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THE EFFECT OF HEAVY PRECIPITATION ON THE INFILTRATION AND INFLOW INTO SMALL SEWAGE TREATMENT PLANTS IN 2010

Summary

The aim of the study was to determine the extent to which heavy rainfall, that occurred in 2010, affected the infiltration into the selected sewage treatment plants in the Małopolskie voivodeship. The research was conducted in four separate sewer systems, located in *poviats* adjacent to the city of Kraków, discharging sewage to mechanical-biological treatment plants with a capacity below 1000 $m^3 \cdot d^{-1}$. The amount of sewage and extraneous water in the average wet year (2008) were used as control.

As a result of heavy precipitation in 2010 the sewer system A received 18 539 m^3 more extraneous water than in 2008 (increase by 343%), the sewer system B – 22 822 m^3 (increase by 163%), the sewer system C – 109 715 m^3 (increase by 248%) and the sewer system D – 30 796 m^3 (increase by 303%). Heavy precipitation in 2010 caused the increase of infiltration and inflow by 264% on average in all studied sewer systems compared to the average wet year. As the result of precipitation, whose annual total in 2010 was higher by 65% than the normal value in 2008, there was an increase in the annual share of extraneous water from 5.3 to 19.7% depending on the facility.

The volume of extraneous water, which was discharged into the studied treatment plants in 2010 (the period of heavy rainfall), constituted the following share of the annual value: in the sewer system A – 41.3%, in the sewer system B – 21.2%, in the sewer system C – 14.4%, in the sewer system D – 22.9%.

Assuming the average gross amount of 3 PLN paid for treatment of 1 m^3 of sewage, cost of extraneous water disposal in 2010 amounted from 78 533 PLN to 552 165 PLN, depending on the facility.

The results obtained in the present study suggest that eliminating or reducing infiltration and inflow into the analyzed sewer systems would allow for large financial savings associated with reducing costs both for their transport and treatment as well as for modernization of facilities to enhance their hydraulic capacity.

Key words: sewage, sewer system, wet weather, infiltration/inflow, treatment plant

INTRODUCTION

The major purpose of the separate sewer system is to collect domestic, industrial and processed sewage from the settling unit, and discharge them. However, sewer systems also receive extraneous water known as infiltration and inflow, which may overload sewer lines, pump stations and treatment plants.

Inflow consists mainly of rainwater or snowmelt-water that enters the sewage manholes through ventilation openings or leaking sewer manhole covers [Michalska and Pecher, 2000; Kaczor, 2009]. Extraneous water contains not only runoff from roof or yard drains illegally connected into house drains, but also water intentionally or unintentionally directed into the sewer system [Karpf and Krebs, 2005].

Infiltration water consists mainly of groundwater flowing into the sewer system through damaged pipes, their connections, leaks through walls and bottoms of the sewer manhole chambers [Kuliczkowski et al., 2004; Ellis and Bertrand-Krajewski, 2010]. Sewer systems receive infiltration water when the pipes are located below groundwater table. Infiltration into the sewage collectors increases after heavy rainfall events and is the highest in early spring and late autumn due to high groundwater levels.

Infiltration and inflow adversely affects functioning and operation of both sewer systems and treatment plants. During heavy rains, gravitational sewer systems, filled with mixtures of sewage and extraneous water, may be hydraulically overloaded, resulting in periodic functioning under pressure conditions. This causes unsealing of pipe connections and - in extreme cases - outflow of pollution into the surface through the well manholes.

Infiltration and inflow cause dilution of pollutants in the sewage incoming to the treatment plant. This also has adverse effects on biological processes occurring in bioreactors [Pecher 1998]. Sewage inflow, increased by extraneous water, reduces the efficiency of mechanical equipment of treatment plants (sand separators, initial and secondary settling tanks), where it is important to maintain constant flow rates and sewage retention time. Extreme sewage and extraneous water flows may result in the washout of activated sludge from the bioreactor chambers and washout of excess sludge from secondary settling tanks. Increased amount of extraneous water resulting from snowmelt in spring also contributes to the drop in sewage temperature, which inhibits biological processes associated with removal of nitrogen and phosphorus compounds.

The increase in operating costs related to energy consumption for transport and aeration of a mixture of sewage and extraneous water is a very significant factor associated with infiltration and inflow into the sewer system [Kaczor and Satora, 2003].

The amount of infiltration and inflow into the sewer system largely depends on the frequency and intensity of precipitation, snow thickness and the intensity of spring snowmelt.

