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Threats to Wastewater Treatment Plant in Combined Sewer System – Analysis of Problems and Possible Solutions on the Example of Lodz

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1. Introduction

Municipal wastewater treatment plants (WWTP), due to the increasing requirements of environmental protection, have to meet more and more stringent requirements regarding both the quality of discharged sewage and operational reliability. This is sometimes difficult due to unforeseen situations, usually independent of the sewer network operator and sewage treatment plant. WWTPs are exposed not only to technical equipment failures, but also to an uncontrolled inflow of toxic substances that can inhibit biological treatment processes and, in extreme cases, lead to their breakdown. Such situations may be caused by intentional action (illegal discharge of wastewater into the sewage system), but also may be the effect of introduction of new substances and products, which in turn results in the introduction of new contaminants to a treatment plant, whose effects on living organisms is not fully recognized. In the case of combined sewage system, hydraulic overload resulting from stormwater inflow after prolonged and intense rainfall, is an additional threat, which may also worsen the effects of treatment. In both cases, not fully treated wastewater may be discharged to the receiver. Such situation causes a threat to the aquatic environment on the one hand, and on the other may result in financial penalties for treatment plants, resulting from non-compliance with the conditions for sewage disposal, as well as costs of removing the effects of failure (e.g. restoration population of microorganisms in activated sludge chambers).

According to the current legal status in Poland, the requirements for the quality of sewage discharged to the receiver increase with the size of the treatment plant, but they do not take into account the size and absorbency of the receiver, which is crucial for the possibility of maintaining its good condition or good ecological and chemical potential. The impact of discharged wastewater on the receiver depends primarily on the pollutant load and the dynamics of emissions, and of course depends on the size of the receiver as well as on type and form of pollution. Intense anthropogenic activities and rapid development of new industries may cause adverse impact on fragile river ecosystems and consequently human health, especially when discharged wastewater contains e.g. heavy metals, xenobiotics, estrogens, priority pollutants, micropollutants, oil and other petrochemical products, pesticides, pharmaceuticals, and emerging contaminants (Han & Currell 2017, Liu et al. 2020, Palli et al. 2019, Végsöová et al. 2019). Rapid changes in the level of pollutant emissions are dangerous especially for small receivers, which is why sewage treatment plants discharging sewage to them should be particularly well protected against the possibility of discharge of not fully treated sewage.

Significant sudden changes in the quality of inflow to WWTP, and primarily the presence of toxic substances, can affect the reduction of the biological treatment efficiency. In particular, nitrifying bacteria are sensitive to the effects of toxic factors such as increased heavy metal concentration, pH changes, reduced oxygen concentration and rapid changes in ammonium nitrogen concentration in the inflowing sewage (Black et al. 2014). Wastewater toxicity is more and more often the subject of research, however, generally used methods do not allow its simple and reliable on-line measurement. Attempts to establish a correlation between sewage toxicity and physicochemical parameters are not effective yet. Vasquez and Fatta-Kassinos (2013) have only established that two parameters: conductivity and ammonium nitrogen concentration are related to toxicity. Research conducted by Liwarska-Bizukojć et al. (2016) in the wastewater treatment plant in Zgierz (Poland) did not show any significant correlation between toxicity and basic parameters of wastewater (pH, BZT_5, COD, ammonium nitrogen, total nitrogen, total phosphorus), and their biodegradability BZT_5/COD). Only a weak correlation was found between the conductivity and toxicity of raw wastewater in the short-time summer campaign.

Rapid changes of inflow may cause difficulties in optimal control of municipal sewage treatment plants cooperating with the combined sewer system which is largely due to the unpredictability of precipitation. For this reason, attempts to forecast inflow to the treatment plant with sufficient time in advance are being made in the world. Based on rainfall data (currently occurring or forecast from radar data) and measurements of sewage depth and flow in the sewers, RTC (Real Time Control) systems are being created (Garcia et al. 2015, Schilling et al. 2010). Solutions for forecasting the WWTP inflow using artificial intelligence methods, such as neural networks, neural-fuzzy networks, etc. are also being developed (Seggelke et al. 2013, Szeląg et al. 2018, van Daal et al. 2017, Vezzaro et al. 2014, Zhou et al. 2019). Attempts to include into these systems tools that enable qualitative forecasting of inflows are being made (Langeveld et al. 2017). According to Vezzaro et al. (2014) controlling the sewage system based on the measurement of WWTP inflow quality allows to mitigate the effects of first flush pollution phenomenon.

However, there are currently no solutions enabling comprehensive forecasting of both the sewage inflow to the treatment plant and the concentration and loads of pollutants. Meanwhile, early warning of treatment plants about the possibility of hazards could enable, for example, storage of some wastewater not only to avoid hydraulic overloads, but also inflow of toxic substances or excessive loads of pollution to the biological part. This would create a chance for optimal control of treatment processes in all conditions and, as a consequence, better protection of the sewage receiver.

2. Studies aim and methods

The aim of the studies is to identify threats to the sewage treatment process in Group WWTP in Lodz. The variability of the wastewater inflow in terms of quantity and quality, which may have an impact on the treatment effects and creating hazards for the quality of receiving waters, will be analysed. Solutions that can minimize these risks will be presented.

3. Analysis of the current state

3.1. Characterisation of Lodz sewer system

Lodz is equipped with a hybrid sewage system. In the central part there is a combined sewer system with 4 main collectors running from the north-east to the south-west of the city towards the Group Wastewater Treatment Plant of the Lodz Agglomeration. There are 18 combined sewer overflows in the combined sewerage. Two sanitary sewers collecting sewage from northern and south-eastern regions of Lodz are included in this system. Two sewage collectors from Pabianice and Konstantynów Łódzki are connected to the system prior to WWTP. Total catchment area is inhabited by nearly 800 thousand people. The designed capacity of the treatment plant is 1.026.260 PE, while the actual load on the treatment plant, calculated on the basis of operational data from 2015-2017, is currently 934.700 PE. Maximum sewage inflow to the treatment plant during dry weather for a probability of 85% is 166,000 m^3 per day.

