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# Influence of extraneous waters on the quality and loads of pollutants in wastewater discharged into the treatment plant

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## Abstract

The aim of the study was to analyze an influence of an inflow penetrating into two selected small sewerage systems during a rainy weather on pollutant concentration and load in raw sewage. Studies were conducted in 2010–2015 on two small sewerage systems in Małopolska province. The studies confirmed that the inflow penetrating into the sewerage systems resulted in a decrease of pollutant concentrations in sewage. However, they also showed that this dilution was not constant for all types of pollutants. The most important outcome of the study was demonstrating that despite its diluting effect on pollutants, the intense inflow into a sewerage system resulted in an increase of a sewage pollutant load. This increase was not regular, but it was rising dramatically when the inflow share in sewage exceeded 50%. The study indicated that the inflow penetrating into the sewerage system should not be disregarded, as it actually presented a significant threat to the wastewater treatment process and in consequence to the quality of recipient waters.

**Key words:** *extraneous waters, i/i, sewage, sewerage system, wastewater treatment plant*

## INTRODUCTION

Deadline for implementing all assumptions included in the Directive 91/271/EEC concerning urban wastewater treatment of 21 May 1991 was 31 December 2015. Provisions of this document forced individual European Union Member States to undertake actions and investments aiming at organizing and improving the wastewater management. In Poland, under the National Programme for Municipal Waste Water Treatment [MŚ 2003] (as amended in 2009) a decision was made to build 177 new treatment plants and to refurbish or expand further 596 of such facilities. Construction of 30,641 km of new sewerage

systems and refurbishment of 2,883 km of already existing network were also declared. However, all actions undertook to improve wastewater management should not focus solely on construction of new and refurbishment of existing systems for wastewater collection and treatment. An issue of similar significance is maintaining required efficiency and reliability of operation in existing sewerage systems and treatment plants that have been in operation for a long time but do not qualify for refurbishment yet, for economic reasons [BAUMAN-KASZUBSKA, SIKORSKI 2009; BIELIŃSKA *et al.* 2014; CHMIEŁOWSKI *et al.* 2016; MLYŃSKI *et al.* 2016; PIASECKI, JURASZ 2015; ŚWIERK 2016]. For currently operated sewerage systems,

maintaining their required tightness and reliability of operation should be the top priority [MADRYAS *et al.* 2010]. The sewerage system tightness should be understood as its resistance to external (infiltration and inflow) waters input and possible wastewater exfiltration from collector sewers into the ground [KACZOR 2012; MADRYAS *et al.* 2010].

Infiltration waters are mainly groundwaters penetrating into the sewerage system through damaged pipes, their connections, and leaking chamber walls and bottoms [CIEŚLAK, PAWEŁEK 2014]. This flow occurs mainly when sewage pipes or other sewerage system components are installed below the groundwater table. However, more serious problems with operation of sewerage systems and wastewater treatment system result in the inflow penetrating into those facilities [DE BÉNÉDITTIS 2004]. The inflow is mainly precipitation (rain) or thaw waters penetrating into sewage pipes through chamber manholes or ventilation openings [KACZOR, BUGAJSKI 2012]. Another common source of the inflow are connections of roof gutters [BUTLER, DAVIS 2011], yard drains [KACZOR 2012], or a lot draining system [PECHER 1998] with house drains illegally constructed by house owners. During sewerage system operation, the inflow, present mainly during heavy rainfalls, results in sewage collector overflow, wastewater pump station overload, or even, in extreme situations, wastewater outflow from inspection chambers onto the ground surface [PECHER 1998]. The strongest negative inflow influence is associated with operation of wastewater treatment plants, in which sizes and capacities of individual technological facilities are not adapted to periodically increasing input. Also of importance is reduced pollutant concentration in wastewater as it is diluted with rainwater, and thus its content of organic substances required for development of microorganisms in activated sludge is lower [BUGAJSKI *et al.* 2016; KACZOR *et al.* 2015]. In consequence, the inflow influence on many aspects of wastewater treatment plant operation leads to periodic reduction in their efficiency, and therefore, to a risk of polluting receiving waters with insufficiently treated wastewater [KOWALIK *et al.* 2015].

