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APPLICATION OF ECONOMIC ANALYSES FOR EVALUATION OF WATER TREATMENT PLANTS

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ABSTRACT: Analyses of the costs of surface water treatment plants (WTP) in Poland show that unit capital and operating costs decline with increasing production. Costs of depreciation, electricity consumption and salaries have the largest share in the total WTP operating costs. Life cycle costing has shown that additional WTP costs may be related to maintenance of too many rapid gravity filters. In the case of complex water supply systems a large water manufacturer is often treated as a reserve source, but assurance of resident supply reliability increases the WTP operating costs. Water treatment plants are also charged with flood protection costs.

KEY WORDS: water treatment plant, cost indices, cost analysis, economic effectiveness

Introduction

Economic analyses of water supply and sewage infrastructure help to reduce capital and operating costs of individual facilities. Identification of these cost elements which may be overly inflated allows to undertake, together with technologists, measures leading to a possible reduction of these costs.

The article presents examples of the use of economic analyses for surface water treatment plants in Poland as conducted by the Water Supply and Water Protection Economics Research Team, working within the Department of Technology in Environmental Engineering and Protection at the Białystok University of Technology as well as NILU Polska team. The authors of this article, respectively, are members of the aforementioned groups. Scientists working at the recently established Department of Economics and Environmental Management at the Faculty of Biology and Environmental Sciences at the Cardinal Stefan Wyszyński University are planning further research on these issues.

Research methodology

The following indicators may be used for analyses of the total costs of water treatment plants:

- total and unit capital costs,
- annual and unit operating costs,
- annual and unit water treatment costs,
- structure of the operating costs (Miłaszewski, 2015a; Broniewicz et al., 2009).

Indices of unit capital costs for the construction of water treatment plants can be determined using the following formula (Miłaszewski, 2015b):

$$i = \frac{J}{Q} \tag{1}$$

where:

i – unit capital costs in PLN/m^3/d,
J – total capital costs in PLN,
Q – average daily capacity of a water treatment plant in m^3/d.

In turn, the unit operating costs of a water treatment plants may be determined by the relationship:

$$k = \frac{K}{Q \times 365} \tag{2}$$

where:
k – unit operating costs in PLN/m^3,
K – annual operating costs in PLN/year,
Q – average daily capacity of a water treatment plant in m^3/d.

In practice, the cost effectiveness indicator is used for selection of the most economically efficient technological alternative of a water treatment plant. These conditions meet the index of annual costs of water treatment. In a simplified manner it may be expressed as the sum of interest on capital, depreciation, and annual operating costs:

$$K_r = I\,(r + s) + K_e \tag{3}$$

where:
K_r – annual water treatment costs in PLN/year,
I – capital costs in PLN,
r – interest rate in year^{-1},
s – depreciation rate in year^{-1},
K_e – annual operating costs (without depreciation) in PLN/year.

On the other hand, assuming the relationship determining the capital recovery factor (α), namely:

$$\alpha = \frac{r(1+r)^n}{(1+r)^n - 1} \tag{4}$$

where:
r – interest rate in year$^{-1,}$
n – accounting period of operations in years.

we get the average annual unit cost of water treatment:

$$k_r = \frac{I \times \alpha + K_e}{W} \tag{5}$$

where:
k_r – unit water treatment costs in PLN/m^3,
I – investment costs in PLN,
α – capital recovery factor,
K_e – annual operating costs (without depreciation) in PLN/year,
W – use effect defined, e.g., by the quantity of water treated in m^3/year.

The expected lowest annual water treatment cost K_r is considered to be the most cost-effective variant. Assuming the constant use effect, the corresponding unit cost kr will also be the lowest.

Analysis of the water treatment plant costs also includes determining the relationship between unit capital costs, operating costs, annual costs and the capacity of the plant. A mathematical model may be used to determine these relationships. Calculation of the power regression coefficients (a, b) was made using an Excel spreadsheet (Miłaszewski et al., 2013a). The capital costs of construction of water treatment plants were converted by using Polish Central Statistical Office price index for construction and assembly for the year 2011.

In the case of a water supply and sewerage utility plant the generic classification system of own costs may be used to determine the structure of the operating costs of a water treatment plant which may be divided into two groups, namely:

- material costs, including the costs of depreciation, material consumption, electric energy and heat energy, and the cost of repair and transport services,
- intangible costs, including wages with surcharges, taxes and costs of other intangible services.

