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Decreasing Population and Rising Costs of Providing Water and Sewage Treatment within Cities: A Case Study

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Decreasing Population and Rising Costs of Providing Water and Sewage Treat- ment for Urban Areas: A Case Study

Halle (Saale), April 2004

Decreasing Population and Rising Costs of Providing Water and Sewage Treatment for Urban Areas: A Case Study¹

Abstract:

The paper investigates empirically how costs per inhabitant depend on population density, considering public water and sewerage industry as example. Diverging from prior work, spatial differences in distribution costs within a German municipality are calculated for both industries by using appropriate cost accounting data. Choosing suitable cost allocation bases turned out to be the main problem. The results provide some evidence of the assumed u-shaped per-capita cost curve only for the distribution of water, whereas per-capita distribution costs of the sewerage industry tend to decrease steadily with rising population density. Thus, cost-cover percentages of water and sewage charges rise with increasing population density. These findings suggest firstly, to take rising per-capita costs of providing network-related goods and services into consideration for city deconstruction programmes (e.g. “Stadtumbau Ost”) and secondly, to differentiate charges for local public goods spatially according to the real costs.

JEL classification: R00, L32, L95, H42

1. Purpose of the Study

Nearly all industrialized countries were confronted with suburbanisation processes during the last decades. Mainly in East Germany this development has been proceeding in a „slow-motion“ manner since 1990. As population decreased particularly in the core cities, idle capacities in network-related infrastructure and therefore, rising per-capita costs of providing those services to the remaining inhabitants were the consequences. Even worse, mainly overcapacities in the distribution systems of water, sewage treatment services or district heating cannot be reduced in the short run.

The resulting problems have to be treated within the superior context of the relationship between spatial distribution of population and (per-capita) costs of supplying certain (congestible) local public goods and services.

¹ I would like to thank the „Hallesche Wasser- und Abwasser GmbH“ for supporting this project by providing the necessary data and patiently answering our questions.

There exist only few empirical studies in the field of local public finance dealing with these questions and most of them focus on comparing aggregated expenditure data of different localities.² US-studies in the field of regional planning (e.g. Downing und Gustely (1977)) provided some evidence for decreasing costs per inhabitant with increasing population density for certain local services: waste collection and disposal, water supply and sewage treatment services.³

Due to their (proposed) importance as “Services of General Interests”, this paper focuses on the water and sewerage industry. Furthermore, the paper puts emphasis on distribution costs rather than on production costs because mainly the costs of distribution per inhabitant, i.e. the per-capita costs attributable to the relevant network infrastructure, vary considerably with population density (which will be shown in section 3). In contrast to previous studies at a more aggregated (macro-)level, this paper investigates spatial differences in distribution costs per inhabitant at micro level, i.e. within a certain urban area. This approach has several advantages: First of all, only at micro level it is possible (at reasonable costs) to evaluate effects of population development by choosing adequate spatial units. This also applies to the possibility of distinguishing between household-, industrial- or public demand for water or sewage treatment services. Furthermore, for comparing cost situations of different localities one has to identify those cost determinants which could be influenced by local providers (internal efficiency of provision) and those which cannot (e.g. geology, topography, population density, size of service area, different levels of regulation etc.). With intra-city cost analysis those problems can be neglected.

For the purpose of this paper the city of Halle in Saxony-Anhalt (Germany) was chosen. On the one hand, Halle is characterized by homogeneous geologic and geographic features within its boundaries. On the other hand, its quarters vary considerably in popula-

² Seitz (2002) for example investigated empirically the impact of population density and size on costs of providing local public services for sewage treatment, road construction and schools. He found some evidence for u-shaped per-capita cost curves according to population size. Similar studies were carried out e.g. by Ladd (1992) for the USA, but the author solely analyzed the determinants of the aggregated expenditures for all goods and services provided by the counties in her sample. Büttner et al. (2004) estimated expenditure functions and elasticities for about 40 categories of public services (with population size, population density and some indicators for the level of the service provided as main determinants), but they focused on the German state level (Bundesländer).

³ For a critical survey of similar US-studies and the supposed relationship between spatial distribution of population and costs of providing local public services see Frank (1989).

tion density and have been suffering partly from extreme decreases in population until now. Therefore, Halle is suited well for analyzing per-capita costs of network-related services by methods of cross-section or longitudinal section analysis.

The question of how to allocate distribution costs of the water and sewage sector to different spatial units according to their origin is emphasized in this paper. Because spatial differences between costs of provision per customer do not seem to play a mayor role in practice as well as in economic literature⁴, at first, some appropriate indicators have to be found correlating with the costs.

The paper is organized as follows. In the next section some economic features of the water and sewage sector are described and determinants of the costs of provision are derived. Section 3 discusses how distribution costs could be apportioned to spatial units and illustrates the relationship between distribution costs and population density in Halle. Section 4 discusses which conclusions can be drawn from the results.

2. Cost Determinants of Network-Related Services of the Water and Sewage Sector

First of all, it is necessary for any further proceeding to introduce some definitions and to discuss the determinants of the production and distribution costs of water and sewage treatment. The term “costs” is used often inconsistently in the relevant practical literature. In this paper, according to the economic literature, costs are defined as short- or long-term consumption of resources. “Investment costs”, i.e. the amount of financial resources needed to replace or buy additional items of fixed assets or to expand or reduce capacity of existing plants or buildings, are no costs in this broad sense. According to the conventional business administration literature, they can be considered as expenditures which will turn into costs in later periods as depreciations or interests.

Furthermore, a distinction has to be drawn between costs of production and costs of distribution. Production costs in the water sector are all inevitable costs for producing the finished good, which include costs of abstraction and/or import of raw water as well as costs of treatment, storage or import of drinking water. Production costs of sewage treatment can be defined as total costs incurring after the sewage has arrived at the sew-

⁴ This may be a result of the broad international consensus among politicians about establishing “uniform living conditions” within a country. As a consequence of this postulate, households and firms are considered to be entitled to have access to uniform quality standards of public goods and services at uniform prices, regardless of their location.

age treatment plant, which also include costs of sludge disposal and discharging the cleaned sewage into rivers or lakes.

Local distribution costs can be defined as costs of transport (in a broad sense) from waterworks and/or cross-country water transmission system to customer or from polluter to sewage treatment plant. Thus, costs of distribution include all costs which can be attributed to the local distribution mains, the local sewer system or the pumping stations. In the following, some hypotheses with respect to the main cost determinants of water and sewage treatment per inhabitant will be worked out.

