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Regional wastewater treatment–an economical solution? Data from 40 years of operation gives the answer

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Abstract

Economic data from 40 years of operation of three regional wastewater treatment companies have been compiled and analysed. The transport systems consist mainly of gravity flow tunnels with lengths of 55–120 km. In spite of the heavy initial investments <20% of the cumulative total costs can be allocated to the transport systems. The treatment plants all remove 90% or more of the influent Biological Oxygen Demand (BOD) and phosphorus and 65–80% of the nitrogen. The wastewater treatment is responsible for about 90% of the cumulative operation costs while the transport system is responsible for 20–40% of the cumulative capital costs. Over time the cost of the transport systems has decreased considerably and is after 40 years of operation only 4–13% of the total costs. Although the main benefit of the regional solutions has been the transfer of wastewater from sensitive inland streams and lakes, the data presented give strong evidence that the regional solutions also has been advantageous from an economic point of view.

Key words: long-time costs, regional solutions, transport vs treatment

INTRODUCTION

In the 1960-ies most Swedish municipalities discharged raw or insufficiently treated wastewater. Both in the Stockholm region and in the Gothenburg region political discussions concluded in the formation of organisations for regional co-operation for wastewater management. To protect the sensitive local lakes and streams it was judged necessary to transfer the wastewater to the sea. Three organisations, owned by the co-operating municipalities, were formed. The three organisations built regional tunnel system covering areas of over 100 km^2. Gravity flow tunnels of 55–120 km transfer the wastewater to three central treatment plants. The local sewer system is operated by the municipalities.

The main reason for regional solutions was the possibility to transfer discharges from local inland waters to the sea. There was also at the time a belief that large scale solutions would be more economical (Deininger & Su 1973). The value of a centralised plant versus local plants has later been questioned and another argument against regional solution has been that the heavy initial investments in tunnels will give an unfair distribution of costs between generations. As all the three plants now have been in operation for 40 years or more, it was believed that some of these questions could be clarified by the examination of the economy of the three organisations.

METHODOLOGY

The municipal co-operation is for two of the organisations in the form of private limited companies and the third has a similar arrangement. Therefore all three are called companies below. The

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companies have to follow the same stringent rules of accounting as public limited companies. This means that the economy is transparent and completely separated from the economy of the owners. The companies produce annual reports. From the reports data on investments, depreciations, interests and operation costs have been collected. The capital costs of the transport systems have been possible to separate from the capital costs of the treatment plants. The operation cost of the tunnel system is more difficult to extract and some assumptions have been necessary to make. The costs for each year have, when relevant, been recalculated to the money value of 2014 by the consumer price index (CPI). All costs are given in SEK. The present relation of SEK to the Euro is 1€ = 9.3 SEK. The total cost is defined as cost invoiced to the connected municipalities minus profit or plus loss from the profit and loss account. Total operation costs are total costs minus interests and depreciations and minus operational incomes. Examples of operational incomes are sale of heat and biogas.

THE PLANTS

Wastewater Treatment Plant (WWTP) G started operation in 1972 with a connection of 300,000 people that rapidly grew to 530,000 as the tunnel system was extended and then gradually to the present 725,000. Major additions to the tunnel systems were made in 1983, 1989 and 2011. The gravity flow tunnel system now has a length of 130 km. The annual inflow is 110–140 million m^3. The plant was operated as a highly loaded activated sludge plant for its first 10 years of operation. Then the plant was extended with primary settlers and more aeration and from 1986 chemicals were added for phosphorus removal. In 1995 the plant was extended for nitrogen removal and has since 2010 a supplementary post denitrification and micro sieves as a tertiary treatment. More details are compiled by Gryaab (2013).

WWTP K started in 1970 with a connection of 250,000 people that gradually grew to the present 490,000. The tunnel system has a length of about 100 km and was complete at the start of operation. The annual inflow to the plant is most years 50 ± 5 million m^3. The plant was operated as an activated sludge plant with phosphorus removal by chemical precipitation for the first 28 years and thereafter by biological P-removal supported by chemical precipitation. In 1998 a major extension was made and since then the plant also removes nitrogen and has tertiary filtration. For more information see Käppala (2014).

WWTP S started operation in 1974. Initially the connection was 130,000 that gradually grew to the present 315,000. The tunnel system has a length of 55 km. Also here the tunnel system was almost complete at the start of operation. An addition was made in 1985. At the start the inflow was much lower than the design flow and only half of the treatment lines were operated. The inflow increased and from 1982 all lines were in operation. The inflow has gradually increased from 20 million m^3 to 40 million m^3 per year. The plant is a moderately loaded activated sludge plant. Since 1991 the plant has operated with nitrogen removal and a tertiary filtration was installed in 1993. In 1997 the nitrogen removal was enhanced by the installation of fluidized beds for post denitrification. For more information see SYVAB (2014).

