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NUTRIENT REMOVAL COSTS OF MUNICIPAL WASTEWATER TREATMENT OF BUDAPEST

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Abstract

In Budapest a large portion of wastewater enters the Danube without any treatment (the level of biological treatment is around 20%).

Harmonisation up to EU standards in Budapest needs significant solutions in the field of sewerage and wastewater treatment. These solutions would mean considerable costs. This study analyses different development scenarios, and their costs. The investigated scenarios are the following:

– **autonomous development (Scenario 1)**

in this scenario all the population of Budapest will be connected to sewerage, and new wastewater treatment capacity will not be built. The calculated P and N emissions by population are in *Table 4;*

– **stand-still scenario (Scenario 2)**

in this scenario we hypothesize, that the nutrient emission will not increase. The estimated values of N, P emission of this scenario are in *Table 5;*

– **25% emission reduction (Scenario 3)**

in this case the limit factor is the N too. To the 25% N reduction 1.5 million PE size primary and secondary new treatment and 300 thousand PE N elimination capacity should be built. In this scenario the P discharge is less than in the present by 53%. The estimated nutrient discharge by population is in *Table 6;*

– **50% emission reduction (Scenario 4)**

in this scenario 1.5 million PE size new primary and secondary sewage treatment capacity, over it 1.3 million PE nitrification-denitrification, and 200 thousand PE chemical phosphorus elimination capacity in South Budapest WWTP are needed. The values of P, N emissions in this case are in *Table 7;*

– **harmonisation up to EU standards (Scenario 5)**

this scenario gives very strict requirements. This would mean a demand for 1.5 million PE size new primary and secondary, 2 million PE nitrification-denitrification, and over it 2 million PE biological-chemical phosphorus elimination sewage treatment capacity. There is not any reality to build it until 2000. The significant investment of building 550 km sewer, around 100 pump stations, 30 km pressure conduits and a new wastewater treatment plant need phased implementation. The values of the estimated nutrient discharge by population is in *Table 8.*

The investment costs of sewage treatment at different scenarios are in *Table 9.* The costs of nutrient elimination can be 200 million ECU (Scenario 1) to 1510 million ECU (Scenario 5). The significant investments need phased implementation.

Keywords: wastewater treatment, nutrient elimination, phased investment, harmonisation up to EU standards, investment costs.

Introduction

The development of sewerage and wastewater treatment in Hungary is in significant backwardness in comparison with water supply. According to the Hungarian technical literature (JUHÁSZ, 1994; DULOVICS, 1991.a., b, 1993; DULOVICS – DOMBI, 1989., 1993.; DULOVICS et al., 1996) the ratio of population connected to water supply is 91%, the ratio of population connected to sewerage is 53 – 54% and the 54% of the collected sewage is treated.

Table 1
EU sewage effluent standards (CEC 1991)

		Size PE		
		< 2 000 – 10 000	10 000 – 15 000	> 15 000
Date of compliance		31.12.2 005	31.12.2 005	31.12.2 000
Receiving waters		fresh, estuarine	all	all
Parameters				
BOD	mg/l	25	25	25
Min. η_{BOD}	%	70 – 90	70 – 90	70 – 90
COD	mg/l	123	125	125
Min. η_{COD}	%	75	75	75
SS	mg/l	60	35	35
Min. η_{SS}	%	70	90	90

Table 2
Additional Requirements for Discharges to Sensitive Areas Subject to Eutrophication

		Size PE	
		10 000 – 100 000	> 100 000
Total phosphorus	mgP/l	2	1
Min. $\eta_{Tot.\ P}$	%	80	80
Total nitrogen	mg N/l	15	10
Min. $\eta_{Tot.\ N}$	%	70 – 80	70 – 80

In Budapest – capital of Hungary – the ratio of population connected to water supply is 98%, the ratio of population connected to sewerage is 89%, the level of biological treatment is about 20% (SOMLYÓDY, 1994). There is no capacity of tertiary treatment. This situation is disadvantageous if we investigate the effluent standards of EU, which are given in *Tables 1* and *2*.

The objective of this study is to analyse the investment costs of the municipal wastewater treatment capacities at different levels, from the present situation to the requirements of EU standards.

1. Present Situation in Budapest

In Budapest there are 2 008 thousand inhabitants, out of this 1789 thousand capita are connected to sewerage, and 219 thousand capita are not connected. About 500 thousand inhabitants are supplied by primary + secondary treatment.