Firstly, the economic literature shows a broad consensus that distribution (mains or sewers) but not necessarily abstraction or treatment are characterized by economies of scale and decreasing average costs for rising amounts of water or sewage transported.⁵ Therefore, doubling or tripling networks would be a highly inefficient waste of economic resources. From a short- or medium-term perspective, distribution costs of the water and sewage sector involve a large portion of fixed costs. Furthermore, the costs of installing pipeline-networks are mostly “sunk costs” because mains, pumping stations, service connections or sewers can hardly be used for alternative purposes. High sunk costs in these industries help to erect further barriers for market entry which only permit competition *for* the market but prevent competition *within* the market. Nevertheless, the tendency towards natural monopolies in unregulated markets for public utilities is not of central interest for this paper because overcapacities due to permanent decreases in population have to be reduced by investor-owned utilities as well as by public enterprises.

It is assumed further that sold quantities of drinking water and disposed amounts of sewage correlate positively with size and density of population. This proposition can be justified by the low price- and income elasticities of household demand for water and waste water treatment services.⁶ Therefore, mainly for distribution economies of scale

⁵ Cf. e.g. O’Sullivan (2003), pp. 506-507. Those empirical studies of US-water utilities by Kim (1985, cross-section analysis of 60 utilities) or Armstrong and Leppel (1996, panel data (?) analysis for 9 investor-owned utilities) which found no empirical evidence for economies of scale, used aggregated total costs instead of estimating separate cost functions for distribution and production.

⁶ Empirical evidence for Germany supports this assumption only from a cross-section perspective, but not for a time-series analysis of the past decade: Consumption of water per inhabitant in Germany (area of the former Federal Republic of Germany and the former GDR) has decreased considerably since 1990 for

and decreasing per-capita costs with rising population density can be expected. But it seems likely, too, that distribution costs may rise in extremely densely populated areas for technical reasons. E.g. for providing water to the upper floors of multi-storeys buildings in densely populated areas additional pumping stations are needed because of insufficient operating pressure of the mains.⁷ Furthermore, construction costs of pipes and sewers rise disproportionately for areas with extreme population density. On the one hand, pipes with large nominal widths (i.e. the internal diameter) have to be installed in these areas and on the other hand, costs of traffic diversion and quality standards required for materials and construction (e.g. in order to prevent bursts or leakages of pipes or sewers below streets with high traffic volume) also rise.

In addition, demand and supply of water (and therefore the amount of sewage) are subject to considerable daily and seasonal fluctuations. This requires both storing of the final product (water) and adapting production and distribution capacities (water, sewage treatment) to daily and seasonal (e.g. in tourist centres) peak loads. Furthermore, additional water demand for fire protection may have to be considered in capacity planning.⁸ For the water industry, daily as well as monthly fluctuations in demand tend to diminish with increasing population size and density. Thus, capacity utilization is more even for municipalities with higher population density.⁹ This also applies to sewage treatment because the amount of sewage (except rain water) correlates closely (for obvious rea-

several reasons. As a consequence, in spite of a 6.1% rise in population the total amount of water sold to households and small enterprises in the former FRG decreased by 2.3% from 1990 to 2001. But a cross-section analysis across all German states ("Bundesländer") for 2001 displays a close positive correlation ($\rho = + 0,9457$) of population size with the amount of water sold (households and small firms). Sources: Statistisches Bundesamt (2003), p. 44 Bundesverband der deutschen Gas- und Wasserwirtschaft (2003), table 3.4 and own calculations. A cross-section analysis of the Saxon counties ("Landkreise") and cities not belonging to a county ("kreisfreie Städte") for 2001 also shows that the amount of water sold to households and small firms positively correlates with population size ($\rho = + 0,8752$) as well as with population density ($\rho = + 0,8480$). (Sources: Own calculations based on Statistisches Landesamt Sachsen (2004).)

⁷ A problem which seems to be less relevant (for obvious reasons) for sewage disposal.

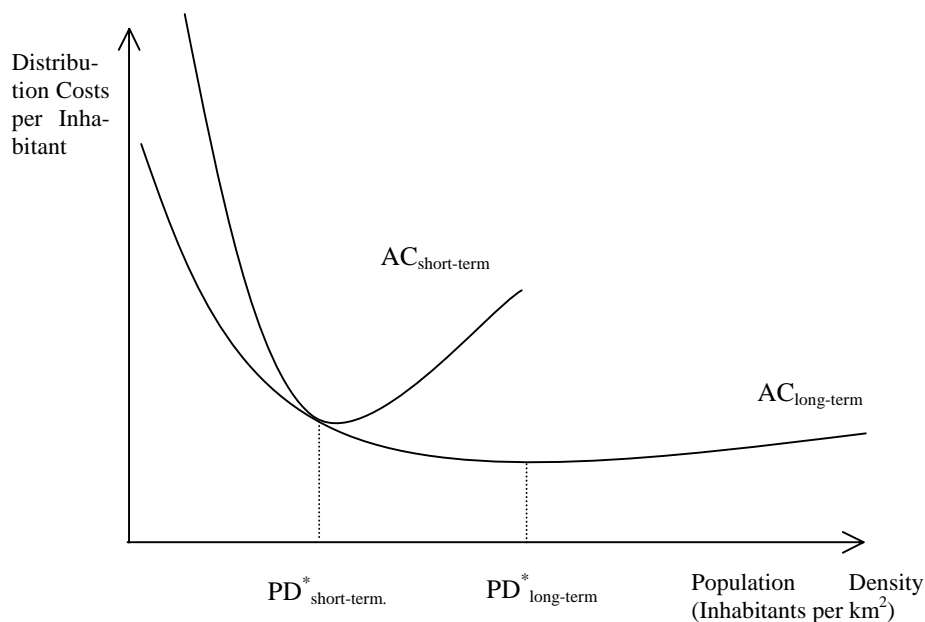
⁸ Taking the current technological standard of German fire protection into account, there is no need for extra capacities for fire fighting in bigger municipalities (more than 20,000 inhabitants). Thus, additional water demand induced by fire protection activities will be served by local waterworks without exceeding maximum capacity. Cf. Mutschmann and Stimmelmayer (2002), p. 635.

⁹ German rural municipalities and small towns are characterized by considerable peak loads in water demand from May until September, whereas water consumption per inhabitant fluctuates only slightly over the year around the average monthly water consumption in large cities due to their smaller portions of green spaces and their larger percentage of industrial areas. The same applies to hourly fluctuations in water consumption in the course of a day. Cf. Mutschmann and Stimmelmayer (2002), p. 15-26.

sons) with water consumption. A more even utilization of production and distribution capacities in densely populated areas may support the proposition that per-capita costs of distribution (and production!) decrease with increasing population density for water and sewage treatment services. In addition, adjusting capacities in water and sewerage utilities to permanent decreases in demand involves high costs (costs of deconstruction, exceptional depreciation of assets etc.).