Analyses of unit capital and operating costs

For cost analysis of a surface water treatment plant the costs may be divided into three groups depending on the quality category of water drawn which has impact on the treatment technology (*Rozporządzenie...*, 2002), namely:

- water category A1, requiring simple physical treatment, in particular, filtration and disinfection;
- water category A2, requiring typical physical and chemical treatment, in particular pre-oxidation, coagulation, flocculation, decantation, filtration and disinfection;
- water category A3, requiring high efficiency physical and chemical treatment, and in particular oxidation, coagulation, flocculation, decantation, filtration, activated carbon adsorption and disinfection (ozonation, final chlorination).

Table 1 illustrates unit cost indices of capital and operating costs (Rauba, 2008; Miłaszewski, 2003) established for five surface water treatment plants drawing A3 category water. Data needed to determine the level of these costs were obtained from various water supply and sewerage utilities.

Table 1. Unit capital and operating costs for surface water treatment plants of A3 water quality category (2011 price level)

No. of plant	Capacity of water treatment plant m^3/d	Unit capital costs i, PLN/m^3/d	Unit operating costs k, PLN/m^3
1.	350	9 622	1.06
2.	2 500	4 300	0.78
3.	5 000	3 233	0.68
4.	10 000	2 433	0.60
5.	54 000	1 218	0.42

Source: (Miłaszewski et al., 2013a).

As table 1 shows, unit capital costs incurred on construction of such type of surface water treatment plants fluctuate between 1.2 to 9.6 thousand PLN/m^3/d. By contrast, unit operating cost indices fluctuate from 0.42 to 1.06 PLN/m^3. These costs decrease as the capacity of a water treatment plant increases.

On the basis of data in Table 1 analytical relationships were determined between:

a) unit capital costs (i) and the capacity (Q) of surface water treatment plants, i.e.:

$$i = \frac{106310}{Q^{0.41}} \text{ [PLN/m}^3\text{/d]} \qquad (6)$$

This relationship is illustrated in Figure 1.

b) unit operating costs (k) and the volume of treated water (Q), i.e.:

$$k = \frac{3.717}{Q^{0.20}} \text{ [PLN/m}^3\text{]} \qquad (7)$$

This relationship is illustrated in figure 2.

Similarly, as in the case of other surface water treatment plants (A1 and A2 quality categories), as well as in treatment of underground waters (Miłaszewski et al., 2013b), relationships between unit capital and operating costs and the plant capacity take the form of a power function regression.

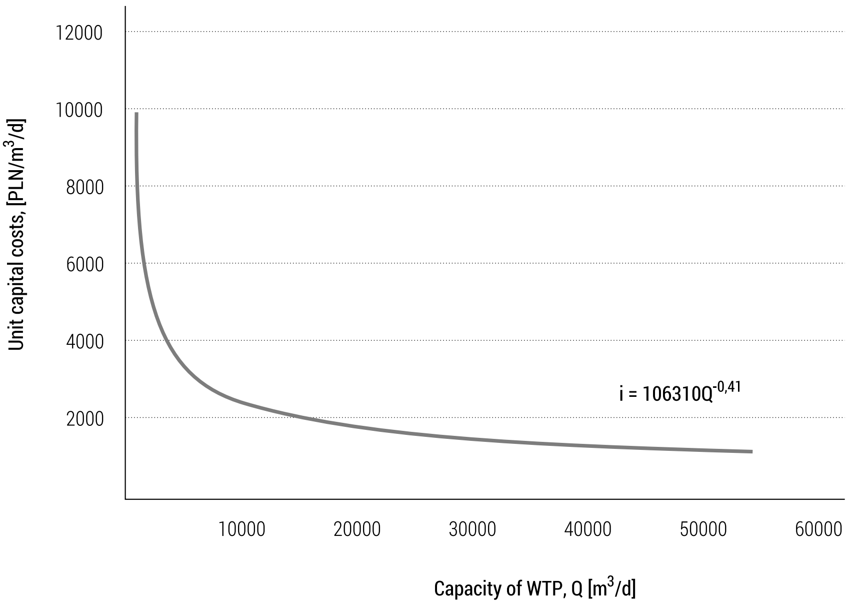

Figure 1. The relationship between unit capital costs and the capacity of an A3 quality category surface water treatment plants (2011 price level)

Source: (Miłaszewski et al., 2013a, p. 249).