The issue of the inflow in sewerage systems is often overlooked as sewerage system operators assume that it mainly dilutes wastewater flowing into and out of a wastewater treatment plant. This may result in a misleading confidence that this phenomenon does not have a negative effect on recipient waters or treatment plant operation. So far, no reports focused on changes in pollutant loads delivered to treatment plants and discharged into a recipient system during wet weather.

The aim of the study was to analyze an influence of the inflow penetrating into two selected small sewerage systems during rainy weather on pollutant concentration and load in raw sewage delivered to a treatment plant.

## DESCRIPTION OF THE STUDY OBJECT

Studies on the inflow influence on pollutant concentrations and load were conducted in 2010–2015 in two small sewerage systems in Małopolska province, located 20 km and 40 km from the center of Kraków. General description of the study objects is presented in Table 1.

**Table 1.** General characteristics of analyzed sewerage networks

Parameter	Sewer system	
	A	B
Sewerage network length excluding drains, km	5.2	15.2
Pipe material	earthenware	
Sewer system age, years	20	17
Number of connections, pcs	330	455
Number of inhabitants served	1485	2050
Annual share of inflow in wastewater discharged from the sewerage system, %	16.4	27.6
Mean daily sewage discharge in dry weather, $\text{m}^3 \cdot \text{d}^{-1}$	185.6	365.2
Maximum daily sewage discharge in rainy weather, $\text{m}^3 \cdot \text{d}^{-1}$	1045.0 22.05.2010	1728.0 22.05.2010

Source: own elaboration.

During heavy rainfalls, the inflow was discharged to both studied sewerage systems. The main sources of the inflow listed by the sewerage system operators included illegal connections of roof gutters or yard drains to house drains, and rain or thaw water penetrating through openings in chamber manholes. Due to their low table groundwaters could not infiltrate into the sewage collectors. Sewage from the sewerage systems A and B were discharged into mechanical and biological treatment plants of capacity of  $225 \text{ m}^3 \cdot \text{d}^{-1}$  and  $563 \text{ m}^3 \cdot \text{d}^{-1}$ , respectively.

## MATERIALS AND METHODS

Studies of daily sewage discharge from both sewerage systems were conducted from January 1, 2010 to December 31, 2015. At both facilities the discharged amount was measured with Ultrasonic Flow-Meters Hydro Ranger I over a triangular overflow. Sewage samples were collected upstream from grates, at the premises of the wastewater treatment plants to which the sewage from the studied sewerage system was delivered. All quality analyses of sewage were performed with reference methods in an accredited laboratory in Kraków. In the studied period, nearly 40 samples were collected in total for each facility during dry and wet weather (8 samples a year on average). The sewage samples were analyzed for pollutant indicators including: BOD<sub>5</sub>, COD, total suspended solids, total nitrogen and total phosphorus. Collected sewage samples were appropriately assigned to dry or to wet

weather. Days classified as dry were those with no precipitation on that day and on five days preceding it, or when any precipitation that occurred did not exceed 1 mm a day. Precipitation events were recorded with tipping buckets installed in the catchment area of the analyzed sewerage systems.

The average daily wastewater discharge from the sewerage system in a given year during dry weather was used to determine an average quantity of actual sewage, not containing the inflow. During the wet weather, a part of daily wastewater flow exceeding the assumed average actual sewage level was classified as the inflow. Therefore, in the wet weather the inflow volume on a relevant day was calculated according to formula (1).

$$Q_{di} = Q_{dw} - Q_{dd} \quad (1)$$

where:  $Q_{di}$  = daily inflow penetrating into a sewerage system,  $\text{m}^3 \cdot \text{d}^{-1}$ ;  $Q_{dw}$  = daily quantity of a mixture of actual sewage and an inflow delivered to a sewerage system during wet weather,  $\text{m}^3 \cdot \text{d}^{-1}$ ;  $Q_{dd}$  = daily quantity of a mixture of actual sewage (without an inflow) delivered to a sewerage system during dry weather,  $\text{m}^3 \cdot \text{d}^{-1}$ .