In the short (and medium) run congestion costs may occur with increasing density of population for given distribution networks. With regard to water distribution networks (capacity shortages in producing water or treating sewage are neglected) this kind of excessive use may shorten useful life, increase failure ratio and therefore, cause higher depreciation or maintenance costs per inhabitant. The following figure compresses the previous discussion by a stylized cost function. The long-term (minimum) average costs (variable network capacities) per inhabitant form the envelope of the short-term (minimum) average costs (fixed network capacities) and therefore the slope of the long-term curve is lower than those of the short-term curve.

Figure 1: Average Costs of Distribution (Water and Sewerage Industry) per Inhabitant and Population Density.



Source: Own Graphic

Besides population density, the size of the area which has to be supplied and therefore, the average distance between customers and waterworks/cross country transmission line or sewage plant is also a main cost determinant. Furthermore, structure of settlement, land-use pattern, soil conditions (determine quality requirements for construction and material of network systems) and topography affect costs. These factors determine distribution costs (attributable costs of sewers) of the sewerage industry as well.

Product differentiation, either by regional differentiation accounting for differences in quality of the raw waters (e.g. different degrees of pollution) or by quality differentiation according to different purposes of water usage (drinking, cleaning, cooling) is not common. Water is provided (except for power plants, mining or some other branches of manufacturing industries with access to own water resources) at the highest (and most costly) quality level. Most of the water from public utilities is provided at legal “hyper quality” because only a small percentage of daily water consumption requires quality standards of table water. This is also true for public sewage treatment, as different sewages with different grades of pollution are mixed together instead of cleaning them separately with higher efficiency. It will not be discussed further if higher “product differentiation” in the water and sewage treatment industry as an alternative to the present system is technically feasible or if it makes sense from an economic point of view.¹⁰

Mainly in Germany legal restrictions determine the costs of water supply and sewage treatment. Although, both industries are regulated in some way by the government in most countries due to their importance for society, density of regulation is supposed to be excessive in Germany.¹¹ Despite of its importance, the discussion about the most efficient design of regulation mechanisms for the water and sewerage industry is of no further relevance for the subject of this paper and will therefore not be continued here.

Internal (i.e. they can be directly influenced by the supplier, at least in the long run) cost factors are age and structure of networks, technologies used, operational and organizational structure, incentives for employees and managers, degree of outsourcing etc.

¹⁰ Technical and economic evaluations of potential quality differentiations for water provision and sewage treatment can be found in Hiessl et al. (2003) or Spulber and Sabbaghi (1994).

¹¹ Mutschmann and Stimmelmayer list about 90 relevant laws, orders and guidelines for the sectors water supply, water extraction, -treatment, -storage, -distribution, fire protection and essential water supply, construction and operation. Cf. Mutschmann and Stimmelmayer (2002), pp. 775-802.

Those factors are relevant for studies in the field of operational cost efficiency but have to be neglected in the following.

The paper is confined to a comparison of distribution costs per inhabitant in relation to population density within a region or urban area. This allows to neglect internal cost determinants or differences in operational inefficiencies respectively, which would have to be considered if different suppliers were compared. As has been mentioned earlier, the chosen example Halle permits to investigate distribution costs for different population densities. In addition, these microanalysis can be performed without calculating cost differences separately which result from altitude differences within the supply area, differences in quality and quantity of local water resources, differences in climate or soil conditions etc.

3. Comparing Per-Capita Costs of Water Supply and Sewage Treatment Services in Relation to Population Density: The Case of Halle

In the following, distribution costs for water supply and sewage treatment will be estimated and compared for different quarters of Halle. In order to calculate costs, cost accounting data and network plans are used which have been provided by the Hallesche Wasser- und Abwasser GmbH (HWA), a 100% subsidiary of the city of Halle. Because it is hardly possible to attribute distribution costs exactly to the locations where they have occurred, some alternative versions have to be computed using different allocation bases. If the different calculations display similar results some general conclusions about the shape of the per capita distribution cost curve can be drawn. To eliminate the effects of decreasing population or different materials¹², some alternative scenarios will be calculated, assuming constant population and after subtracting repair costs. Precisely, the years 1994 and 2002 will be compared (because of data availability) without performing some time series analysis.

3.1 Changes in Population, Excess Housing Capacities and General State of the Water and Sewerage Industry in Halle (Saale) after the German Reunification

The former GDR-district Halle, which had been one of the most important locations of manufacturing industry (chemical industries), has faced considerable changes in popula-

¹² And therefore higher probability of leakages or bursts.

tion size since the German reunification. All in all, the city of Halle has lost about 71,500 or nearly a quarter of its former 300,000 inhabitants since 1990.¹³ But this seemingly dramatic situation has to be put into perspective. On the one hand, as will be made clear below, not all quarters were affected by decreasing population in the same way. On the other hand, population grew by 27% in the surrounding county (the “Saalkreis”) from 1990 to 2000. This unexpected growth resulted from migration movements from the core city to the neighbouring municipalities. Many people moved to the periphery of Halle because the highly condensed housing structure (“Plattenbau”) of some areas in Halle no longer corresponded to the preferences of those inhabitants who could afford more comfortable houses.

The decreasing population has coincided with a rising number of unoccupied dwellings in Halle since 1990. At the end of June 2003 about 31,000 apartments or 20.5% of 152,000 were untenanted, although considerable differences existed between quarters. Thus, the percentage of unoccupied dwellings has doubled since 1995. Due to the forced demolition of unoccupied residential buildings (subsidized by the federal project “Stadtumbau Ost”) has started in autumn 2003, the percentage of unoccupied dwellings is expected to fall in 2004.¹⁴

The decrease in population has also been reflected by a constantly falling amount of water sold and effluent treated since 1990. This trend was boosted by a nation-wide decrease in per-capita water consumption after reunification, causing massive under-utilization of capacities. From 1994 to 2002 the amount of water sold per inhabitant decreased in Halle by 35%, the amount of sewage treated by 21%. The following graphics depict this development.

¹³ See Amt für Statistik und Wahlen Halle (different years).

¹⁴ All figures are based on data supplied by the municipal department for city planning and development in Halle.