Over the past decade the highest annual precipitation was observed in 2010. According to Kaczorowska's classification [1962], the year 2010 was evaluated as extremely wet with the highest precipitation observed in May (with the total annual precipitation of 1021 mm [Concise Statistical Yearbook, 2011]). Total precipitation in May (with 28 rainy days [Powódź..., 2011]), averaged for Nowy Sącz, Tarnów, Kraków and Zakopane, reached 306.5 mm. Total precipitation in May 2010 in the Małopolskie voivodeship represented 352% of the monthly amount over the multi-year period. Total precipitation in Kraków in May 2010, amounting to 302.4 mm, was four times higher than the standard amount of 73.6 mm [Powódź..., 2011].

These extreme weather conditions caused two floods in the Małopolskie voivodeship: from May 14th to June 3rd and from June 4th to July 2nd. The flood directly affected 61 of 182 communes of the Małopolskie voivodeship. A total of 50.4 thousand ha were flooded, i.e., 3.3% of the total area of the voivodeship. The flood damaged 218 sewer system facilities and devices, 73 sewage treatment plants, 199 km of sanitary sewer system and 56 km of storm sewer. Financial losses in sewer infrastructure were estimated at over PLN 36.6 million [Powódź..., 2011].

Many sewage treatment plants and sewer network facilities, although not located directly in the flooded areas, were affected by heavy precipitation that occurred in 2010 – because of increased amount of infiltration and extraneous water incoming to the sewer systems. Favorable conditions for water infiltration into the sewer systems remained for a long time after the precipitation due to high groundwater tables.

AIM, SCOPE AND METHODS OF RESEARCH

The aim of the study was to determine the extent to which heavy rainfall that occurred in 2010 affected the amount of infiltration into the selected sewage treatment plants in the Małopolskie voivodeship.

The research was conducted in four separate sewer systems, located in poviats adjacent to the city of Kraków, discharging sewage to mechanical-biological treatment plants with a capacity below 1000 $m^3 \cdot d^{-1}$ and PE (population equivalent) below 2000. The analyzed sewer systems receive mainly domestic sewage from detached house estates and a negligible part of industrial sewage from small manufacturing or service companies.

As requested by the management of the described facilities, who provided data for the research, the names of towns and studied facilities have been omitted.

The basic parameters characterizing the studied sewage collection and treatment systems are summarized in Table 1.

Table 1. Basic parameters of the studied systems of sewage collection and treatment

Symbol of the sewer system	Material, which the sewer system is built of	Length of the system (without discharges), [m]	Pipe diameters, [mm]	Type of treatment plant	Average daily flow at dry weather [$m^3 \cdot d^{-1}$]
A	Stoneware	5 150	200 – 250	A2O	181.3
B		10 000	250 – 400		274.4
C		22 000	250 – 300		500.8
D	PVC	36 000	200 – 400	SBR	302.2

The study included daily sewage flows for the three calendar years: 2008, 2009 and 2010. Based on annual total precipitation and classification of Kaczorowska [1962], the year 2008 may be considered normal in terms of wetness (93.5% of the average total precipitation of a multi-year period), 2009 – as wet (111.0% of the average total precipitation of a multi-year period), while 2010 – as extremely wet (154.2% of the average total precipitation of a multi-year period). The average total precipitation for Krakow, over a multi-year period of 1971–2000, is 662 mm [Concise Statistical Yearbook, 2011]. Analysis of extraneous water received by sewer systems over the studied three-year period enables determining the variability of infiltration and inflow with different total annual precipitation.

Daily precipitation was measured with impulse precipitation sensors equipped with tipping-buckets installed at the four analyzed sewage treatment plants.

Daily amount of sewage and extraneous water in each treatment plant was measured with ultrasonic level controllers Hydro Ranger I (Milltronics) and MSP-USTD1 (Mobrey).

In the presented research the amount of infiltration and inflow was analyzed altogether, because with heavy rains it is practically impossible to separate the volume of inflow, penetrating into the sewer system from the surface, from groundwater infiltration.

The volume of infiltration and inflow was calculated by comparing daily sewage amount received by the treatment plant at dry and wet weather.

When the daily amount of precipitation did not exceed 1 mm and the last precipitation event (higher than 1 mm) occurred no later than 5 days before the analyzed period, the weather was considered dry.

It was assumed that the amount of sewage (excluding extraneous water) was described by the average daily inflow to the treatment plant at dry weather. Under this assumption, each daily amount of sewage, greater than the value calculated for dry weather, contains a certain volume of extraneous water. The daily amount of extraneous water, per each day of the year, was determined based on the difference between the daily discharge to the treatment plant and the average daily value calculated for dry weather.