Table 3
Nutrient discharge by population of Budapest in the present

Level of supply		Emission of TN		Emission of TP	
	th. PE	t/yr.	%	t/yr.	%
a) Connected to I.+II. + III. treatment	–	–	–	–	–
b) Connected to I.+II. treatment	500	1642.5	20.5	574.9	19.6
c) Connected to sewerage without treatment	1289	5645.8	70.6	2217.0	75.5
d) Not connected, disposal into soil	219	700.2	8.9	143.9	4.9
e) Total	2008	7988.5	100.0	2935.8	100.0

Two sewage treatment plants – North Budapest and South Budapest – exist, with conventional mechanical-biological technology.

The specific discharge (emission factor) of P would be calculated today in Hungary as 4.5 g P/capita.d, or 1.64 kg P/capita.year, because of the detergent used that is not P free (SENATOR CONSULT, 1993). In the year 2000 the decrease of specific P discharge can be hypothesized as 3 g/capita.d, or 1.09 kg/capita.year, because of the P free detergent.

The specific discharge (emission factor) of N could be calculated as 12 g N/capita.d (KAYSER, 1991; SENATOR CONSULT, 1993), or 4.38 kg N/capita.year, both in the present and in the future.

The efficiency of P removal in the primary and secondary treatment can be calculated as 30% (OSZOLY et al., 1994), and in the soil this value can be about 60%. The efficiency of N removal in the primary and secondary treatment can be hypothesised as 25% (EMDE V.D. et al., 1990;

FLECKSEDER, 1990; ÖLLŐS, 1991), and in the soil this value can be estimated as 27%.

The total N and P discharge of Budapest by the population in present can be seen in *Table 3*.

2. The Costs of Reducing Nutrient Discharges by Population in Year 2000 at Different Scenarios

2.1. Scenarios

Harmonisation up to EU standards needs investments, and these solutions would mean significant costs. In this study there are analysed different scenarios of probable development, and their costs.

The investigated scenarios are the following:

1. **Autonomous development:** All inhabitants will be connected to sewerage, but new wastewater treatment capacity will not be built.
2. **Stand-still scenario:** All inhabitants will be connected to sewerage , but the nutrient pollutant discharge by population into surface water will not increase.
3. **25% emission reduction scenario:** 25% emission reduction of nutrient pollutants by population into surface water.
4. **50% emission reduction scenario:** 50% emission reduction of nutrient pollutants by population into surface water.
5. **Harmonisation up to EU standards scenario:** Sewerage and wastewater treatment capacity will be built by requirements of EU standards.

2.2. N and P Emissions by Population at Different Scenarios

2.2.1. Base Conditions

Probably the population in Budapest will decrease. Thus the probable value of population, by our estimation might be about **2 million inhabitants,** in the year 2000.

In the year 1993. 3707 km length sewer existed, 757.6 km length of this there were in separated system, and 2949.4 km in mixed system (KSH, 1994). Mainly separated system should be developed. It seems to be necessary to build about **550 km length new sewer** (50 km length of the main sewers in mixed system, 500 km length of branch sewers in separated system), **around 100 pump stations, and 30 km length**

pressure conduits to the year 2000 (BME, 1996). In this case will be possible to collect the wastewater to the WWTPs, and all the inhabitants of Budapest will have the possibility to connect to the sewerage system.

Table 4
Estimated nutrient discharge by population of Budapest in the year 2000, according to Scenario 1

Level of supply		Emission of TN		Emission of TP	
	th. PE	t/yr.	%	t/yr.	%
a) Connected to I.+II. + III. treatment	–	–	–	–	–
b) Connected to I.+II. treatment	500	1642.5	20.0	574.9	25.9
c) Connected to sewerage without treatm.	1500	6570.0	80.0	1642.5	74.1
d) Total	2000	8212.5	100.0	2217.4	100.0

2.2.2. N and P Emissions and Solutions of Reducing at Different Scenarios

1. Autonomous Development Scenario

In this scenario all the population of Budapest will be connected to sewerage, and new wastewater treatment capacity will not be built. The calculated P and N emissions by population are in *Table 4*.

Hypothesizing the P free detergent, the P emission would decrease 25%. The N emission would increase around 3% because of the effect of increased population connected to sewerage, without wastewater treatment.

2. Stand Still Scenario

In this scenario we hypothesize, that the nutrient emission will not increase. The limit factor is N, because of the P free detergent. In this case primary and secondary treatment with capacity of 215 thousand PE should be built.