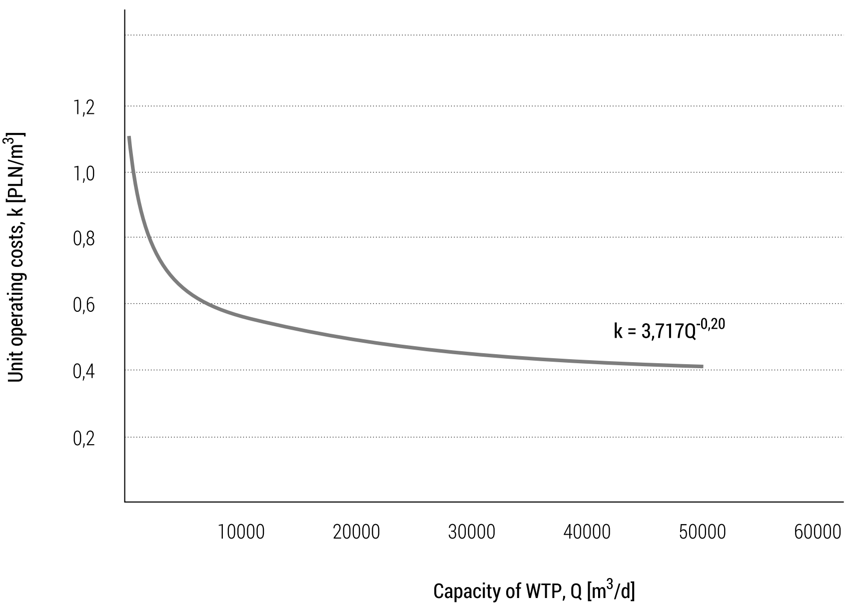

Figure 2. The relationship between unit operating costs and the capacity of an A3 quality category surface water treatment plants (2011 price level)

Source: (Miłaszewski et al., 2013a, p. 253).

Analysis of cost structure of water treatment plants

The study of the cost structure of five surface water treatment plants (Miłaszewski, 2015b) shows that depreciation costs have the largest share in the total operating costs of these stations (about 25%). The share of material use costs is 6% and the cost of electricity consumption is approximately 8%.

A different cost structure is observed in the Goczałkowice WTP (Panasiuk & Nowacka, 2011) supplying Katowice agglomeration. The main element of the cost structure of this water treatment plant is depreciation. In the years 2000–2009 (Kowalczyk, 2010) its share in the total plant costs averaged in the range of 25–49%. This was followed by the cost of electricity consumption, which fluctuated during this period in the range of 14–28%. Electricity consumption is dependent of the use of water gravity drop from the Soła river. While water is collected from the Czaniec reservoir on the Soła river only one pump with a power of 630 kW is used for plant needs. However, when water is collected from the closer the Goczałkowice reservoir on the Wisła river, 2 pumps by 1 MW power must work. Electricity consumption also increased following the plant modernisation completed in 2004 due to initiation of water ozonation, the use of carbon filters and a new inter-facility pumping station.

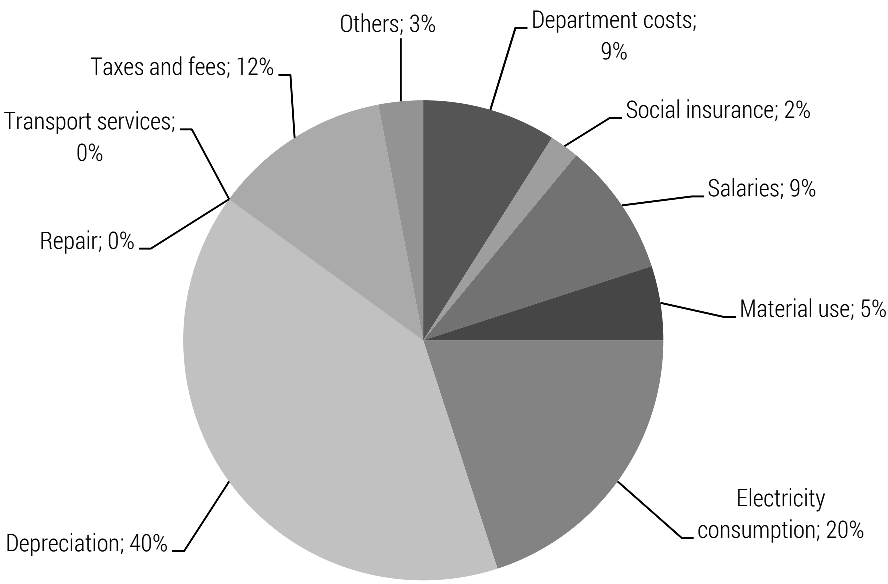

Figure 3. The cost structure in the Goczałkowice WTP in 2009

Source: (Panasiuk & Nowacka, 2011).