In the comparative analyses, a daily inflow volume delivered to a sewerage system is usually described by a percentage indicator called extraneous water share (SEW) [PECHER 1998]. A daily inflow share in a daily volume of actual sewage and inflow was calculated according to formula (2).

$$SEW = \frac{Q_{di}}{Q_{dw}} 100 \quad (2)$$

where:  $SEW$  = daily inflow share in sewage discharged from a sewerage system, %;  $Q_{di}$  = daily inflow penetrating into a sewerage system,  $\text{m}^3 \cdot \text{d}^{-1}$ ;  $Q_{dw}$  = daily quantity of a mixture of actual sewage and an inflow delivered to a sewerage system during wet weather,  $\text{m}^3 \cdot \text{d}^{-1}$ .

To evaluate how the daily inflow discharge influenced a concentration of selected pollutants, the values of inflow share and concentrations of individual pollutants were paired. Pollutant loads discharged from the sewerage system during dry and a wet weather were calculated using formula (3).

$$L_x = S_x Q_{dw} \quad (3)$$

where:  $L_x$  = mean daily load of a given pollutant  $x$ ,  $\text{g} \cdot \text{d}^{-1}$ ;  $Q_{dw}$  = daily discharge of a mixture of actual sewage and an inflow from a sewerage system,  $\text{m}^3 \cdot \text{d}^{-1}$ ;  $S_x$  = concentration (or value) of relevant pollution indicator  $x$ ,  $\text{g} \cdot \text{m}^{-3}$ .

## RESULTS AND DISCUSSION

At the first stage of the results analysis, distribution diagrams were plotted, showing a relationship between a percentage share of inflow in daily dis-

charge from a relevant sewerage system (SEW) and a value of a given pollution indicator. All samples from the whole study period were used in the analysis, not divided into years. Outliers or unreliable data were discarded. The relationship observed in the distribution diagram was described with a linear regression equation. A statistical distribution of analyzed variables was verified in terms of a possibility to use a regression analysis. An example of a relationship between the inflow share and  $\text{BOD}_5$  in the sewage discharged from the system A is shown in Figure 1. Equations for adjusted regression lines were used to present in Table 2 the values of five selected pollution indicators for the sewage discharged from the studied sewerage systems, depending on the SEW. The presented results confirmed previously reported observations indicating that the inflow (rain or thaw waters) usually reduced pollutant concentrations in sewage [PECHER 1998].

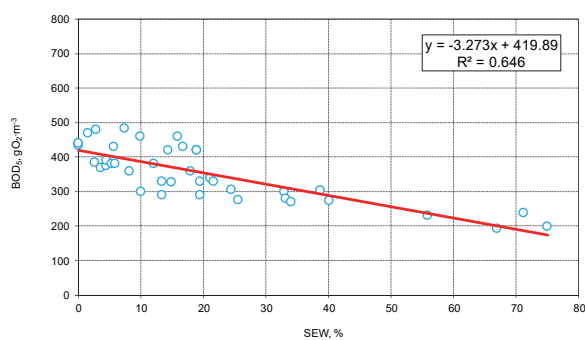


Fig. 1. A linear relationship showing an inflow share (SEW) influence on  $\text{BOD}_5$  in sewage discharged from the system A; source: own elaboration

In the sewerage system A, dilution of  $\text{BOD}_5$ , COD, total suspended solids (TSS) and total nitrogen was proportional to the inflow share. For example, when the inflow share in wastewater was 50% (i.e., the quantity of the inflow was equal to quantity of household wastewater), the values of  $\text{BOD}_5$ , COD, total suspended solids and total phosphorus were lower by 39%, 42%, 44%, and 43%, respectively (versus dry weather when  $SEW = 0\%$ ). For total nitrogen this relationship was different. This indicator was only slightly diluted and for  $SEW = 50\%$  it amounted only to 14%. This indicated a significant quantity of total nitrogen in the inflow. It could be washed out of green areas or crop lands, where it could be used as a component of natural or artificial fertilizers.