Figure 2: Amount of Water Sold and Sewage Treated within the City Area of Halle in m³

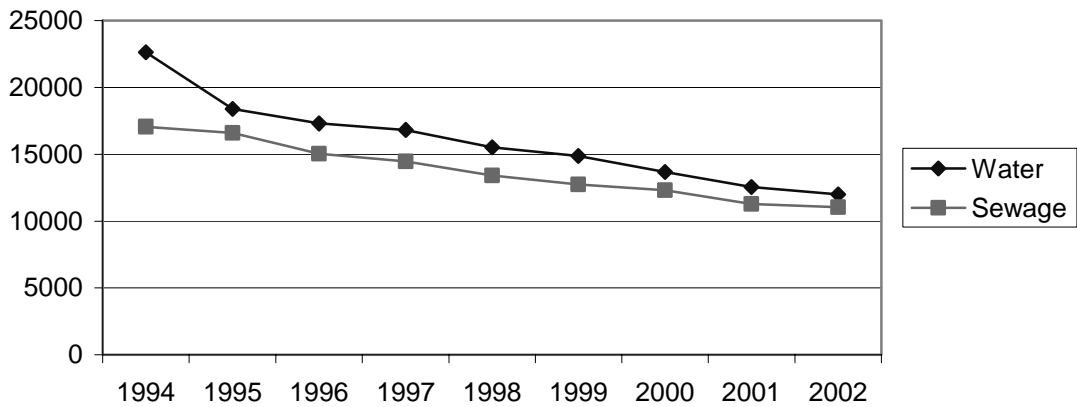
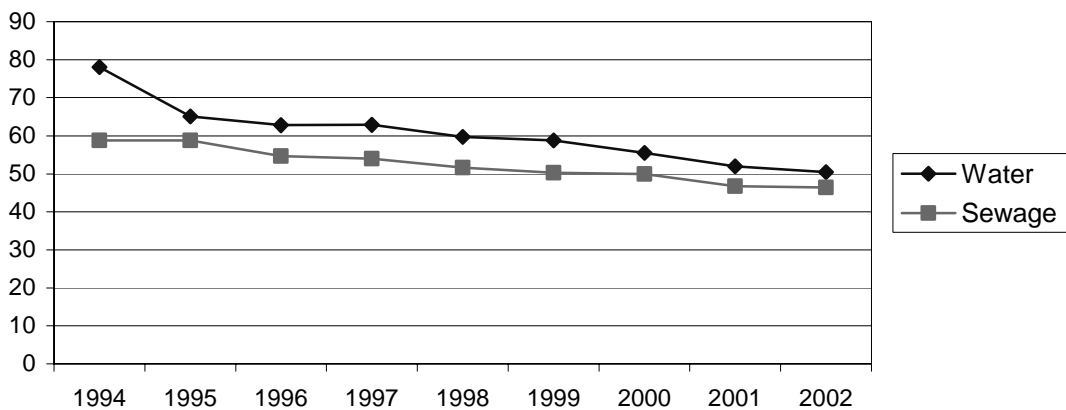


Figure 3: Amount of Water Sold and Sewage Treated within the City Area of Halle per Inhabitant in m³



Sources: Data supplied by the HWA and own calculations.

The consumption per inhabitant shown in figure 3 is too high because the available data also contain the amount of water sold to firms and public institutions. According to the HWA, annual per-capita consumption of private households was 46.3 cubic metres in 1995 and 39.4 cubic metres in 2001.¹⁵

The significant decrease in consumption per inhabitant may have been induced by rising water- and sewage charges since 1990, which may have increased incentives to install technologies of water recycling or reuse for firms or to buy water-saving appliances for

¹⁵ Cf. Amt für Statistik und Wahlen Halle (2002), p. 368.

households. While the volume-based charge per cubic metre water for ordinary customers remained constant, the fixed charge for a typical household meter rose by 2/3 from 1994 to 1999. Since 2000 the basic charge in Halle has been calculated by referring to the average residential water consumption per inhabitant which led to a further rise. The effect of rising sewage charges based on water consumption may have been even more unfavourable. In Halle average sewage charges (including charges for rain water disposal) rose by 55% from 1994 to 2000. In 2001 sewage charges were split into two separate charges for sewage disposal (based on water usage) and rain water disposal (based on square metres of real estate) and the average charge for sewage disposal was reduced by 11%. The distributive effects of this measure have not been evaluated yet, but households in densely populated areas may have benefited most of it.¹⁶

3.2 Structural Features of the Selected Quarters

It has been found impossible (for reasons of data availability) to investigate all quarters of Halle. Therefore, a sample of five quarters was selected according to population density, building structure and urgency of the problems caused by decreasing population. Table 1 compresses the most relevant characteristics of the quarters in the sample.

¹⁶ Figures were calculated according to the data provided by the HWA.

Table 1: Main Characteristics of the Quarters Included in the Sample

Quarters	Popu- lation Density 1994 (Inhabi- tants per Square Kilo- metre)	Popu- lation Density 2002 (Inhabi- tants per Square Kilo- metre)	Chan- ges in Popu- lation 1994- 2002 in %	% of the City Area of Halle 2002	Indus- trial Area 2001 (% of Total Area)	Resi- dential area 2001, Includ- ing Mixed and Special Pur- pose Areas (% of Total Area)	Agri- cul- tural Area 2001, Includ- ing Forests (% of Total Area)	Single Occu- pancy House s 2003 (% of All Build- ings)	Unoc- cu- pied Dwell- ings 2002 (% of All Dwell- ings)	Resi- dential Build- ings 2003: Most Fre- quent Years of Com- pletion (% of All Resi- dential Build- ings)
Dölau	636.5	917.38	+44.69	3.05	0.40	32.60	39.50	71.4	3.3	1900-48 (39.6), since 1990 (39.4)
Kröllwitz	915.65	1031.22	+14.50	3.39	0.40	36.90	18.70	58.6	8.0	1900-48 (44.4), 1964-89 (17.4)
Heide- Nord/Blu- menau	6957.75	4608.70	-50.97	1.21	0.00	58.10	14.10	29.9	20.7	1964-89 (71.7), since 1990 (12.3)
Halle- Neustadt	12123.6	7803.68	-34.80	7.21	8.93	38.96	10.05	1.3	20.6	1964-89 (96.9)
Sil- berhöhe	17941.4	8942.62	-49.96	1.51	2.10	66.10	0.00	0.7	37.4	1964-89 (99.5)
City Area of Halle	2147.62	1762.72	-17.92	100	26.7	6.20	27.90	39.6	19.8	1900-48 (47.4), 1964-89 (23.2)

Sources: Amt für Statistik und Wahlen Halle (different years); Department for City Planning and Development, own calculations.

Quarters included in the sample are predominantly residential areas located in the South and West of Halle with varying population density and different shares of single occupancy houses. Except for Halle-Neustadt, all quarters feature insignificant percentages of industrial areas or business zones and, except for Dölau, only below-average percentages of agricultural areas (including forests, moor and heathland).

Heide-Nord, Silberhöhe and Neustadt are relatively young large residential areas with medium or high density of apartment blocks and multi-storey buildings made of precast

concrete slabs (“Plattenbau”). The buildings in these quarters were completed during the 60ies, partly during the mid-70ies (of the past century). Therefore, their water and sewerage networks are also of relatively low age.