The decrease of P discharge, caused by the new wastewater treatment capacity, and P free detergents can be 33.3%. The estimated values of N, P emission of this scenario are in *Table 5.*

3. 25% Emission Reduction of Nutrient Discharge Scenario

In this case the limit factor is the N too. To the 25% N reduction 1.5 million PE size primary and secondary new treatment and 300 thousand PE N elimination capacity should be built. In this scenario the P discharge is less with 53%, than in the present. The estimated nutrient discharge by population is in *Table 6.*

Table 5
Estimated nutrient discharge by population of Budapest in the year 2000, according to Scenario 2

Level of supply		Emission of TN		Emission of TP	
	th. PE	t/yr.	%	t/yr.	%
a) Connected to I.+II. + III. treatment	–	–	–	–	–
b) Connected to I.+II. treatment	715	2348.8	29.4	548.0	28.0
c) Connected to sewerage without treatm.	1285	5628.3	70.6	1407.1	72.0
d) Total	2000	7977.1	100.0	1955.1	100.0

Table 6
Estimated nutrient discharge by population of Budapest in the year 2000, according to Scenario 3

Level of supply	Emission of TN			Emission of TP		
	th. PE	t/yr.	%	th. PE	t/yr.	%
a) Connected to I.+II. + III. treatment	300	394.2	6.6	–	–	–
b) Connected to I.+II. treatment	1700	5584.5	93.4	2000	1533.0	100.0
c) Total	2000	5991.4	100.0	2000	1533.0	100.0

4. 50% Emission Reduction of Nutrient Discharge Scenario

In this scenario 1.5 million PE size new primary and secondary sewage treatment capacity, over it 1.3 million PE nitrification-denitrification, and 200 thousand PE chemical phosphorus elimination capacity in South Budapest WWTP are needed. The values of P, N emissions in this case are in *Table 7*.

Table 7
Estimated nutrient discharge by population of Budapest in the year 2000, according to Scenario 4

Level of supply	Emission of TN			Emission of TP		
	th. PE	t/yr.	%	th. PE	t/yr.	%
a) Connected to I.+II. + III. treatment	1300	1708.2	43.7	200	109.5	7.3
b) Connected to I.+II. treatment	700	2299.5	56.3	1800	1379.7	92.7
c) Total	2000	3907.7	100.0	2000	1489.2	100.0

5. Harmonisation up to EU Standards Scenario

This scenario gives very strict requirements. This would mean a demand for 1.5 million PE size new primary and secondary, 2 million PE nitrification-denitrification, and over it 2 million PE biological-chemical phosphorus elimination sewage treatment capacity. There is not any reality to build it until 2000. The significant investment of building 550 km sewer, around 100 pump stations, 30 km pressure conduits and a new wastewater treatment plant need phased implementation. The values of the estimated nutrient discharge by population are in *Table 8.*

Table 8
Estimated nutrient discharge by population of Budapest in the year 2000, according to Scenario 5

Level of supply		Emission of TN		Emission of TP	
	th. PE	t/yr.	%		
a) Connected to I.+II. + III. treatment	2000	1752.2	100.0	657.0	100.0

2.3 Costs of Different Scenarios

The specific costs are depending on the size of sewage treatment plant, and on the efficiency of the treatment processes (BARTHA, 1970; TIHANSKY, 1974; HAHN, 1983). We investigated the data of investment and operational costs of sewerage and sewage treatment in Hungary and in Austria (DULOVICS, 1991; NOWAK, 1991; HENZE et al., 1994). The Hungarian and Austrian specific investment cost data in ECU are very similar to each other, at the same conditions.

The total additional investment cost of sewerage and pump stations would be together 200 million ECU.

The investment costs of sewage treatment at different scenarios are in *Table 9.*

3. Discussion

The sewerage and wastewater treatment investments to meet EU standards – as is shown in *Table 9* – require tremendous capital in Budapest. The budgetary of the municipality cannot afford to make the needed investments, particularly over the next few years.

In general the affluent EU countries can yearly afford 0.5 – 1% of their own GDP to the investments of sewerage and wastewater treatment. This share in Hungary could be 12.5 – 25 ECU/capita.year. The harmonisation up to EU standards would need in the next five years about 150 ECU/capita.year – which sum is six – twelve times more than the possible. This is probably