The industrial loads on the plans are low; about 10% of the total organic load. The three plants now remove 90% or more of BOD and phosphorus and 65–80% of nitrogen. The development of the performance of the plants is shown in Figure 1. During the first 10–15 years of operation plant G has heavily loaded with lower removals of BOD and phosphorus.

RESULTS

Figure 2 shows the CPI-adjusted total cost per connected person. During the 40 years of operation the interest rates have varied considerably. Interest costs for each year have therefore been adjusted to the

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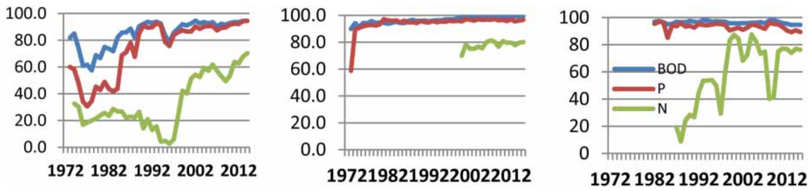

Figure 1 | Percentage removal of influent BOD_7, phosphorus and nitrogen at WWTP G, K and S.

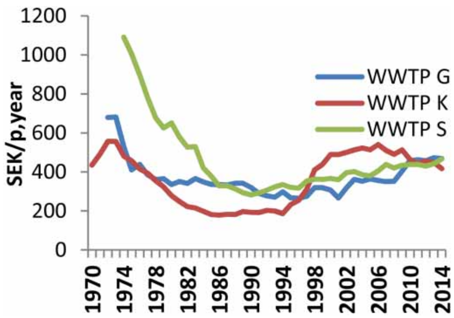

Figure 2 | CPI-adjusted per capita total cost.

average interest rate for the whole period of operation. During the first 20 years the cost per capita cost decreased due to increasing connection and decreasing capital costs. In the mid 1990-ies the cost increases due to investments for nitrogen removal. Figure 3 shows the CPI-adjusted cost of operation for the three plants. Also the operation costs decrease during the first 20 years and then the more stringent effluent requirements resulted in increased operation costs.

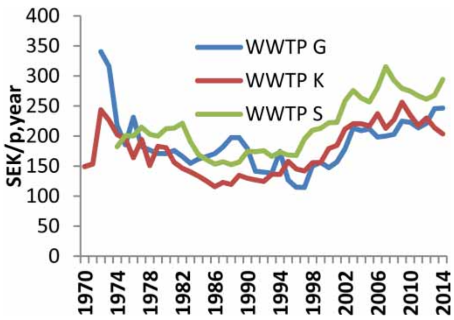

Figure 3 | CPI-adjusted per capita costs of operation.

For the transport system the interests and depreciations are important cost factors. The direct operation costs of the transportation system are low. However, the transportation of the wastewater in the regional system is mainly by gravity flow and at the treatment plants the wastewater arrives at depth of 18–54 meters below ground level. In order to make a fair comparison between a local and a regional solution the increased pumping costs have to be allocated to the transportation systems. Figure 4 shows the percentage the total cost that can be allocated to the transport system since the start of operation. Plant K had made all investments in the transportation system when the treatment plant started operation while for plant G and S additional investments in the transport system were made also after the start of the WWTP operation. Thereafter the relative cost of the transport systems has steadily decreased and is now below 10% for all the three plants. The main explanation for this is the increasing costs for wastewater treatment and the decreasing share of the fixed capital assets for the transport system.

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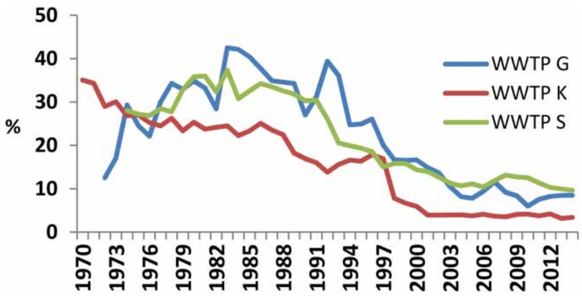

Figure 4 | The transport systems share in percent of the total costs.

In Table 1 the percentage of the accumulated costs of capital and operation for transport and treatment are calculated for all years of operation.

Table 1 | Distribution of cumulated CPI-adjusted total costs, capital costs and operation cost in percentage for 40 years of operation

	WWTP G		WWTP K		WWTP S	
	Transport	Treatment	Transport	Treatment	Transport	Treatment
Total	25	75	13	87	18	82
Capital	42 (86)	58 (40)	18 (76)	82 (51)	30 (69)	70 (45)
Operations	8 (16)	92 (60)	7 (24)	93 (49)	13 (31)	87 (55)

Figures within parenthesis are the distribution of capital and operation cost for transport and treatment resp.