On the other hand, Dölau and Kröllwitz are older and less densely populated areas at the periphery of Halle with a large portion of single-occupancy houses. Due to the rise of population in Dölau after 1990, its percentage of buildings completed since 1990 is above-average. Of course, water and sewage distribution systems are older than their counterparts in the other quarters of the sample. Cast iron pipes which have been neither produced nor installed (due to their inclination to break rather easily) since the 1970ies (at least in Germany) are the prevalent materials. As will be shown below, the older systems are characterized by significantly lower failure rates (in absolute figures as well as per kilometre of pipe length) than the younger networks in Silberhöhe, Heide-Nord and Neustadt.

3.3 Spatial Allocation of Distribution Costs for the Water and Sewerage Industry

In this section distribution costs in a more narrow sense in contrast to production costs only include costs which can be attributed directly to the distribution system (without overhead costs!). Operational costs of pumping stations (water and sewerage sector) will not be taken into account for the spatial attribution of distribution costs because these costs cannot be allocated properly to the single quarters.

Total costs of the water industry in Halle 2002 can be divided into costs of distribution in a narrower sense 40.5%, production costs (including costs of pumping station Halle – Silberhöhe) 51%, costs of other pumping stations 1.5% and other costs 7%. Directly attributable total costs of the HWA’s sewerage sector included 2002 43% costs of distribution (in a narrower sense), 38% sewage treatment costs, 11% costs of pumping stations and 8% other costs.

Overhead costs of utilizing centralized services (e.g. accounting, finance, controlling, internal consulting, global organization-, planning- or management functions etc.) at firm or corporate level are omitted due to data unavailability. Therefore, the cost data on which the following calculations are based as well as the spatially allocated costs are

only a lower limit. The distribution costs of 2002 can be subdivided according to cost types (before internal cost allocation) as follows:

Table 2: Classification of Distribution Costs of the Water Supply and Sewerage Sector According to Cost Types

Cost types	Water 2002	Sewerage 2002
Cost of Materials*	13.3%	4.0%
Labour Costs	25.1%	8.8%
Depreciation	33.8%	38.3%
Interest Costs	24.8%	48.4%
Miscellaneous	3.0%	0.5%
Σ Total	100.0%	100.0%
thereof variable costs**:	13.3%	4.0%
thereof fixed costs**:	86.7%	96.0%

* Sewerage: including cost of electricity, other energy, fuels, chemicals, sludge disposal, miscellaneous materials and other services purchased. Water: including cost of water imported instead of sludge disposal, otherwise same cost types included as in the sewerage sector.

** It is assumed that labour costs and miscellaneous costs, besides interests and depreciation, are also fixed costs. Cost of materials may partly occur independently of output volume. Nevertheless, they are assumed to be variable costs.

Sources: HWA, own calculations.

The table above shows (as expected) that distribution costs in both industries mainly consist of fixed costs (from a short- or medium-term perspective) and involve a high percentage of interests and depreciation.

As the HWA has not been able to supply data of distribution costs sufficiently subdivided into spatial units, the main problem is to break down costs to the spatial units where they occurred. To this end, the following central hypothesis is introduced: Due to the large percentage of fixed costs (mainly interests on fixed capital and depreciation) it is assumed that the distribution costs of water and sewage treatment of the particular quarter are mainly determined by its portion of the water and sewerage network. "Portion" may be either defined as proportionate length or as proportionate volume of the particular networks. The paper concentrates primarily on the relationship between distribution costs and population density. Therefore, it has to be abstracted from the effects of decreasing population in certain quarters and from different failure rates due to different materials of pipes etc. For this purpose several versions will be computed:

Case 1: Costs allocated proportionately to percentage of network length (1994 and 2002).

Case 2: Costs allocated proportionately to percentage of network volume (1994 and 2002).

Case 3: Costs allocated proportionately to percentage of weighted network volume (1994 and 2002).

Case 4: Corresponding to case 3 after deduction of repair costs.

Case 5: Corresponding to case 4 for water and case 3 for sewerage using cost data of 2002 and population data of 1994.

Case 6: Corresponding to case 4 for water and case 3 for sewerage using cost data of 1994 and population data of 2002.

Distance between customer and waterworks, cross-country transmission system or sewerage plant will be ignored because costs of a central transmission lines would have to be broken down to the quarters connected, which would cause further allocation problems. Nevertheless, distance is an important determinant of distribution costs.

Furthermore, pipes with nominal width beyond 500 mm will not be included in the calculations for the water sector because according to the HWA, those pipelines are central mains for supplying the whole city area and cannot be attributed to different quarters.¹⁷ Corresponding to the approach of another study, the whole stock of sewers within the boundaries of a particular quarter is included in the calculation for the sewerage industry.¹⁸ In the next section the proceedings of the several cases will be explained.

The proceeding for *case 1* (allocation in proportion to network length) is rather self-explanatory. But the unweighted network length cannot be used as a cost allocation base because primarily construction costs per metre of pipe length (and therefore attributable interests and depreciation) increase with increasing nominal width.¹⁹ Construction costs

¹⁷ As a result of this proceeding the sum of the distribution costs caused by mains with large widths are allocated to the specific quarters in proportion to their stock of water pipes.

¹⁸ Cf. Energieagentur Sachsen-Anhalt (2002), p. 132.

¹⁹ Data provided by the HWA confirm some basic results in the literature about the relationship between construction costs and nominal width. Thus, construction costs of pipes made of the prevalent materials

of a one metre pipe with nominal width of 200 mm are *ceteris paribus* lower than for a one metre pipe with 400 mm of nominal width. Thus, distribution costs are allocated proportionally to pipe volume for *case 2*. Attributable distribution costs for each quarter (DC_{St}) are calculated by the following formula:

$$(1) \quad DC_q^j = DC_{ua} \cdot \frac{PV_q^j}{PV_{ua}} = DC_{ua} \cdot \frac{\sum PL_q^{i,j} \cdot (NW^i)^2}{\sum RL_{ua}^i \cdot (NW^i)^2}.$$

DC_{ua} : Total Distribution costs of the urban area.