The annual share of infiltration and inflow into the treatment plants was calculated based on the formula (1) [Pecher, 1998]:

$$UWO = \frac{Q_o}{Q} \cdot 100 \quad [\%] \tag{1}$$

where:

- Q_o – annual amount of extraneous water (infiltration and inflow) received by the treatment plant, m^3,
- Q – total annual amount of sewage and extraneous water received by the treatment plant, m^3.

The share of infiltration and inflow in the daily amount of sewage received by the treatment plant was calculated based on the formula (2) [Pecher, 1998]:

$$DWO = \frac{Q_o}{Q_{bd}} \cdot 100 \quad [\%] \tag{2}$$

where:

- Q_o – annual amount of extraneous water (infiltration and inflow) received by the treatment plant, m^3,
- Q_{bd} – annual amount of sewage received by the treatment plant (excluding extraneous water), m^3.

The calculated share of extraneous water (the value is always less than 100%) indicates the percentage of infiltration and inflow in the annual sewage amount received by the treatment plant. On the other hand, the value of extraneous water supplement indicates the percentage of annual increase in the amount of sewage flowing into the treatment plant resulting from infiltration and inflow. The value of extraneous water addition may be, and often is, greater than 100%.

ANALYSIS OF RESULTS

Table 2 summarizes the calculated annual amount of sewage and extraneous water received by the analyzed treatment plants in 2008, 2009 and 2010. The amount observed in 2008 (average wet year) was used as control.

Table 2. Annual amount of sewage and extraneous water (infiltration and inflow) received by each sewer system

Sewer system	Year	Annual amount of sewage and extraneous water [m^3]	Annual amount of sewage [m^3]	Annual amount of extraneous water [m^3]	Share of extraneous water [%]	Supplement of extraneous water [%]
A	2008	79288	71649	7639	9.6	10.7
	2009	84176	69437	14739	17.5	21.2
	2010	95007	68829	26178	27.6	38.0
B	2008	117350	81293	36057	30.7	44.4
	2009	159094	107459	51635	32.5	48.1
	2010	163778	104900	58878	36.0	56.1
C	2008	244348	170008	74340	30.4	43.7
	2009	297120	183086	114034	38.4	62.3
	2010	367381	183326	184055	50.1	100.4
D	2008	117323	102134	15189	12.9	14.9
	2009	148321	108383	39938	26.9	36.8
	2010	143198	97213	45985	32.1	47.3

In 2008 extraneous water constituted 9.6% of annual sewage inflow to the sewer system A, 30.7% - to the sewer system B, 30.4% - to the sewer system C, and 12.9% - to the sewer system D (Table 2). As a result of heavy precipitation that occurred in 2010, the sewer system A received 18 539 m^3 more extraneous water than in 2008 (increase by 343%), the sewer system B – 22 822 m^3 (increase by 163%), the sewer system C – 109 715 m^3 (increase by 248%), the sewer system D – 30 796 m^3 (increase by 303%). Compared with the average wet year, the amount of infiltration and inflow into all studied sewer systems increased on average by 264%.

In 2010 the volume of extraneous water accounted for 27.6% of annual sewage amount received by the sewer system A and even 50.1% of annual sewage amount received by the sewer system C. Thus, the 65% increase in the total annual precipitation caused the increase of extraneous water share in the range from 5.3 to 19.7%.

The volume of infiltration and inflow into the sewer system often depends on the length of the sewer network. Given this relation, the daily amount of extraneous water per 1 km of the sewerage network was calculated for each of the analyzed facilities. In 2008 the calculated amounts ranged from 1.2 $m^3 \cdot d^{-1} \cdot km^{-1}$ in the sewer system D to 9.8 $m^3 \cdot d^{-1} \cdot km^{-1}$ in the sewer system B. In 2010 these values increased and ranged from 3.5 $m^3 \cdot d^{-1} \cdot km^{-1}$ in the sewer system D to 22.9 $m^3 \cdot d^{-1} \cdot km^{-1}$ in the sewer system C.

Analysis of precipitation data from the sensors installed in the sewage treatment plants showed that total precipitation in May ranged from 219.6 mm in the drainage basin of the sewer system C to 404.7 mm in the sewer system D.

These values accounted for 23.8% of the total annual precipitation in the sewer system C and 31.1% of the total annual precipitation in the sewer system D.

