagen; Schriftenreihe Siedlungswasserwirtschaft Bochum **32**, Gesellschaft zur Förderung des Lehrstuhls für Siedlungswasserwirtschaft und Umwelttechnik of the Ruhr-Universität Bochum, Germany.

Helland, B. and Adamsson, J. (1998). Performance indicators: benchmarking between six cities in Scandinavia. *J. Water SRT-AQUA*. **47**(6), 284–288.

Kingdom, B. (1998). Use of performance indicators and performance benchmarking in the North American water industry – findings from studies recently completed for AWWA and WEF research foundations. *J. Water SRT-AQUA*. **47**(6), 269–274.

Kraemer, A., Hansen, W. and Piotrowski, R. (1998). Studie zu den Abwassergebühren im internationalen Vergleich; Schriftenreihe Siedlungswasserwirtschaft der Ruhr-Universität Bochum, Bochum, Germany. **34**, 183 –197.

NN. (1991). Richtlinie des Rates vom 12. Mai 1991 über die Behandlung von kommunalem Abwasser (91/271/EWG); Amtsblatt der Europäischen Gemeinschaften No. L 135/40–L 135/52 of May, 30 (1991).

Rudolph, K.-U. (1998). Leistung hat ihren Preis; Entsorga-Magazin Entsorgungs-Wirtschaft, No. 11, pp. 40–42.

Schulz, A., Schön, J., Schauerte, H., Graf, P. and Averkamp,W. (1998). Benchmarking in der Abwasserbehandlung. *Korrespondenz Abwasser*, **45**(12), 2297–2302.