PV_q^j : Pipe volume of quarter j,

PV_{ua} : Pipe volume of the urban area,

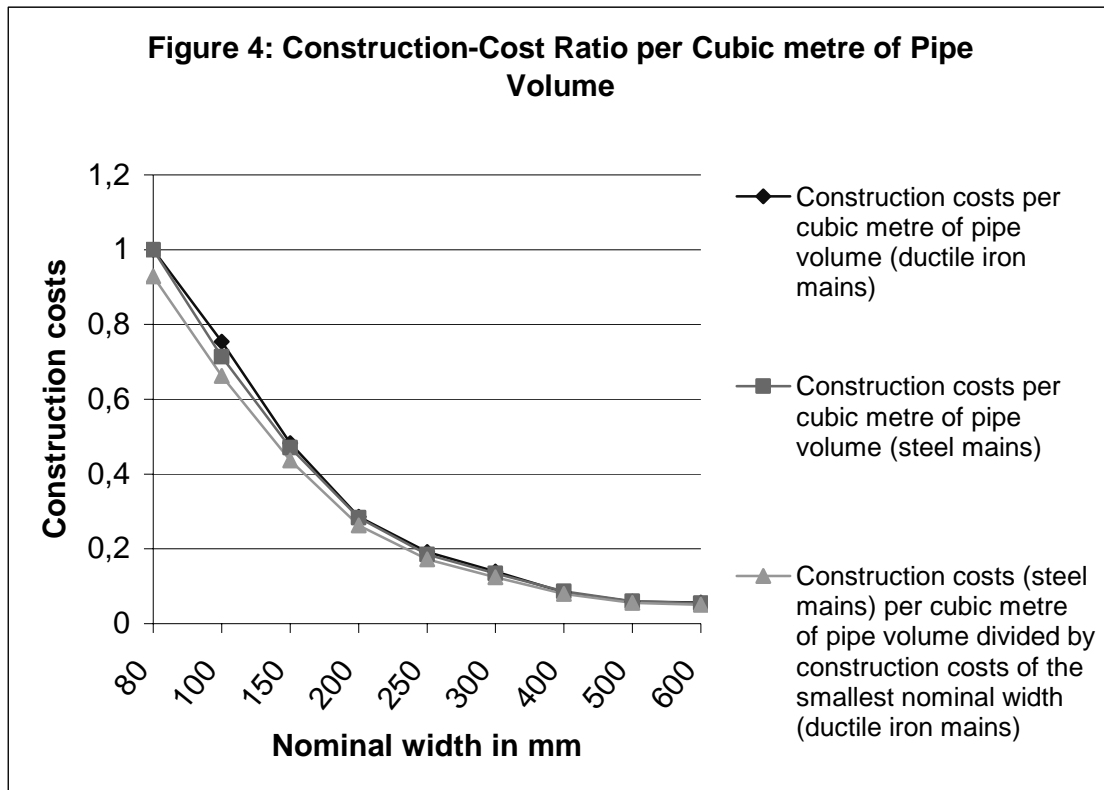
$PL_q^{i,j}$: Pipe length of nominal width i mm of quarter j,

PL_{ua}^i : Pipe length of nominal width i mm of the whole city area,

NW^i : Nominal width i mm.

A mayor drawback of this method of cost allocation is that construction costs per cubic metre of pipe volume decrease with increasing nominal width. The next graphic illustrates this functional dependency for the prevalent materials used for water pipes, representing about 70 to 85% of the water network in Halle. Firstly, the graphic displays the ratio of construction costs per cubic metre of pipe volume of the particular nominal width and material divided by the construction costs of the smallest (conventional) nominal width (80 mm) of the same material. Secondly, the graphic depicts the construction-cost ratio of steel pipes to ductile iron pipes of the smallest nominal width.

(ductile iron, steel) tend to rise superproportionally for small nominal widths (< 150 mm), rise subproportionally for medium nominal widths (150-500 mm) and rise again superproportionally for nominal widths larger than 500 mm. Cf. e.g. Mutschmann and Stimmelmayer (2002), p. 694. For the sewerage industry, Halbach et al. (2003) assume a linear relationship between construction costs and nominal width $CC(NW) = 150 + 0,5556 \cdot NW$ for nominal widths between 200 and 500 mm. The author's calculation of the function is based on a diagram in Halbach et al. (2003), p. 22.



Construction costs per cubic metre with nominal width 80 mm = 1.00.

Sources: Data supplied by the HWA, own calculations.

Some similar cost curve per cubic metre of volume as a function of nominal width can be derived for the sewerage sector from the cost curve per metre of pipe length mentioned above.²⁰

Declining average costs per cubic metre of pipe volume follow from the fact that doubling of pipe volume at equal length only needs multiplying the nominal width by $\sqrt{2}$. For identical internal pressure (and ceteris paribus identical height above ground, identical traffic volume) the necessary wall thickness has to be increased only subproportionally to the external diameter.²¹ Consequently, the volume of the wall (and therefore the mass of the pipe) will rise subproportionally to the internal volume, too.

²⁰ Precisely, the following cost function $C(x)$ with construction costs C per cubic metre of sewer volume as dependent and nominal width x as independent variable can be derived:

$$K(x) = \frac{4}{\pi} \cdot 1000^2 \cdot \left(\frac{a}{x^2} + \frac{b}{x} \right), \text{ with } a, b = \text{constant}, a \geq 0 \text{ and } 0 < b.$$

²¹ In addition, if pipes of lower internal diameter are replaced by pipes with larger diameter the internal pressure will fall if water demand remains unchanged. In this case, a lower wall thickness is sufficient.

Figure 4 also illustrates that construction-cost ratios of water pipes differ only slightly in materials. This is due to only 20% of the construction costs being genuine material costs while 80% of the costs account for road making (scarifying, resurfacing) and pipe construction (laying, earthworks).²² Therefore, differences in costs of materials will be neglected for allocation of distribution costs (mainly interests and depreciation). About 70 to 80% of the sewerage system of Halle consists of stoneware- or concrete pipes and - to some minor extent – of fibre glass reinforced plastic pipes. In some quarters (Silberhöhe, probably also in Neustadt and Heide-Nord) the sewerage systems contain a larger stock of PVC pipes of the GDR-era. As – according to the technical literature and the information given by the HWA – material plays only a minor role for canalisation costs, differences in pipe materials between sewerage systems will also be neglected for the spatial allocation of distribution costs.

Consequently, for the *third case* a “weighting factor” will be introduced which refers to the construction cost ratios per cubic metre pipe volume of different nominal widths. Thus, additional costs are allocated to quarters with nominal widths below average, whereas some distribution costs have to be subtracted from quarters with nominal widths above average.

$$(2) \ DC_q^{j,w} = DC_q^{j,u} \cdot (\alpha + (1-\alpha) \cdot w_q^j)$$

$DC_q^{j,w}$: Distribution costs of quarter j allocated by the weighted pipe volume.

$DC_q^{j,u}$: Unweighted distribution costs of quarter j (case 2).

$(1-\alpha)$: Proportion of depreciation and interest costs of the distribution costs.

α : Proportion of other components of the distribution costs.

w_q^j : Weighting factor of quarter j.

According to the calculated proportions of cost for the municipal water sector in Halle, $(1-\alpha)$ is set 0.6 for 2002 and 0.5 for 1994. For the sewerage industry $(1-\alpha)$ is set 0.85 (2002) or 0.8 (1994) respectively.

Based on the functional dependency between construction costs per cubic metre pipe volume and nominal width displayed in figure 4 a weighting factor is calculated for the local water sector. It reflects the ratio of construction costs per cubic metre of pipe vol-

For calculating the wall thickness of pipes under pressure cf. e.g. Mutschmann and Stimmelmayer (2002), p. 569-571.