Figure 1 compares the share of infiltration and inflow in monthly amount of sewage received by the analyzed treatment plants in May 2008 and in May 2010. Monthly amount of extraneous water received by each sewage treatment plant in May 2010 represented the following share in the total annual infiltration and inflow: 41.3% in the sewer system A, 21.2% in the sewer system B, 14.4% in the sewer system C and 22.9% in the sewer system D.

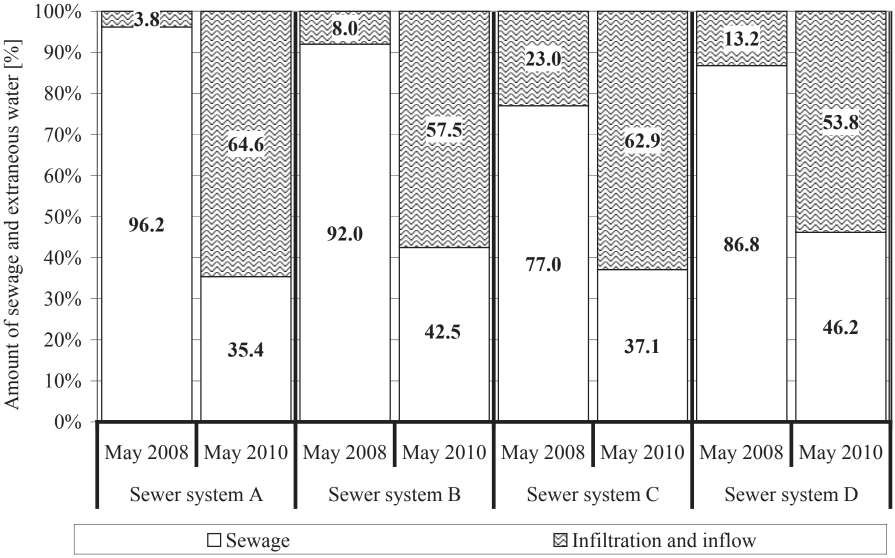

Figure 1. Comparison of infiltration and inflow amounts in a monthly sewage amount received by the analyzed sewer systems in May 2008 and 2010

The presented results indicate that the annual and monthly sewage amount received by the analyzed treatment plants in 2010 was increased by an enormous amount of water, which by definition did not require any treatment. This was reflected in the corresponding increase in operating costs incurred for transport and aeration of a mixture of sewage and extraneous water. Assuming the average gross cost of 3 PLN for 1 m^3 of sewage treatment – in 2010 the disposal of extraneous water cost 78 533 PLN in the facility A, 176 635 PLN in the facility B, 552 165 PLN in the facility C and 137 956 PLN in the facility D. These are considerable amounts.

The problem of extraneous water in the separate sewer system was strongly underestimated in recent years in Poland, as the share of infiltration and inflow in dry years was rather small. However, the year 2009, classified as wet, and the extremely wet year 2010 showed that extraneous water may constitute even 50% of the annual amount of sewage received by the treatment plant. Two of the analyzed treatment plants were intended for modernization to improve their hydraulic capacity. The presented results indicate, however, that eliminating or reducing the amount of extraneous water would allow operation of these facilities at their current capacity. Obviously, sealing and renewing of the sewer network is very expensive, but extraneous water often enters sewer systems through illegal connections or improperly built sewer manhole covers. In the first place, elimination of these reasons and inspection of sewer systems using video technology and then removing the local damage to the network or network facilities may cause significant improvement.

CONCLUSIONS

1. As a result of heavy precipitation in 2010 the annual amount of infiltration and inflow into the analyzed sewage treatment plants was from 163 to 343% higher than in 2008 (average wet year).
2. In the extremely wet year 2010 the volume of extraneous water in the annual sewage amount received by the analyzed sewer systems reached from 27.6% (facility A) to 50.1% (facility C).
3. In 2010 the highest monthly total precipitation was observed in May (404.7 mm). The volume of extraneous water, which entered each treatment plant that month, represented the following share of the total annual amount: 41.3% in the sewer system A, 21.2% in the sewer system B, 14.4% in the sewer system C and 22.9% in the sewer system D.
4. Assuming the average gross cost of PLN 3 for 1 m^3 sewage treatment – in 2010 the disposal of extraneous water cost from PLN 78 533 to 552 165, depending on the facility.
5. The results obtained in this study indicate that elimination or reduction of infiltration and inflow into the analyzed sewer systems would allow for large financial savings associated with reducing costs both for their transport and treatment as well as for modernization of facilities to enhance their hydraulic capacity.

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