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THE PROBLEM OF EXTRANEOUS WATER IN SANITARY SEWER SYSTEMS IN POLAND AND FRANCE

Grzegorz Kaczor[1], Léo Pujol[2], Błażej Stęplewski[1]
[1]Uniwersytet Rolniczy im. H. Kołłątaja w Krakowie
[2] National Engineering School in Water and Environment of Strasbourg (ENGEES)

Abstract

The objective of this research was to compare the amount of extraneous water flowing into selected gravitational separate sewer systems which discharge domestic sewage from the settlement of single-family houses in Poland and France during a year with a standard annual amount of precipitation. The study included a total of four sewer systems, including two operating in Poland and discharging the sewage from settlements near Krakow in the Malopolska Province and two systems operating in France and discharging the sewage from settlements of single-family houses near Lorient, Brittany, Morbihan Department. As part of the analysis, an average daily tributaries of extraneous water into sewers under the research, values of addition and share of this water were compared. Analysis of the research results demonstrated that the hydraulic load of sewer systems with extraneous water does not depend on the age of the sewer system, but mainly on the number of house drains, and to a lesser extent its length. It was also determined that the average daily amount of extraneous water flowing into sanitary sewer systems in wet weather is 0,107 $m^3 \cdot d^{-1}$ per 1 sewer connection. The study showed that tributaries of extraneous water into the separate sewer system occurring during the intense precipitation are a major operating problem both in Poland and France.

Key words: sewage, sewer system, i/i, extraneous water

INTRODUCTION

The implementation of Directive 91/271/EEC of 21 May 1991 started general efforts aimed at setting in order the wastewater management in countries of the European Union. €14 billion was allocated for this purpose in the years 2007-2013. In the existing EU Member States (EU-15) with the participation of this support good standards of waste treatment were maintained and the situation in terms of the protection of the so-called sensitive water resources was improved. While in new Member States (EU-12), first and foremost, the condition of technical infrastructure used for the disposal and treatment of the sewage was thoroughly improved. In Poland, as part of the National Programme for Municipal Waste Water Treatment (2003-2015), a number of measures was taken, most important of which involved the modernization or construction of 1163 sewage treatment plants for the disposal of municipal waste. The last update of the above mentioned programme carried out in 2015 adopts the construction of 119 new sewage treatment plants, including 91 after 2015 (Krajowy Program Oczyszczania..., 2015). All newly built and modernized sewage treatment plants are prepared for biological removal of biogenic compounds. In France, after the introduction of Directive 91/271/EEC there was observed an increase by 72% of the sewage discharged to mechanical and biological sewage treatment plants in the years 1992-2005. Since 2007, 146 major sewage treatment plants in France are included in the government project, within which these facilities began to be adapted to the current requirements. There were difficulties with the implementation of the objectives of Directive 91/271/EEC in France and Poland which is confirmed by the fact that in 2014 still 3260 sewage treatment plants out of a total number of 19,688 did not meet established requirements for their effective operation. In 2009 alone, €2.6 billion was allocated for the development of wastewater management, of which more than €1.9 billion were funds intended for the sewage treatment (www.developpement-durable.gouv.fr; www.planetoscope.com).

All activities taken in Poland and France in order to protect the quality of surface and ground water should not, however, focus exclusively on the construction of new and modernization of existing systems for sewage disposal and treatment. It is equally essential to keep the appropriate effectiveness and reliability of the operation of sewer systems and sewage treatment plants already existing but not yet economically eligible for the modernization. With regard to the existing sewage treatment plants, one should have in mind maintaining the proper technical condition of all mechanical as well as structural equipment of these facilities and acquiring planned effectiveness of removing individual pollutants. While in the case of existing and operating sewer systems their tightness and required capacity should be maintained. The aspect of tightness is understood as the protection of sewer channels against tributaries of infiltrating water and possible exfiltration of wastewater from their interior as well as the ongoing elimination of potential sources of extraneous water (Pujol, 2017).

Infiltration (*French: d'infiltration*) means tributaries of mainly ground water to the sewer system caused by a damage of pipes, their connections and leaky walls and bottom of the sewage well (Pujol, 2017). Tributaries of infiltrating water to the sewer system occur when pipes are arranged below groundwater table. The intensity of the flow of infiltrating water to sewer channels is directly proportional to the height of water column above the pipe (Madryas and all, 2010). Tributaries of infiltrating water into sewage collectors gain in strength after intense precipitation and are the largest in the early spring and late autumn due to the high position of groundwater table (Błażejewski, 2003).