Table 9
Investment costs in thousand ECU at different scenarios

Scenario	Investment	Capacity th. PE	Costs 106ECU
1	Sewerage*		200.0
2	Sewerage*		200.0
	Sewage treatment I.+II.	215	50.0
	Total		250.0
3	Sewerage*		200.0
	Sewage treatment I.+II.	1500	350.0
	N elimination	300	150.0
	Total		700.0
4	Sewerage*		200
	Sewage treatment I.+II.	1500	350.0
	N+P elimination	1300	610.0
	P elimination	200.0	20.0
	Total		1180.0
5	Sewerage*		200.0
	Sewage treatment I.+II.	1500	350.0
	N+P elimination	1500	700.0
	N+P elimination	2×250	260.0
	Total		1510.0

*Sewerage 550 km, pump stations 100 pieces, pressure conduits 30 km.

could not be fulfilled, or it needs six – twelve times longer period. Thus it is necessary to use phased implementation, multi-stage and cost-effective solutions with interim technologies. In a five year long investment phase the maximum capital cost can be around 125 – 250 million ECU.

That is a question – which needs further investigations – when will be needful to satisfy all the very strict requirements of EU standards at the Danube river which recipient has a high dilution of pollutants and a significant background pollution.

The requirements of EU standards can be fulfilled in the following steps:

– *First* of all it seems to be necessary to use up the existing sewage treatment capacity, and to connect mixed system main sewers and pressure conduits to the North Budapest WWTP (see Scenario 1). It can be suggested to test the applicability of low dosage chemical upgrading, a three-week full-scale test was performed adding 30 mg/l $FeClSO_4$ prior to the primary clarifier and one of two operating trains was overloaded by more than 60% (SOMLYÓDY et al., 1997). Effluent water quality remained unchanged (e.g. COD = 75 mg/l) except for TP and Cr, which improved significantly (TP = 2 mg/l). Under the same compressor operation as earlier, the oxygen level increased considerably in the experimental aeration tank. There was no detectable change in sludge production and pH values. The amount of $FeClSO_4$ used for sludge dewatering could be reduced, indicating the chemical usage within the plant can be further optimized (SOMLYÓDY, 1994).

The investment cost of implementation leading to a reliable interim technology for treating 220 – 250 thousand m^3/d wastewater (including additional dewatering facilities) is not more than a couple of million ECU. This should be contrasted to several hundred million ECU which is required for a harmonising plant up to EU standards (see *Table 9*).

– *Second step is:* to continue the implementation of mixed system main sewers and pressured conduits to the direction of the new 1.5 million PE size WWTP, and parallel with it to start the investment of 1.5 million PE size new WWTP in primary treatment, with interim chemical technology to solve the sludge dewatering and nutrient emissions reducing.

– *Third step is:* to complete the new 1.5 million PE size WWTP in biological treatment including the sludge treatment process, too.

In this step the separated system branches sewers can be developed (see Scenario 1).
Probably only these three steps can be implemented until 2010 (see Scenario 4). These can reduce the TP emission by 50%, and the TN emission by 30%.

– Thus the harmonisation up to EU standards can be only the *fourth step* and after the year 2010 (see Scenario 5). In this case the nutrient emission will be reduced with 78%.

4. Conclusions

Prescribed EU standards – in the field of sewerage and wastewater treatment – require significant investments in Budapest to the year 2000. This study analyses different scenarios and these investment costs in the reducing of effluent nutrient pollutants of population.

The maximum costs of nutrient elimination can be 1510 million ECU, in case of the harmonisation up to EU standards (Scenario 5). This scenario gives very strict requirements. This would mean a demand for 1.5 million PE size new primary and secondary treatment plant, 2 million PE nitrification-denitrification and over it 2 million PE biological-chemical phosphorus elimination sewage treatment capacity. There is no any reality to build this until 2000, but it is necessary to start, and design these in a phased, multi-stage fashion. It can be fulfilled in the following four steps;

⇒ The *first step* consists:
- the investment of the main sewers and pressure conduits in the directions of the North Budapest WWTP,
- the upgrading of the chemical P elimination in South, and North Budapest WWTPs, with interim technology.

⇒ The *second step* consists:
- the starting of investment in primary treatment of 1.5 million PE size new WWTP, with interim chemical technology,
- the continuing of mixed system main sewers and pressure conduits to the direction of the new WWTP.

⇒ The *third step* consists:
- the continuing of new 1.5 million PE size WWTP in biological treatment, including the sludge treatment process, too,
- developing of separated sewerage system, in order to connect the whole population of Budapest to the sewerage.

  Probably only these three steps can be realized until 2010 (see Scenario 4). This three steps can reduce the TP emission with 50%, and the TN emission with 30%.

⇒ Thus the harmonisation up to EU standards can only be the *fourth step,* and after the year 2010 (see Scenario 5). In this case the nutrient emission will be reduced with 78%.

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