The costs of materials used in the Goczałkowice WTP gradually grew from 2.4 % in 2005 to 4.9 % in 2009. In turn, repair costs decreased from 12% in 2000 to zero in 2009. Taxes and fees, salaries with social insurance contributions (ZUS) as well as department costs are also important elements of the overall plant costs. Figure 3 shows the cost structure in 2009.

Costs related to water purchase are not shown in this configuration, because water intakes are owned by the Upper Silesian Water Company (GPW SA). In the case of water used for own consumption charges for water supply are the only costs.

Comparing the cost structure of the Goczałkowice WTP in years 2000–2009, the share of material costs and depreciation, taxes and fees and department costs increased while the share of costs of electricity consumption and repair decreased. Throughout the period, the share of salary and transport service costs remained unchanged.

Life cycle cost for water treatment plant

Life Cycle Costing (LCC), is a tool which is often used in managing technical infrastructure. It assumes separation of four phases in the life cycle of every technical facility, namely design, construction, operation and disposal (Bykowski et al., 2005; Korpi & Ala-Risku, 2008). It can be used in analysis of the economic viability of operation of technical facilities in variable use conditions. The method of the life cycle cost combines economic and technical aspects in evaluation of the profitability of technical facility implementation. This may be done analyzing cash flows in particular phases of operations and may be described by the following equation (Zimoch, Szymik-Gralewska, 2015):

$$[LCC] = [CF]_d + [CF]_c + [CF]_o + [CF]_{dl} \tag{8}$$

where:
LCC – life cycle cost, PLN,
CF_d – cash flow in the design phase, PLN,
CF_c – cash flow in the construction phase, PLN,
CF_o – cash flow in the operation phase, PLN,
CF_{dl} – cash flow in the disposal phase, PLN.

Life cycle costing was used, among others, for a water treatment plant. It was chosen for two oversized systems of rapid filters operating in a parallel manner. In the study bona fide operation data for the years 2005–2012 were used. The first technological system consisted of 24 filters, each with a surface of 46 m^2 and a bed volume of 115 m^3. The second system consisted of 40 filters with a unit surface of 44.8 m^2 and volume of 216 m^3. In the final part of the study, 18 fully efficient filters in first system were used and 29 filters in the second system. In table 2, calculating the reviewed LLC values, were taken into account cash flows that have already occurred and those which will occur within 30 years of operation of both filtration systems (discounted values).

Table 2. The life cycle costs of elements of the filtration system

Filtration system element		LCC [PLN]	
		Operating state	Reserve state
First system	Building	90 765 109	90 765 109
	Filters	3 970 602	2 086 789
	Pump	246 225	188 503
Second system	Building	136 138 023	136 138 023
	Filters	3 199 290	2 032 533
	Pump	561 201	509 646

Source: (Zimoch, Szymik-Gralewska, 2015).

Based on the LCC analysis, Zimoch and Szymik-Gralewska (2015) proposed a new method for evaluation of water supply facility performance, comprising a combination of reliability theory and cost accounting. Within framework of this method were used new indicators for the evaluation of the operation quality of water supply systems, for example, unit indicator of consequences of operational decisions. As a result of application of this method for testing rapid filter systems, it was demonstrated that they were used incorrectly because the reliability of their operations was greater than was necessary. This generated additional costs associated with operating a greater number of filters than was needed.

Cost analysis for limitation of water intake from a WTP

In the case of complex water supply systems, construction of own water intakes by households, industrial plants and local water works can generate problems. A large water works is then treated as a reserve source. However, guaranteeing supply reliability for the whole agglomeration increases WTP unit operating costs.

An example of this is the Upper Silesian Water Company (GPW SA), which provides water for 3 million people in the Katowice and Rybnik agglomerations. The water supply system of Upper Silesia and Zagłębie Dąbrowskie consists of water intakes, 2 large water treatment plants in Dziećkowice and Goczałkowice and 9 other treatment plants in Będzin, Bibiela, Czaniec in Kobiernice, Kozłowa Góra, Łazy, Maczki, Miedary, Strumień and Zawada, the main network and several pressure tanks (GPW, 2016). For years, an increased use of own water intakes by municipal water companies has been observed. In addition, water is purchased from competitive plants from Ostrava in the Czechia and Bielsko-Biała (Panasiuk, 2016). As a result, water sale by GPW SA decreased from 1.3 million m^3/d in 1991 to 365 thousand m^3/d in 2013 (Kania, 2013).