Exfiltration (*French: exfiltration*) is defined as underground sewage outflow from sanitary sewer systems or sewage wells as a result of damaged or leaky connections of individual elements of the sewer system (Ellis and Bertrand-Krajewski, 2010).

Serious problems in the operation of sewer systems, and particularly sewage treatment plants are due to tributaries of extraneous water (De Bénédittis, 2004). Extraneous water (*French: eaux parasites / eaux accidentel*) is mostly rainwater (rain or snowmelt) penetrating into sanitary systems through manhole covers of sewage wells or illegally introduced into the sewer system by inhabitants through the inclusion of the gutter outlets (Butler and Davis, 2011), yard drains (Kaczor, 2012) or drainage outlets used for drainage of water from the property to house drains (Pecher, 1999). Extraneous water also includes water directed into the sewer system, intentionally or unintentionally, discharged during construction or renovation works, cooling water as well as water penetrating into the sewer system through manhole covers after washing streets or vehicles (Strategien ..., 2005).

During the operation of sewer systems, extraneous water most often occurs in the course of intense precipitation and causes overflow of channels, overload of sewage pumping stations, periodic flow of the sewage in gravitational channels under pressure conditions or in extreme situations even a flow of the sewage out of sewage wells on the land surface. Extraneous water has the most negative impact on sewage treatment plants. Primarily, it is the cause of hydraulic overloads of technological equipment of sewage treatment plants such as grids, sand separators, primarily and secondary settlement tanks. It also affects negatively the operation of biological reactors causing decreased temperature of the sewage (especially when the snow melts) and reduces the retention time of the sewage in individual chambers or zones of the reactor. Not without significance is also lowering concentrations of pollutants in the sewage by their dilution with rain water, thus their depletion in substances necessary for the growth of microorganisms of the activated sludge (Kaczor *et all.*, 2015). The influence of extraneous water on numerous aspects of the functioning of the sewage treatment plant consequently leads to reduced effectiveness of its operation, and thus is a significant risk for the water quality of the sewage receiver.

In recent years, the problem of extraneous water has lost some of its importance both in Poland and France due to the presence of chiefly dry or average years, characterized by a relatively low annual sum of precipitation. The amount of extraneous water flowing into the sewer system during the year is highly correlated with the intensity and frequency of precipitation which in recent years occurs less common, but can be very intense (Kaczor, 2011; Ziernicka-Wojtaszek i Kaczor, 2013). Intense precipitation results in strong, but short-term hydraulic overloads of the sewage treatment plant. In such situation technological facilities of the plant are protected by throttling the flow of the sewage. In the short term, such actions with the appropriate retention of channels can to some extent protect especially small facilities from the maximum flows (Kaczor, 2012).

There are performed many activities in Poland and France aimed at eliminating or at least limiting the flow of extraneous water into the sewer system (Monnier, 2006; Cieślak and Pawełek, 2014). The most common are smoke tests, dye tests, water or air tightness tests, thermal performance, soundproof, ultrasonic and geoelectric tests as well as detailed inspections of the channel interiors using modern automatically controlled video cameras. As part of the exchange of experience and knowledge as well as Polish and French research it was undertaken to compare in this paper the amount of extraneous water flowing into sewer systems used for discharging sanitary sewage from the settlement of single-family houses in Poland and France.

OBJECTIVE, SCOPE AND METHODOLOGY OF RESEARCH

The objective of this research was to compare the amount of extraneous water flowing into selected gravitational separate sewer systems which discharge domestic sewage from the settlement of single-family houses in Poland and France during a year with average annual amount of precipitation.

In view of the fact that the volume of extraneous water flowing into sanitary sewer systems depends largely on the annual sum of precipitation, it was decided that the comparative analysis will be based only on years characterized by a standard annual sum of precipitation as the most frequently occurring. Humidity of a given year was estimated on the basis of the criterion of Kaczorowska (1962) with mean annual precipitation totals from the years 1991-2015 This archival data was used to determine the extent of an annual amount of precipitation at which a given year can be assessed as an average wet one. In case of Krakow, a year is considered as an average when the annual amount of precipitation is between 90 – 110% of the mean annual precipitation from the years 1991-2015 amounting to 662 mm, that is in the range from 596 to 728 mm. Research of the overload of sewage systems with extraneous water was carried out in Krakow from 2000 to 2015. During this period, a year average humidity whose total annual precipitation is from 90 to 110% of the average mean annual precipitation occurred 7 times, which is at a frequency of every 2.3 year. An average annual precipitation for France has been obtained from online database (www.currentresults.com/Weather/France/average-yearly-precipitation.php). For the region of Lorient analyzed in the following paper this value is 951 mm. Therefore, for the analyzed area of France the year in terms of precipitation can be considered as an average if its total annual precipitation is in the range from 856 to 1046 mm.