In the system B, pollutants were less diluted by the inflow than in the system A (Tab. 2). For example, when  $SEW = 50\%$ ,  $\text{BOD}_5$ , COD, TSS, and total phosphorus were reduced by 33%, 29%, 25% and 43% versus the dry period. It can therefore be assumed that the inflow brought certain quantities of pollutants, thus the wastewater was not diluted as much as in the system A. However, the observed total nitrogen dilution in this system was almost maximal, reaching nearly 49%.

**Table 2.** Effect of the inflow share (SEW) on the values of selected pollution indicators in raw sewage

SEW %	BOD <sub>5</sub> , g O <sub>2</sub> ·m <sup>-3</sup>		COD, g O <sub>2</sub> ·m <sup>-3</sup>		TSS, g·m <sup>-3</sup>		Total nitrogen, g N·m <sup>-3</sup>		Total phosphorus, g P·m <sup>-3</sup>	
	sewer system A	sewer system B	sewer system A	sewer system B	sewer system A	sewer system B	sewer system A	sewer system B	sewer system A	sewer system B
0	420	484	769	875	373	337	79.5	93.5	15.0	14.2
10	387	452	704	825	340	320	77.3	84.4	13.7	13.4
20	354	420	639	774	307	304	75.0	75.3	12.4	12.6
30	322	389	575	723	275	287	72.7	66.2	11.1	11.8
40	289	357	510	673	242	270	70.5	57.1	9.8	11.1
50	256	325	446	622	209	254	68.2	48.0	8.6	10.3
60	224	294	381	571	177	237	65.9	38.9	7.3	9.5
70	191	262	317	520	144	220	63.7	29.8	6.0	8.7
80	158	230	252	470	111	203	61.4	20.7	4.7	7.9

Explanations: BOD<sub>5</sub> = the 5 day biochemical oxygen demand, COD = chemical oxygen demand, TSS = total suspended solids.  
Source: own elaboration.

Using the values of five pollution indicators for different inflow shares in the sewage, pollutant loads discharged from the studied systems A and B were calculated. The results are presented in Table 3. To better depict the changes in pollutant concentrations and loads resulting from the inflow to the studied sewerage systems, the diagrams shown in Figure 2 were plotted.

The results shown in Figures 2 and 3, and in Table 3 clearly indicated that with an increase in the in-

flow share, the pollutant loads in the sewage discharged from the sewerage systems also increased. For example, when SEW = 50%, loads of individual pollutants in the system A increased in a range from 12% for total suspended solids to 72% for total nitrogen, versus the dry weather (when SEW = 0%). In the system B, for the same inflow share, the loads increased in a range from 3% for total nitrogen to 50% for total suspended solids.

**Table 3.** Effect of the inflow share (SEW) on the pollutant load in raw sewage

SEW %	BOD <sub>5</sub> , kg·d <sup>-1</sup>		COD, kg·d <sup>-1</sup>		TSS, kg·d <sup>-1</sup>		Total nitrogen, kg·d <sup>-1</sup>		Total phosphorus, kg·d <sup>-1</sup>	
	sewer system A	sewer system B	sewer system A	sewer system B	sewer system A	sewer system B	sewer system A	sewer system B	sewer system A	sewer system B
0	71.4	208.0	130.6	376.4	63.3	144.9	13.5	40.2	2.6	6.1
10	73.1	216.0	133.0	394.0	64.2	153.1	14.6	40.3	2.6	6.4
20	74.8	223.5	135.2	410.5	65.0	160.7	15.6	40.4	2.6	6.7
30	76.6	232.0	137.6	429.2	66.0	169.3	16.7	40.6	2.7	7.0
40	79.9	246.7	141.9	461.7	67.6	184.3	18.7	40.8	2.7	7.6
50	81.9	255.9	144.6	482.0	68.6	193.7	20.0	40.9	2.8	7.9
60	87.1	279.9	151.6	534.8	71.2	218.0	23.2	41.3	2.9	8.8
70	95.0	315.8	162.1	614.0	75.1	254.6	28.0	41.8	3.1	10.2
80	108.1	375.6	179.6	746.0	81.6	315.5	36.1	42.7	3.4	12.5

Explanations as in Tab. 2.  
Source: own elaboration.