²² Cf. e.g. Milonig (1995), p. 63.

ume at average nominal width of the particular quarter divided by the construction costs per cubic metre of pipe volume at average nominal width of the five quarters in the sample. It takes values between 0.8 (Halle-Neustadt, above-average nominal width) and 1.29 (Silberhöhe, nominal width significantly below average).

For the sewerage industry the same factors are calculated according to the construction cost function per cubic metre pipe volume derived from Halbach et al. (2003, p. 22). The results range from 0.8 (Kröllwitz, significantly above-average nominal width) to 1.10 (Silberhöhe, below-average nominal width).

To eliminate the effects of different conditions of the local networks, for which the age of the pipes is a very insufficient indicator, from the calculations, in *case 4* the costs of repairing bursts, leakages and other failures which are directly attributable to the particular quarters are deducted from the local distribution costs. According to the HWA, in 2002 about 1669 failures occurred in the whole water-network of Halle (1994: 1697, 2000: 2174), 406 in Neustadt, 34 in Dölau, 25 in Heide-Nord, 43 in Kröllwitz and 105 in Silberhöhe. Especially the relatively young systems in Halle-Neustadt and Silberhöhe seem to be in very bad repair.

The costs of repairing the sewerage system have to be neglected, because the HWA only registers bursts of sewers in its statistics. (In 2002 only 29 bursts of sewers were reported.) Therefore, repair costs can only be allocated insufficiently in space. According to the HWA, detailed registration of other kinds of failures is too costly (e.g. damaged manhole covers, damaged cramp irons, blockages, intrusion of surface water caused by rootage or damaged sockets in sewers built of stones or bricks).

3.4 Costs of Providing Water and Sewage Treatment per Inhabitant Depending on Population Density

3.4.1 Water

The following table shows the results of the calculations of distribution costs per inhabitant in the water industry relative to the average value of the whole city area. The order of the quarters corresponds – see table 1 – to the inverse order of their population density.

Table 3: Distribution Costs (Water) per Inhabitant and Quarter Relative to the City's Average (Average Per-Capita Distribution Costs in Halle = 1.00)

	Case 1: Costs Allocated Proportionately to Percentage of Network Length		Case 2: Costs Allocated Proportionately to Percentage of Network Vol- ume		Case 3: Costs Allocated Pro- portionately to Percentage of Weighted Net- work Volume		Case 4: Cor- responding to 3 After De- duction of Repair Costs.		Case 5: Corre- sponding to 4 Us- ing Popu- lation Data of 1994	Case 6: Corre- sponding to 4 Us- ing Popu- lation Data of 2002
Quarters	1994	2002	1994	2002	1994	2002	1994	2002	2002	1994
Dölau	4.056	2.398	2.726	1.560	3.042	1.788	3.1049	1.826	3.219	1.761
Kröllwitz	2.285	1.640	1.975	1.394	1.469	1.049	1.4737	1.053	1.470	1.056
Heide- Nord/Blu- menau	0.372	0.463	0.289	0.360	0.238	0.298	0.2385	0.299	0.241	0.296
Neustadt	0.462	0.574	0.521	0.652	0.470	0.573	0.4603	0.560	0.445	0.580
Silberhöhe	0.550	0.902	0.342	0.566	0.393	0.664	0.4035	0.681	0.415	0.662
City Area of Halle	1.000	1.000	1.000	1.000	1.000	1.000	1.0000	1.000	1.000	1.000

Source: Own calculations.

The different variants of computation imply a more or less distinctive u-shaped run of the per-capita distribution cost curve with rising population density. Only Neustadt, probably due to the large industrial area within its boundaries and the resulting lower “pipe density” per inhabitant, “gets out of line” in cases 2 to 5. If the calculations were confined to Neustadt’s mere residential areas they would eventually yield lower per-capita distribution costs than for Silberhöhe. Comparing case 4, 5 and 6 may lead to the conclusion that the by far higher decrease in population in Silberhöhe compared to Neustadt caused the order of cost relations of both quarters to reverse. One may conclude from this results for the water industry that under certain circumstances an optimum population density exists (e.g. in Heide-Nord/Blumenau) for providing water at minimum cost per inhabitant. If the population density exceeds a certain threshold value the costs of water provision per inhabitant will rise again. But without further, more comprehensive research work, e.g. by including all quarters of Halle or other towns, the results cannot be generalized.

3.4.2 Sewage Treatment Services

The following table contains distribution costs of sewage treatment per inhabitant in Halle relative to the average value of the whole city area:

Table 4: Distribution Costs (Sewage Treatment) per Inhabitant and Quarter Relative to the City's Average (Average Per-Capita Distribution Costs in Halle = 1.00).

	Case 1: Costs Allocated Proportionately to Percentage of Network Length		Case 2: Costs Allocated Proportionately to Percentage of Network Volume		Case 3: Costs Allocated Proportionately to Percentage of Weighted Network Volume		Case 5: Cor- responding to 3 Using Population Data of 1994	Case 6: Cor- responding to 4 Using Population Data of 2002
Quarters	1994	2002	1994	2002	1994	2002	2002	1994
Dölau	2.942	1.733	2.093	1.193	2.114	1.172	2.066	1.199
Kröllwitz	2.022	1.568	1.958	1.417	1.651	1.178	1.643	1.184
Heide- Nord/Blu- menau	0.839	0.988	0.741	0.874	0.776	0.881	0.711	0.962
Neustadt	0.617	0.842	0.491	0.614	0.494	0.623	0.495	0.621
Silberhöhe	0.364	0.633	0.287	0.456	0.306	0.498	0.304	0.502
City Area of Halle	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000

Source: Own calculations.

In contrast to the results of the water industry, in all cases distribution costs decrease with rising population density. The “outsider-position” of Kröllwitz in case 2 and 3 resulted from the above-average nominal width of its local sewerage network and the lower population growth compared to Dölau. These deviations were (partly) corrected in variant 3 by applying appropriate reductions. Although, the massive decrease in population in Silberhöhe, Neustadt and Heide-Nord has lead to some equalization of the per-capita distribution costs since 1994 the ranking of the quarters remained unchanged. The findings provide some evidence that Silberhöhe’s extreme population density is cost-minimizing for the sewerage sector and an even higher population density might have further reduced distribution costs per inhabitant. Different costs compared to the water sector may result from the relatively low dimensions of the sewerage system. More general conclusions cannot be drawn from the available data.²³

4. Conclusions

The empirical results of the case study only indicate for the water industry the assumed u-shaped relation between distribution costs per inhabitant and population density, whereas distribution costs in the sewerage sector seemed to fall with increasing population density. What makes this findings interesting is the fact that the ranking of per-capita distribution costs was not changed by the massive decrease in population in some

²³ Cf. Energieagentur Sachsen-Anhalt (2002), p. 167.

former densely populated quarters, at least for the sewerage industry in this case study example.