The annual volume of extraneous water was determined based on the difference of domestic sewage outflow from sewer systems under the research during dry and wet weather.. A daily sewage outflow was classified to dry weather if in that day and five previous days there was no precipitation or it occurred, but its daily amount did not exceed 1 mm.

The average daily outflow of the sewage from the sewer system during dry weather was used to determine the average amount of the proper sewage (not including extraneous water). Due to the fact that in dry weather the daily outflows of the sewage were subject to cyclical weekly fluctuations, it was assumed that the maximum daily outflow of the sewage during this period is equal to the average value increased using standard deviation. A value calculated by means of this method represented the limit above which the sewage outflow contained only extraneous water. Such calculations were carried out separately for each of 4 facilities under research.

In comparative analyses the amount of extraneous water flowing into the sewer system is expressed most often using two indicators represented in percentage value: extraneous water share and extraneous water addition (Pecher, 1999). Extraneous water share (*SEW*) in the daily inflow to the sewer system can be computed using the following formula:

$$SEW = \frac{Q_{dew}}{Q_d} \cdot 100 \quad [\%] \tag{1}$$

where:

Q_{dew} – daily inflow of extraneous water to the sewer system [$m^3 \cdot d^{-1}$],

Q_d – total daily inflow of the sewage and extraneous water to the sewer system [$m^3 \cdot d^{-1}$].

Extraneous water addition (*DWP)* to the daily inflow to the sewer system is calculated using the following formula:

$$AEW = \frac{Q_{dew}}{Q_{ds}} \cdot 100 \quad [\%] \tag{2}$$

where:

Q_{ds} – daily inflow of the sewage to the sewer system in dry weather [$m^3 \cdot d^{-1}$].

SEW and AEW parameters are used as standard to compare the overload with extraneous water of various sewer systems.

DESCRIPTION OF SUBJECT OF RESEARCH

The research included separate sewer systems made of the same material and discharging domestic sewage from the settlement of single-family houses. There were difficulties in finding facilities operating for a similar period of time as well as serving a similar number of inhabitants. However, bearing in mind that extraneous water is not directly associated with the age of the sewer system, but mainly its length and a number of house drains, two sewer systems operating in Poland and discharging the sewage from settlements near Krakow in the Malopolska Province and two systems operating in France and discharging the sewage from settlements of single-family houses near Lorient, Brittany, Morbihan Department were ultimately chosen for the research (fig. 1).

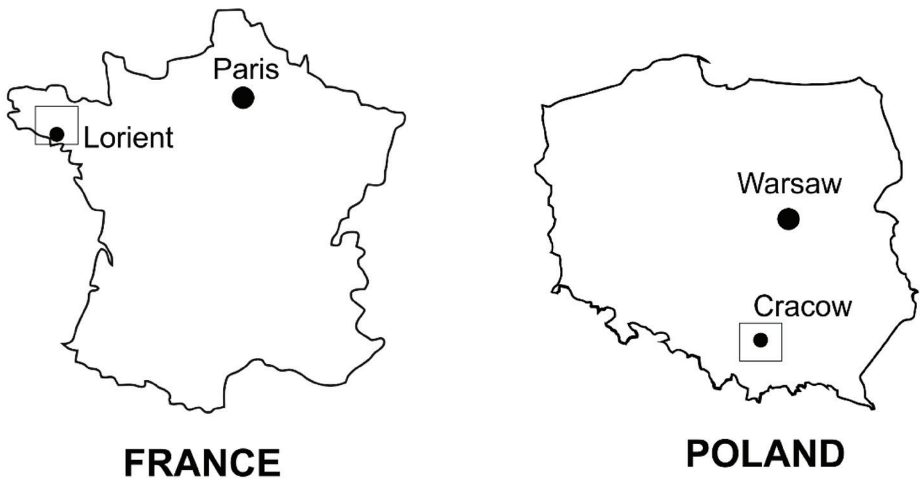

Figure 1. Location of sewer systems under the study in France and Poland

General characteristics of sewer systems analysed comparatively are presented in Table 1. The longest of the analysed sewer systems is the one in Keryado (France), while the shortest is in Bielany (Poland). Sewer systems included in the study are operated for 17 years (Wadów) up to 47 years (Keryado and Bois-du-Château). The greatest number of houses is operated by the sewer system in

