COST OF RAIN WATER TREATMENT AT MEDIUM-SIZE MUNICIPAL WASTEWATER TREATMENT PLANT

J. Mikosz

Institute of Water Supply and Environmental Engineering,
Cracow University of Technology, ul. Warszawska 24, 31-155 Cracow, Poland
(Email: jmikosz@pk.edu.pl)

ABSTRACT
The paper presents results of the research performed in 2002 on costs of treatment of rain water at a medium-size municipal wastewater treatment plant in southern Poland. Wastewater and rain water were supplied to the plant through combined sewerage system. Preliminary economic analyses performed by the plant's management and intuition have indicated that treatment of rain water supplied to the plant with domestic wastewater during wet weather might be responsible for significant portion of total operational costs of the plant. These costs were reflected in annual cost balance presented by the plant to the city authorities however its exact magnitude was unknown. In results the costs was carried over on all users of the sewerage system, regardless of how much of rain water was discharged to the sewerage system from their properties. The purpose of the research was to answer the question what portion of treatment costs could be assigned to treatment of rain water flow at the plant.

KEYWORDS
Wastewater treatment; treatment costs; computer simulation; combined sewerage system.

INTRODUCTION

Municipal wastewater treatment plants that treat wastewater collected in combined sewerage system are faced with problem of treatment of large volumes of diluted wastewater during wet weather. Moreover rain water in urbanized areas usually carries significant loads of organic matter and suspended solids, which add up on pollution loads typically contained in domestic wastewater. Both these factors much affect variable and constant costs of a plant. In order to properly set tariff table for the consumers, it is essential for the plant to know what portion of the costs is associated with treatment of domestic wastewater and with rain water. Otherwise, rain water treatment costs would be carried over on all consumers as a "hidden cost" included in price of domestic wastewater treatment and disposal.

The purpose of the research was to estimate the unit operational costs associated with treatment of rain water supplied to the wastewater treatment plant through combined sewerage system. During the investigations computer simulation methods were used with GPS-X v. 4.0 program. Computer simulation was used to estimate unit variable costs for both, dry weather and wet weather conditions for the entire plant, including wastewater treatment and sludge processing lines. Then, constant costs component calculated on 2001 year basis was added.

Integrated part of the research was master's thesis developed by a student of Environmental Engineering Department of the Cracow University of Technology.

DATA FOR RESEARCH

The plant is a medium–size municipal wastewater treatment plant located in southern Poland. Wastewater is supplied to the plant through combined sewerage system. The wastewater treatment line plant uses high- effective biological nutrient removal system configured in modified Bardenpho scheme with primary sedimentation. No chemical precipitation of phosphorus is used. In sludge processing line the plant uses anaerobic digestion technology with mechanical thickening of waste sludge and mechanical dewatering of digested sludge.

The simulation model was calibrated with data gathered at the plant in January-March 2002. The research was carried on with data collected at the plant in September 2001. Based on proportions of pollution loads contained in rain water flow and in total wastewater flow (rain water and domestic wastewater) supplied to the plant in 2001 separate characteristics were developed for domestic wastewater and for rain water as presented in table 1.

Table 1. Load-balance based characteristics of wastewater supplied to the plant in 2001.

Indicator	Unit	Domestic wastewater	Rain water	Combined
Flow	m^3/d	11 150	5345	16 495
BOD_5	gO_2/m^3	505,6	56,6	360
COD	gO_2/m^3	815,0	281	642
TSS	g/m3	262,7	316	280
Ammonia	$g\ N\text{-}NH_4/m^3$	17,9	0	17,9
Total N	$g\ N/m^3$	28,0	0	28,0
Total P	$g\ P/m^3$	5,3	0	5,3

Cost indicators applied during research were as follow:

- Electric power cost: 0,282 PLN/kWh
- Chemicals cost:
  - for sludge thickening (at dose 4,0 g/kg d.s.): 11,37 PLN/kg (2,80 €/kg)
  - for sludge dewatering (at dose 4,5 g/kg d.s.): 15,43 PLN/kg (3,80 €/kg)
- Utilization costs (including transport and environmental fees):
  - dewatered sludge – 65 PLN/t
  - screenings and sand - 71 PLN/t

For simplification of calculations some costs, such as water supply, gas, environmental fees for phenols and heavy metals, were treated as part of constants cost, which were not related to wastewater flow rate

METHODOLOGY

Simulation model

The simulation model developed in GPS-X v.4.0 considered all major components of the wastewater treatment line and sludge processing line including screening, sedimentation, pumping stations, overflows, biological nutrient removal, sludge thickening, anaerobic digestion and dewatering. Scheme of the model is shown in Fig. 1. The model used different hydraulic and kinetic models of the CNP library and allowed for calculation of costs for chemicals, electric power consumption and disposal.