In the diagrams, the dotted line indicates an assumed reference level at which the maximum reduction (dilution) of a given pollution indicator value would occur if the inflow was free of any pollutant.

The study results indicated the assumption that pollutants were diluted by the inflow during the wet weather was true, but this situation also resulted in increased pollutant loads delivered to wastewater treatment plants, and this must certainly affect effectiveness of those facilities. Research results reported by KACZOR [2012] indicated that during the inflow, wastewater that underwent the treatment process usually (though not always) contained lower concentrations but higher loads of pollutants discharged into receiving waters. As the load increase was not linear, it should be emphasized that when SEW exceeded 50%, the rise in loads was more intense than when

SEW was below this value. For example, in the system B, when SEW value rose from 50% to 60% (an increase by 10% only), loads of certain pollutants rose even by 25% (total suspended solids).

The analysis demonstrated that changes in total suspended solids and total nitrogen might vary, possibly depending on the inflow sources in different sewerage systems. The inflow could contribute to increased quantities of those pollutants, but in some cases they could be free of them and dilute them significantly.

The conducted studies confirmed that the inflow, though frequently dismissed by researchers, was a significant threat to the wastewater treatment process, and thus to quality of recipient waters. Therefore, when increased wastewater flow occurs during wet weather, activities aiming at elimination of causes