The observed cost curves of the water industry may be explained by other reasons than the cost increasing factors mentioned in section 2 (additional pumping stations, super-proportionally rising construction costs of pipes with large nominal widths etc.): Primarily water networks, unlike the relatively narrow sewer-systems, in the former “Plattenbau”-quarters are oversized for the post-socialist demands of fire protection and the current habits of water usage, even for their original population of 1990.²⁴ According to the costs of sewage treatment, the networks in Silberhöhe and Neustadt are properly dimensioned. But further research is necessary to check if these results can be generalized for Halle or Germany by using appropriate cost data.

Some conclusions can be drawn from these results, which have to be checked by further investigations: Firstly, allocative and distributive effects and secondly, implications for the federal programme of reconstructing East-German cities (“Stadtumbau Ost”).

Decreasing distribution costs with rising population density for public utilities are closely connected with the question of spatial price differentiation. This point seems to be widely omitted in the literature as well as in public debates. Uniform (spatial) pricing is common international practise for the mostly regulated water and sewerage enterprises. Opponents of spatially differentiated water prices (e.g. Crew and Kleindorfer (1986), p. 246) argue that equity problems, high administrative costs and a lack of consumer acceptance had made such pricing policy an “infrequently used practise” in the U.S. water industry.

But lack of spatial price differentiation may involve a significant social component, especially from an inner-city point of view: Quarters with high population density and lower per-capita costs of provision subsidize quarters with low population density and higher per-capita costs of provision. The distributive aspects of spatial uniform pricing for water and sewage treatment will become clear if one takes into account that quarters with low population density and high shares of single occupancy houses (e.g. Dölau or Kröllwitz) are predominantly inhabited by high-income households. For illustrative

²⁴ Cf. Energieagentur Sachsen-Anhalt (2002), p. 125 and p. 167.

purposes, cost-cover percentages of water charges in 2002 were computed for the five quarters in the sample:

Table 5: Total Cost-Cover Percentages of Water Charges in 2002

	Dörlau	Kröllwitz	Heide-Nord	Neustadt	Silberhöhe
A: Distribution Costs Allocated Proportionately to Network Length	0.48	0.30	1.30	1.02	1.10
B: Distribution Costs Allocated Proportionately to Weighted Pipe Volume Including Repair Costs	0.58	0.38	1.39	0.98	1.15

Source: Own calculations.

Local cost-cover percentage water = $(0.5 \times \text{accumulated fixed charges} + \text{accumulated volume-based charges}) \div \text{local total costs}$.

Local accumulated fixed charges were estimated according to the common practise of the HWA for the single quarters by dividing the local amount of water sold in 2002 by 35 m^3 ²⁵ and multiplying the results (the hypothetical number of inhabitants) by 0.097 € and 365. Because the sewage charges in Halle (at least for sewage disposal) are based on water consumption, only half of the estimated fixed charges were allocated to the revenues from water sales. Accumulated volume-based charges were calculated by multiplying the amount of water sold in the particular quarter by the current price of 1.29 € per cubic metre.

For mere residential areas like Dörlau, Kröllwitz, Heide-Nord and Silberhöhe this proceeding ought to yield quite exact results. Solely for Neustadt (higher industrial density) the estimated accumulated fixed charges may be too high. Accumulated volume-based charges should have been calculated correctly because, except for customers paying special negotiable charges (according to information given by the HWA, this applies only to a manufacturer of soft drinks in Neustadt within the whole area included in the sample), all commercial or other customers are charged the same prices as residential households.

Distribution costs were allocated either proportionately to network length (case 1) or proportionately to the share in weighted pipe volume including repair costs (case 3). All other costs (production costs, costs of pumping stations, other costs excluding overhead

²⁵ According to the HWA, this amount corresponds to the current average annual consumption per inhabitant in Halle.

costs) were spatially allocated separately for fixed and variable costs. Fixed costs (labour costs, depreciation, interest costs and miscellaneous costs) were apportioned according to population size²⁶, variable costs (cost of materials) proportionately to the local amount of water sold. If those overhead costs being attributable to the water sector were taken into account local cost-cover percentages would decline further.²⁷

Therefore, it has to be concluded for allocative²⁸ and distributive reasons: If households choose their residence on the outskirts of town or in sparsely populated, remote regions it ought not to be debated in a market economy that they have to pay the adequate market price of housing and local public goods. In Germany (and most other countries) the lack of spatial price differentiation for local public goods and services is contrary to this basic insight and reinforces other forms of governmental subsidization of suburbanization (tax privileges/-deductions for real estate, imputed rental income, commuting costs etc.).

Furthermore, costs of infrastructure for network-related local goods and potential changes in costs of provision per inhabitant resulting from changes in population density have to be considered for the “Stadtumbau Ost”. In particular, localities and their public utilities which are confronted with massive decreases in population and oversized networks have to compare costs of different possible measures. Admittedly, it seems rather strange that in some of the most affected localities the management of the public utilities has not yet initiated computer-simulations etc. to evaluate the potential effects of a continuing decrease in population on the water and sewage system, e.g. decreasing flow velocity in pipes or sewers. Consequently, those city officials will be unable to more than guess the expected future costs.²⁹

²⁶ Probably, the number of water meters or the number of service connections would be more suitable to include commercial or other customers. But those data were not available.

²⁷ The higher cost-cover percentage in Dölau compared to Kröllwitz resulted from (though Dölau has about 1,000 inhabitants less) a significantly higher per-capita water consumption in Dölau. Therefore, in 2002 the estimated accumulated fixed and volume-based charges for Dölau exceeded water sales revenues in Kröllwitz by far. Furthermore, Dölau featured lower accumulated distribution costs and lower repair costs. In addition, the higher apportioned variable costs (due to higher water consumption) only amount to a relatively small percentage of total costs in the water sector (see e.g. table 2). Thus, apportioned total costs were lower and water sales revenues higher in Dölau than in Kröllwitz, which yielded a higher cost-cover percentage rate than Dölau.

²⁸ This mainly refers to excessive land use.

²⁹ Cf. Energieagentur Sachsen-Anhalt (2002), p. 86 and 136.

The core problem of the municipalities affected by decreasing population size is to decide whether to keep oversized networks or to adjust network capacities. Minimizing (long-term) costs of provision per inhabitant should play a mayor role in the future deconstruction process in East German cities, e.g. by tearing down buildings and deconstructing water and sewage systems at the periphery rather than in the centre. Planning of several East-German cities involve combinations of partial deconstruction (disconnecting superfluous pipes, constructing new ring connections etc.), selective reduction of nominal widths and additional operational measures (flushing etc.).³⁰

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³⁰ Cf. *Energieagentur Sachsen-Anhalt* (2002), p. 126 und p. 167.

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