Keryado (3 309), while the smallest number in Bielany (330). Sewer systems in French were characterized by the greatest daily flow of the sewage in dry weather ranging from 1175 $m^3 \cdot d^{-1}$ in Keryado to 1138 $m^3 \cdot d^{-1}$ in Bois-du-Château. In Polish sewer systems included in the analysis a daily flow of the sewage in dry weather ranged from 182 $m^3 \cdot d^{-1}$ in Bielany up to 469 $m^3 \cdot d^{-1}$ in Wadów. All sewer systems under the research are made of stoneware.

Table 1. General characteristics of sewer systems under the study in France and Poland

Location / Parameter	Keryado (near Lorient)	Bois-du-Château (near Lorient)	Wadów (near Krakow)	Bielany (near Krakow)
Length [km]	36	17	22	10
Material [–]	Stoneware	Stoneware	Stoneware	Stoneware
Exploitation time [years]	47	47	17	61
Number of houses [–]	3 309	2 492	730	330
Number of inhabitants [–]	11 581	8 720	3 650	1 485
Average flow in dry weather [$m^3 \cdot d^{-1}$]	1175	1138	469	182

RESEARCH RESULTS AND DISCUSSION

Analysis of the results was based on data covering daily outflow of the sewage from individual sewer systems and precipitation data. The first stage of the research involved periods of dry weather, including information on daily amount of precipitation. Then, the average daily flow of the proper sewage (not including extraneous water) was calculated for these periods. Subsequently, on the basis of the calculation procedure described in the methodology of the research the daily outflows of the proper sewage and extraneous water were determined for each facility under the research. Exemplary result of the calculation for the sewer system in Wadów (Poland) is presented in Fig. 2. Black colour indicates a daily inflows of extraneous water to the sewer system, while white colour shows a daily inflows of domestic sewage.

Detailed results of the calculation of the average daily outflows of the sewage, extraneous water and their share and addition in daily flows for the year with the average annual amount of precipitation are presented in the Table 2. Relevant in the context of this analysis values of share (SEW) and addition (AEW) of extraneous water turned out to be very similar for all facilities under the study. The greatest amount of extraneous water during the year with a standard annual sum of precipitation reached the sewer system in Keryado (annually 21.5% of the outflow from this sewer was extraneous water). Whereas the smallest amount of extraneous water during (annually 15.7% of the outflow from this sewer was extraneous water) in the year with the average amount of precipitation reached the sewer system in Wadów. While calculated and presented in Table 2 values of addition of extraneous water indicate the percentage increase of the sewage outflow from a given sewer system during wet weather in relation to the sewage outflow from this sewer during dry weather. Achieved results show that it increased in Keryado by 27.5% in relation to the flow in dry weather, while in Wadów only by 17.5%.

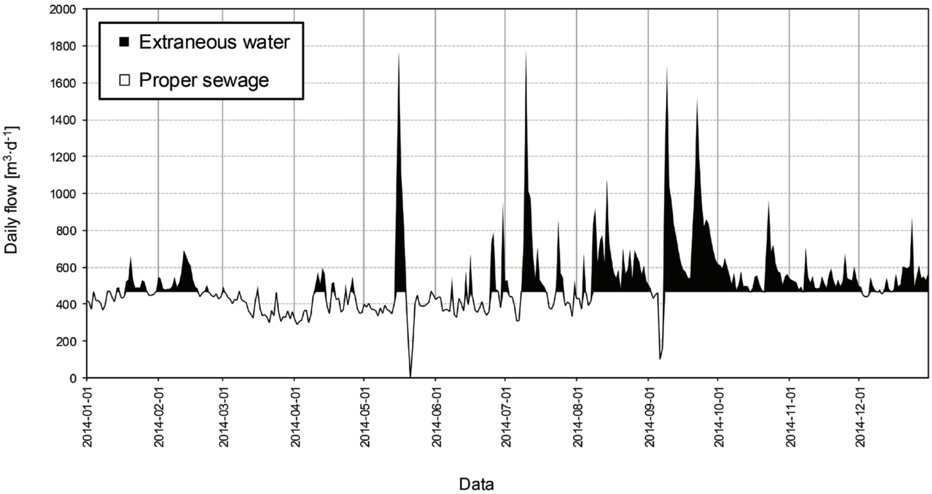

Figure 2. Proper sewage and extraneous water in the daily outflow from the sewer system in Wadów in 2014