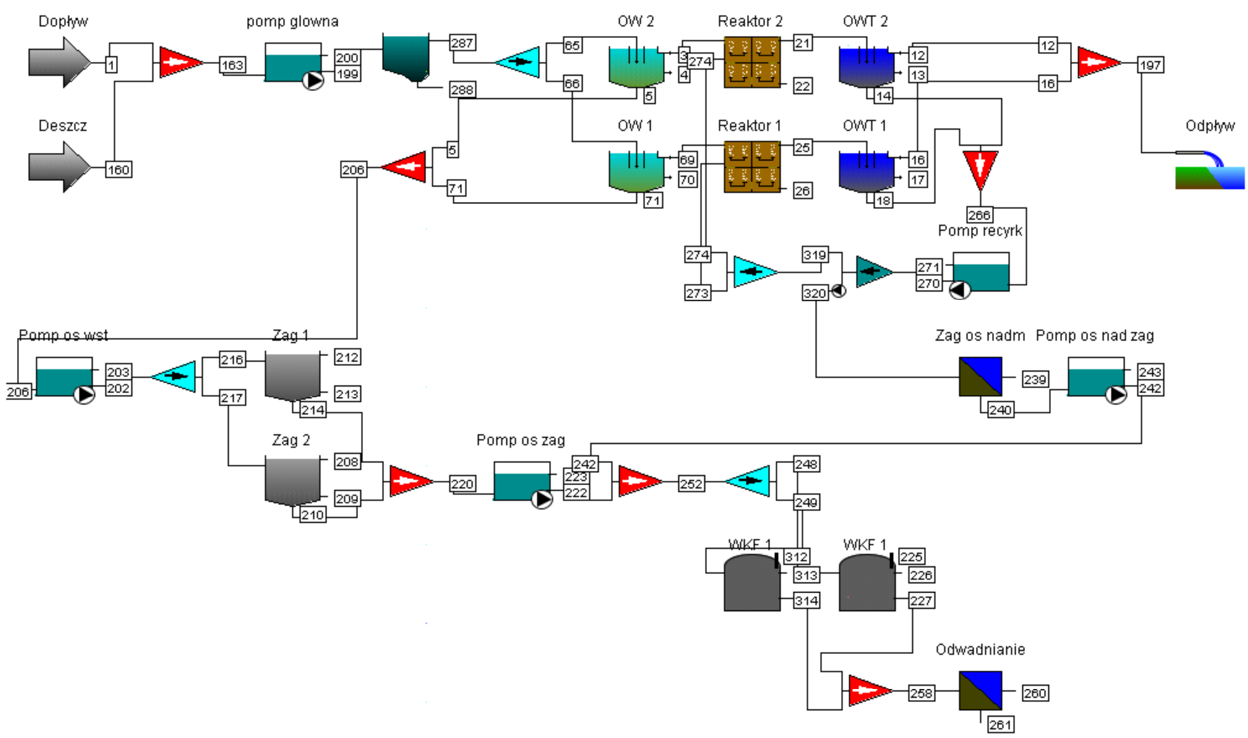

Figure 1. Scheme of the simulation model used during research.

Model calibration

The simulation model was calibrated according to technological and economic criteria. During the latter stage of calibration the annual cost data for 2001 were used. The results of this stage of model calibration are presented in table 2.

Table 2. Results of cost calibration of the model (in PLN/day)

	Model	Plant (2001)
Total operational costs including:	2721,8	2742,3
- electric power costs	1056,7	1126,8*)
- chemical costs	285,9	300,1
- utilization costs	1379,2	1362,3

*) refers to total consumption at the plant

Organization of research

The research was organized in two stages:

Stage 1 – simulation of dry weather flow to the plant in order to determine operational costs of the plant for dry weather conditions. Wastewater composition has been assumed as presented in Table 1. Influent flow was set a 1/365 of annual wastewater and infiltration water flow in 2001, i.e. 11150 m^3/d.

Stage 2 – simulation of wet weather flow. In addition to wastewater and infiltration flows, rain water flow of 5345 m^3/d was considered. Quality of wastewater in regard to BOD_5, COD and TSS was set as presented in Table 1.

In the next step, variable costs for dry weather (stage 1) were substracted from variable costs for wet weather (stage 2) what produced approximate value of variable costs increase associated with rain water treatment. The obtained value was recalculated into unit cost per 1 m^3 of rain water flow and then complemented with a set portion of capital costs. In result a unit cost of rain water treatment at the plant in 2001 year price was obtained.