Water treatment plants located on dammed reservoirs are also charged with flood protection costs. In the case of GPW SA there are water management costs for the Goczałkowice and Kozłowa Góra reservoirs. Three million customers of this plant pay for flood protection of areas located below the reservoirs (Pustel, 2009), instead of financing these costs by the province or state budgets. In 2010, the maintenance costs for the Goczałkowice reservoir burdened the price of water produced by the Goczałkowice WTP and the Strumień WTP by 0.13 PLN/m^3. The costs for the Kozłowa Góra reservoir increased production costs by 0.17 PLN/m^3 (Kania, 2012). Other sources of the cost increase include high property taxes paid by GPW SA, which are paid into the budgets of municipalities where dams and water treatment plants are located and which burden water consumers in other municipalities.

In order to determine the effects of further decrease in water production, cost analysis for scenarios of water intake limitation from the Goczałkowice WTP was provided (Panasiuk, 2013). This plant is the most modern water treatment plant in the GPW SA and generates some of the lowest costs of water pumping into the main network (0.82 PLN/m^3). Therefore, the option of not exploiting the Goczałkowice WTP could occur only in the event of mass resignation by local water companies from GPW SA services. However, it would then be difficult to supply millions of Upper Silesia and Zagłębie Dąbrowskie residents with an alternative source of surface or ground waters.

Limiting water intake from the Goczałkowice WTP could be a realistic scenario. In the years 2003–2011 the annual production of drinking water in this plant (Panasiuk & Nowacka, 2012) amounted to an average of 71 million m3. Limiting water intake from the Goczałkowice WTP could be achieved by reducing intake from the Goczałkowice reservoir. Due to the gravity flow, water intake from the Soła river is more cost effective. On the other hand, however, it is exposed to flood risk and low water levels.

In the analysis a limit of water production by the Goczałkowice WTP up to maximum 50%, or from 72 million m^3 in 2009 to maximum 36 million m^3 was assumed. Salaries with social insurance contributions, depreciation, repairs, transport services, taxes and fees as well as department and other costs were classified as fixed costs. In 2009 they accounted for approximately 70% of the total plant costs. Costs of electricity consumption and materials, which accounted for approx. 30% of the total plant costs, were classified as variable costs (Kowalczyk, 2010).

Limitation of water production would generate an increase of unit fixed costs and ultimately an increase in the unit production costs of the Goczałkowice WTP, see table 3.

Table 3. Increase of the cost of pumping water from the Goczałkowice WTP while limiting water production (2009 price level)

Water production	Unit variable cost, PLN/m^3	Unit fixed cost, PLN/m^3	Unit cost, PLN/m^3
72	0.25	0.57	0.82
66	0.25	0.62	0.87
60	0.25	0.69	0.94
54	0.25	0.76	1.01
48	0.25	0.86	1.11
42	0.25	0.98	1.23
36	0.25	1.14	1.39

Source: (Panasiuk, 2013, p. 22).

Limiting water production by the Goczałkowice WTP by 25%, i.e. to 54 million m^3, could increase the plant costs to the level recorded for smaller groundwater intakes such as the Miedary and Łazy WTP. Limiting production by half, i.e. to 36 million m^3, would make production by the Goczałkowice WTP more expensive than water produced by the Maczki, Strumień (currently deactivated) and the Zawada WTP. Given the high share of fixed costs, limiting production by the Goczałkowice WTP would reduce competitiveness of the GPW SA. It would be more reasonable to limit production of other water treatment plants belonging to the company.

Conclusions

Previous analyses of costs of surface water treatment plants in Poland showed that unit capital and operating costs decline in a parallel manner to production increase. Costs of depreciation, electricity consumption and salaries have the biggest share in the total water treatment plant operating costs. Life cycle costing has shown that additional costs incurred by water treatment plants may be related to maintenance of more rapid gravity filters than is necessary.

In the case of complex water supply systems, construction of own water intakes by households, industrial plants and local water companies generates problems. Large water works are often treated as reserve sources, but guaranteeing resident supply reliability increases the WTP operating costs. Water treatment plants localised on dammed reservoirs are also burdened with flood protection costs.

The contribution of the authors

Rafał Miłaszewski – factual contribution, 50%
Damian Panasiuk – factual contribution, 50%

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