To sum up this part of the analysis, it can be stated that all four tested sewer systems are in a similar degree loaded with extraneous water during intense precipitation. There is also a visible and strong correlation which indicates that the amount of extraneous water increases with the length of the sewer system (correlation coefficient R = 0.71) and the number of house drains (correlation coefficient R = 0.99). Having in mind achieved correlation dependence it was attempted to determine indicative unit values such as the amount of extraneous water in relation to 1 km of the sewer system and the amount of extraneous water in relation to 1 sewer connection. Calculation results are presented in Table 3. Results summarized in Table 3 clearly indicate that the amount of extraneous water flowing into sewer systems under the research depends primarily on the number of connections to buildings, and to a lesser extent on the length of the sewer system. It can be assumed based on these dependencies that the main source of extraneous water in all examined sewer systems are illegal connections to house drains of gutter outlets. This is confirmed by video inspections of sewer systems performed in France, Poland as well as other countries (Pecher, 1999; Butler and Davis, 2011; Kaczor, 2012; Pujol, 2017).

Table 2. Characteristics of the sewage outflow from sewer systems included in the research along with addition and share of extraneous water in the year with the average amount of precipitation

Parameter	Value of individual parameters for analysed sewer systems			
	Keryado	Bois-du-Château	Wadów	Bielany
Average daily outflow of the sewage and extraneous water from the sewer system [$m^3 \cdot d^{-1}$]	1499	1408	523	219
Average daily outflow of the proper sewage from the sewer system [$m^3 \cdot d^{-1}$]	1175	1138	469	186
Average daily outflow of extraneous water from the sewer system [$m^3 \cdot d^{-1}$]	323	270	82	36
SEW [%]	21,5	19,2	15,7	16,4
AEW [%]	27,5	23,7	17,5	19,4

Table 3. Indicative unit values to describe the load of individual systems with extraneous water

Parameter	Value of individual parameters for analysed sewer systems				Average value
	Keryado	Bois-du-Château	Wadów	Bielany	
Average daily outflow of extraneous water from the sewer system in relation to 1 km length of the system [$m^3 \cdot d^{-1} \cdot km^{-1}$]	9,0	15,9	3,7	3,6	8,05
Average daily outflow of extraneous water from the sewer system in relation to 1 sewer connection [$m^3 \cdot d^{-1}$]	0,100	0,108	0,112	0,109	0,107

Whereas, nearly constant unit value of the tributary of extraneous water in relation to one sewer connection is a surprising fact. The average value for four analysed sewer systems is 0,107 $m^3 \cdot d^{-1}$ per 1 sewer connection with a standard deviation of only 0,0051 $m^3 \cdot d^{-1}$. The analysis presented in this paper is based on a small sample, but the results achieved provide the basis to continue the research with correspondingly reliable number of facilities.

CONCLUSIONS

1. Based on review of the literature and performed tests and analyses, it was concluded that tributaries of extraneous water into separate sewer systems occurring during the intense precipitation are a major operating problem both in Poland and France.
2. Hydraulic load of sewer systems with extraneous water does not depend on the age of the sewer system, but mainly on the number of connections. This may indicate that the main source of extraneous water in Poland and France are illegal connections of roof gutters to sanitary drains.
3. The average amount of extraneous water flowing into the sanitary system during wet weather is 0,107 $m^3 \cdot d^{-1}$ with a standard deviation of 0,0051 $m^3 \cdot d^{-1}$ in relation to one house drain (sewer connection).
4. All activities taken in Poland and France in order to protect the quality of surface and ground water should not, however, focus exclusively on the construction of new and modernization of existing systems for sewage disposal and treatment. It is equally essential to keep the appropriate effectiveness and reliability of the operation of sewer systems and sewage treatment plants already existing but not yet economically eligible for the modernization.

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dr hab. ing. Grzegorz Kaczor,
mail: rmkaczor@cyf-kr.edu.pl,
mgr ing. Błażej Stęplewski
mail: overflow@vp.pl
Uniwersytet Rolniczy w Krakowie
Katedra Inżynierii Sanitarnej i Gospodarki Wodnej
30-059 Kraków, al. Mickiewicza 24/28
tel. 12 662 40 85

ing. Léo Pujol,
mail: lpujol@engees.eu
National Engineering School in Water and Environment of Strasbourg (ENGEES)
1 quai Koch – BP 61039 – 67070 Strasbourg Cedex, FRANCE

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