The portion of constant costs associated with rain water treatment was determined in result of calculations, which were based on COD load balance. It was set that approximately 14% of constant costs were associated with rain water treatment, and the remaining 86% was associated with wastewater treatment (with infiltration flow).

RESULTS

During the research simulated were concentrations in effluent, pollution loads discharged into river and operational costs related to wastewater treatment and sludge processing. The costs included direct variable costs (energy costs, chemicals costs and utilization costs) and environmental fees for discharge of pollution loads into environment. The rates of environmental fees were set as specified in Polish regulations. Fees for storage of screenings, sand, sludge were included in utilization costs.

Variable costs component

Difference in variable costs for dry weather and wet weather flows for each category of variable costs indicates that there is an extra cost associated with treatment of rain water flow. For each category such extra cost could be recalculated into unit cost when divided by daily rain water flow value as presented in table 3.

Table 3. Daily increase of plant's variable costs and unit costs caused by treatment of rain water flow (all costs in PLN/day)

Variable costs component	Costs for		difference	Unit cost increase per m^3/d of rain water
	wet weather flow	dry weather flow		
Electric power cost	1214,00	1108,00	106,00	0,0198
Utilization cost	1441,00	1259,00	182,00	0,0341
Chemicals cost	291,00	291,00	0,00	0,00
Pollution discharge fees	1112,40	450,48	661,92	0,1238
Total	**4058,40**	**3108,48**	**949,92**	**0,1777**

Annual variable costs of treatment of wastewater and rain water equal to PLN 1 481 316,00, and annual costs of treatment of wastewater (with infiltration flow) are equal to PLN 1 134 595,20. This means that the annual variable cost of treatment of rain water at the plant is PLN 346 720,80. When recalculating this value into unit cost (for rain water flow rate 5345 m^3/d), it produces value of 17,77 gr/m^3*d, i.e. treatment of each cubic meter of rainwater generates additional variable cost of almost 17,77 gr per day all year around. These costs consist of the following components:

- pollution load discharge fees increased by 12,38 gr/d as compared to dry weather flow
- refuse utilization costs increased by 3,41 gr/d as compared to dry weather flow
- energy consumption costs increased by 1,98 gr/d as compared to dry weather flow.

Constant costs component

Constant costs are costs, which do not increase with increased flow rate and pollution loads. Some of the presented cost categories are not pure constant costs, but they have been classified so in order to avoid unnecessary complication of the calculations. Thus the following constant cost categories have been considered (in PLN/year based on 2001 prices):

a. Amortization	1 379 616,78
b. Materials (excl. polyelectrolytes)	80 443,87*)
c. Water	62 932,80*)
d. Natural gas	30 953,02*)
e. Salaries	601 727,34
f. Property tax and other taxes	171 787,05
g. Maintenance	173 530,65
h. Departmental costs	48 002,56
i. Transport	175 626,92
j. Laboratory	81 702,36
k.Insurance	5 697,90
l. Other costs	377 899,49
m. Environmental fees for phenols and heavy metals	15 000,00*)
TOTAL	**3 204 920,74**

*) – variable costs, but treated as constant costs due to lack of detailed data

In order to calculate unit constant costs, total annual constant costs should be divided by annual flow of wastewater and rain water to the plant:

$$k_{j\,st} = 3\,204\,920{,}74/(11150 + 5345) = 194{,}30\ PLN/m^3{*}year = 0{,}5323\ PLN/m^3{*}d$$

However this value does not tell anything about constant costs incurred to the plant by rain water flow. Thus, as it was explained earlier, based on COD load calculations it has been set that 86% of total constant costs was assigned to treatment of wastewater and 14% - to treatment of rain water. This means that in 2001 the constant costs of 2 756 231,84 PLN/year were associated with treatment of wastewater (with infiltration flow) and cost of 448 688,90 PLN/year was associated with treatment of rain water. Recalculated into unit costs it gives the following values per day:

- for domestic wastewater (with infiltration): 0,6772 PLN/m^3 of wastewater
- for rain water:
  0,2300 PLN/m^3 of rain water

Total costs

Total costs are the sum of variable and constant costs for wastewater flow and for rain water flow. For the considered plant the total costs are presented in table 4, and unit costs are presented in table 5.

Table 4. Total treatment costs for wastewater and rain water based on computer simulation.