Table 1 shows that for the three WWTP's the capital costs dominate for wastewater transport while for wastewater treatment the operation costs are 50–60% of the total costs. For the total costs, treatment stands for three quarters or more. The total costs for the 40 years of operation have also been calculated for 10 year intervals, Table 2.

Table 2 | Changes in cost distribution in percent between transport and treatment during 40 years of operation

	WWTP G		WWTP K		WWTP S	
Years of operation	Transport	Treatment	Transport	Treatment	Transport	Treatment
1–10	31	69	26	74	30	70
11–20	31	69	20	80	28	72
21–30	22	78	14	86	15	85
31–40	14	86	4	96	11	89

In Figures 5–8 the per capita costs for capital and operation of the transport systems and the treatment plants for the three companies are compared. The operation costs for the transport system do not vary much over the years, while the capital costs steadily decrease over time.

The transport system operational cost for WWTP S is higher than for the other two plants. This is explained by the fact that the inlet pumps here lift the wastewater over 50 meters, while the lifting heights at the two other plants are <20 meters. For the treatment, the costs decrease during the first 20 years mainly due to increasing connections. Later the cost curves turn upwards due to cost increases for personnel, energy and chemicals for nitrogen removal and for tertiary particle removal to cope with requirements for effluent phosphorus levels below 0.3 mg/l.

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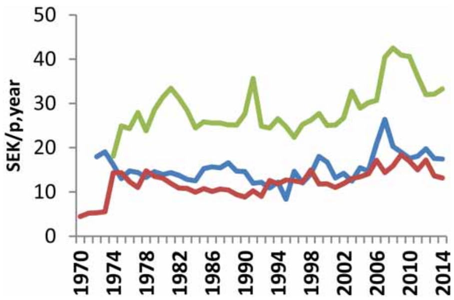

Figure 5 | CPI-adjusted per capita costs of operation for transport system.

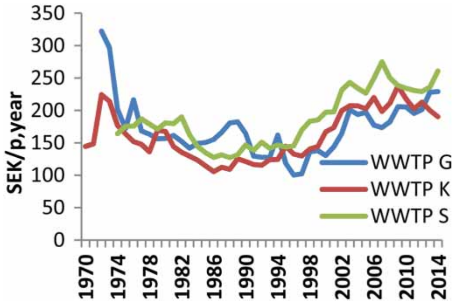

Figure 6 | CPI-adjusted per capita costs of operation for the wastewater treatment.

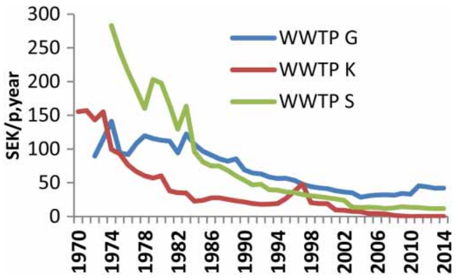

Figure 7 | CPI-adjusted per capita capital costs for the transport system.

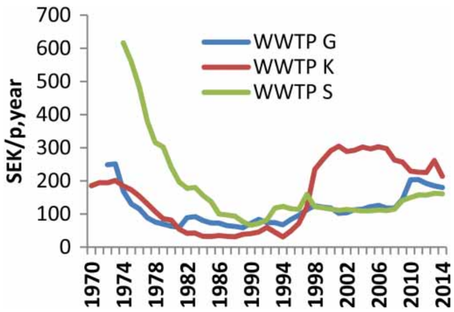

Figure 8 | CPI-adjusted per capita capital costs for the wastewater treatment.

DISCUSSION

The main benefit for all the regional solutions has been the increased quality of the local lakes and watercourses that were relieved of wastewater discharges. From an economical point the transport

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system is responsible for <20% of the total cost at two of the plants. The somewhat higher cost for transport at treatment plan G is due to a recent expansion of the tunnel system. For wastewater treatment there is economy of scale both in investments and in operations. There is strong evidence that the regional solutions for the three companies have been advantageous from an economical point of view. From Table 2 it is obvious that the benefits of the regional solutions have been more and more pronounced over the years. This is even more accentuated if the fact that the gravity flow tunnels have very large capacities making it possible to accept new connections up to the treatment capacity. When the treatment capacity has to be extended or when the treatment requirements becomes more stringent the regional solutions will have the economy of scale benefit.

If the distribution of costs on different generations is examined, Figure 1 indicates that the first generation takes a larger share due to the initial costs for the transport systems and that also the present generation takes a larger share due to the more stringent effluent requirements. It seem that the generation in between have been favoured.

It could be tempting to make more direct comparisons between the three companies. However this requires a more in-depth analysis as factors as financing costs and depreciation rates differ between the companies.

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