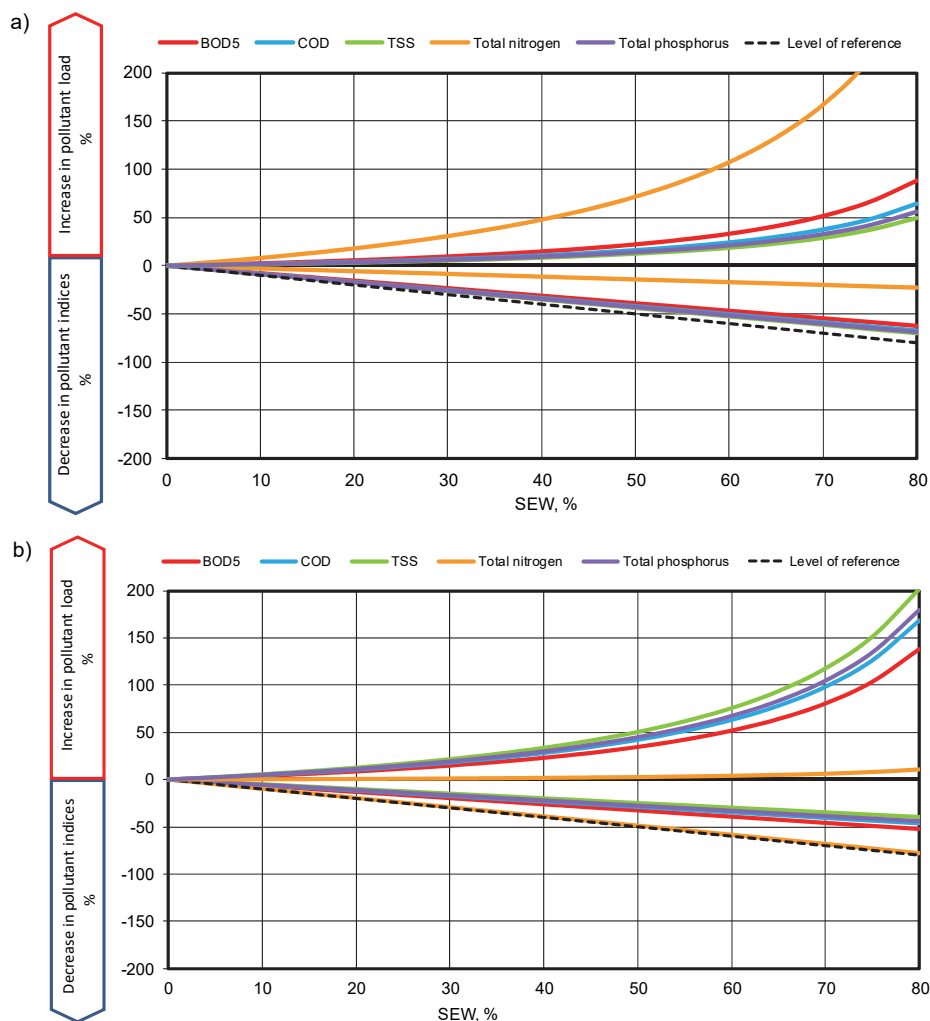


Fig. 2. Changes in concentrations and loads of selected pollutants for different inflow shares in the sewage discharged from a) the system A, b) the system B; BOD<sub>5</sub>, COD, TSS as in Tab. 2; source: own elaboration

of inflow or infiltration penetration into a sewerage system must be initiated immediately. This will improve the wastewater treatment plant effectiveness, and in consequence, quality of wastewater discharged into recipient water bodies.

### CONCLUSIONS

1. The study confirmed that the inflow into a sewerage system reduced concentrations of pollutants in sewage. However, this dilution was not constant for all types of pollutions, and it was not as strong as when clear water was used. Therefore, it can be concluded that the inflow carried certain quantities of additional pollutants.

2. The study also demonstrated that despite dilution of pollutants by the inflow flowing into the sewerage system, the pollutant loads in wastewater increased significantly. That increase was not linear, but happened rapidly when the inflow share exceeded 50%.

3. The study demonstrated that the inflow into the sewerage system was a significant threat to the waste-

water treatment process, and thus to quality of recipient waters. Therefore, when such inflow is found, effective activities aimed at its elimination should be initiated urgently. This will improve the wastewater treatment plant effectiveness, and in consequence, quality of wastewater discharged into recipient water bodies.



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### **Wpływ wód przypadkowych na zmienność stężeń i ładunków zanieczyszczeń w ściekach dopływających do oczyszczalni**

#### **STRESZCZENIE**

Celem badań było przeanalizowanie wpływu wód przypadkowych, dopływających do dwóch wybranych małych systemów kanalizacyjnych podczas pogody deszczowej, na stężenie i ładunki zanieczyszczeń w ściekach surowych. Badania prowadzono w latach 2010–2015 w dwóch małych systemach kanalizacyjnych funkcjonujących w województwie małopolskim. Przeprowadzone badania potwierdziły, że dopływy wód przypadkowych do kanalizacji powodują zmniejszenie stężenia zanieczyszczeń zawartych w ściekach. Jednakże rozcieńczenie to nie jest stałe w odniesieniu do wszystkich rodzajów zanieczyszczeń. Najważniejszym rezultatem badań było wykazanie, że – mimo rozcieńczenia ścieków – intensywny dopływ wód przypadkowych do kanalizacji sanitarnej powodował zwiększenie ładunków zanieczyszczeń w dopływie do oczyszczalni. Zwiększenie to nie było regularne, lecz gwałtownie przyrastające, gdy udział wód przypadkowych w ściekach przekraczał 50%. Wyniki badań wskazują, że dopływów wód przypadkowych do kanalizacji nie należy lekceważyć, gdyż stanowią one w rzeczywistości istotne zagrożenie dla procesu oczyszczania ścieków, a w dalszej kolejności – jakości wód w odborniku.

**Słowa kluczowe:** *kanalizacja, oczyszczalnia ścieków, ścieki, wody przypadkowe*