Cost component	Domestic wastewater treatment Q=11150 m^3/d	Rain water treatment Q=5345 m^3/d	Total
	Annual costs in PLN/year		
Variable costs, K_{zm}, including:	**1 134 595,20**	**346 720,80**	**1 481 316,00**
• Electric power	404 420,00	38 690,00	443 110,00
• Refuse utilization	459 535,00	66 430,00	525 965,00
• Chemicals	106 215,00	0,00	106 215,00
• Discharge fees	164 425,20	241 600,80	406 026,00
Constant costs, K_{st}, including:	**2 756 231,84**	**448 688,90**	**3 204 920,74**
• Amortization	1 186 470,43	193 146,35	1 379 616,78
• Materials (excl.	69 181,73	11 262,14	80 443,87
polyelectrolyte)	54 122,21	8 810,59	62 932,80
• Water	26 619,60	4 333,42	30 953,02
• Natural gas	517 485,51	84 241,83	601 727,34
• Salaries	147 736,86	24 050,19	171 787,05
• Property tax and other taxes	149 236,36	24 294,29	173 530,65
• Maintenance	41 282,20	6 720,36	48 002,56
• Departmental costs	151 039,15	24 587,77	175 626,92
• Transport	70 264,03	11 438,33	81 702,36
• Laboratory	4 900,19	797,71	5 697,90
• Insurance	324 993,56	52 905,93	377 899,49
• Other costs	12 900,00	2 100,00	15 000,00
• Environmental fees for phenols and heavy metals			
Total costs, K_{calk}	**3 890 827,04**	**795 409,70**	**4 686 236,74**

Table 5. Unit treatment costs for wastewater and rain water based on computer simulation

Cost component	Domestic wastewater treatment Q=11150 m^3/d	Rain water treatment Q=5345 m^3/d
	*Unit costs in PLN/m^3*d* [*)]	
Variable unit costs, $k_{j\ zm}$	0,2888	0,1777
Constant unit costs, $k_{j\ st}$	0,6772	0,2300
Total unit costs	**0,9660**	**0,4077**

[*)] Unit costs expressed per m^3 of treated wastewater or per m^3 of treated rain water.

The calculations presented in tables 4 and 5 show that it is feasible to calculate the costs associated with treatment of domestic wastewater (0,9626 PLN/ m^3*d), and costs associated with treatment of rain water (0,3939 zł/m^3*d) in combined sewerage systems. The average unit cost of treatment of a mixture of wastewater and rain water may be easily calculated from a simple flow balance equation as shown below:

C_j = (0,9660 zl/m^3d * 11150 m^3/d + 0,4077 zl/m^3d * 5345 m^3/d)/(11150 m^3/d + 5345 m^3/d)= 0,7851 m^3/d

CONCLUSIONS

Rain water supplied to municipal wastewater treatment plant through combined sewerage system causes increased hydraulic loading of the plant. Such extra loading has obvious adverse effects on efficiency of technological processes. However, it also has significant economic effects. Treatment of rain water, which often carries high load of organic matter and suspended solids, requires extra energy for pumping, aeration and sludge processing, more chemicals for sludge thickening and dewatering, generates extra refuse utilization fees and increased environmental fees for discharge of pollution. These costs are of significant magnitude and should be identified for each individual plant, and considered in tariff table applied by a plant's operator.

The research performed on example of a medium-size municipal wastewater treatment plant showed that advanced computer simulation techniques could be effectively used to determine the costs associated with treatment of rain water. Typical dry weather and wet weather flows to the plant were simulated and variable costs generated at the plant were followed during both simulations. Comparison of both costs produced variable costs increase associated with rain water treatment. Then the identified variable costs were complemented with a set portion of constant costs. In result the total costs of rain water treatment at the plant have been identified.

For the analyzed wastewater treatment plant the following costs have been calculated:

1. Treatment of wastewater and infiltration flow (at average flow of 11150 m^3/d) incurs total cost of 0,9660 PLN/d for each m3 of treated wastewater. This includes variable costs of 0,2888 PLN/d and constant costs of 0,6772 m^3/d.
2. Treatment of rain water (at average flow of 5345 m^3/d) incurs extra cost of 0,4077 PLN/d for each m^3 of treated rain water. This includes variable costs of 0,1777 PLN/d and constant costs of 0,2300 PLN/d.

The calculated costs are much dependent on constant costs portion assigned to treatment of rain water at the plant. During the research this cost was distributed on the basis of average daily COD load balance in wastewater and in rain water. However, it should be recognized that this is only one of the possible approaches to constant costs calculations and this issue will require further research.

REFERENCES

Watson, B. et al. (1994). „Modelling of Full-Scale Wastewater Treatment Plants: How Detailed Should It Be?" *Wat.Sci.Tech.*, **30** (2), 141-147.

Jeppsson, U. (1996). „Modelling Aspectes of Wastewater Treatment Processes". Doctoral dissertation. Lund Institute of Technology, Department of Industrial Electrical Engineering and Automation, Lund, Sweden, pp. 15-50