Wastewater flowing into WWTP is first subjected to mechanical treatment in the screens building, than wastewater flows into the grit chamber. The final facilities of mechanical wastewater treatment are rectangular preliminary settling tanks. Biological sewage treatment is carried out in activated sludge chambers operating in MUCT technology. In each technological line the anaerobic, anoxic, and aerobic zones are separated. The final treatment facilities are rectangular secondary settling tanks blocked with activated sludge chambers. The treatment plant scheme is presented in Fig. 1.

In dry weather, the sewage inflow to the treatment plant, in terms of both quantity and quality, is stable. Under these conditions, the characteristics of the inflow during the day or week are repeatable, and its changes are relatively small. It is different during wet weather, when the amount of inflowing sewage increases significantly, sometimes rapidly, and can cause WWTP overload, especially the biological part. Therefore, there are situations in which not all wastewater flowing into the WWTP is fully treated. Part of the wastewater after the primary settling tanks, and in extreme cases after the grit chambers, is directed to the bypass channel, which may contribute to increased emission of pollutants to the receiver compared to other periods.

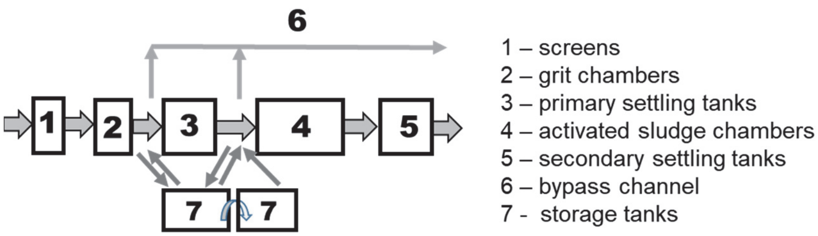

Fig. 1. Schematic of the Group Wastewater Treatment Plant of the Lodz Municipal Agglomeration

3.2. Wastewater inflow to WWTP

Although in recent years the annual rainfall in the city and the number of wet weather days do not show an upward trend, the occurring rainfall is characterized by a higher maximum intensity, which may cause a rapid increase in sewage inflow to WWTP (Fig. 2).

Measurements of sewage inflow to WWTP in Lodz indicate that for about half the days in a year the sewage treatment plant has to cope with increased inflows resulting from precipitation, and several or more times a year the volume of inflowing sewage exceeds twice the reliable maximum flow for the sewage treatment plant, which releases from the need to meet requirements contained in the water-legal permit regarding the composition of discharged wastewater (Table 1). In such cases, some of the wastewater is discharged through a bypass channel without biological treatment. Storage them could help avoid such situations.

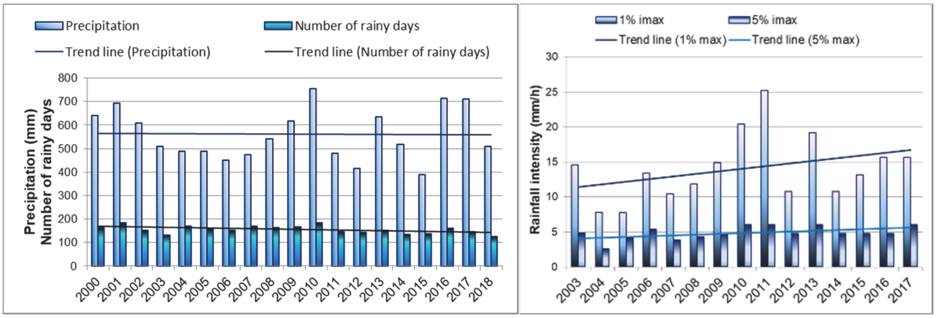

Fig. 2. Precipitation height and number of days with precipitation (a) and the intensity of precipitation with the highest intensity (mm/h) according to 5-minute records (data for 1% and 5% of highest values and trend lines) (b)

Table 1. Number of exceedances of the daily sewage inflow to WWTP jn Lodz Qd in relation to the maximum dry weather flow Q_m = 166.000 m^3/day

Year	Qm < Q_d < $2Q_m$		Q_d > $2Q_m$	
	monthly	per year	monthly	per year
2017	4-29	201	0-4	14
2018	1-25	143	0-2	5

The analyses carried out using the US EPA SWMM program have shown that an effective solution limiting sewage discharge to bypass channel is the construction of storage tanks (Sakson et al. 2018). The effectiveness of such tanks depending on their volume is shown in Fig. 3.

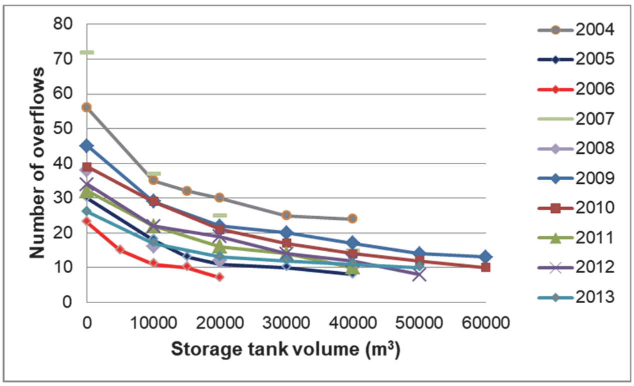

Fig. 3. Impact of separated storage tank volume on the reduction of biologically untreated sewage discharge by the bypass channel in Lodz WWTP (Sakson et al. 2018)

It is also possible to use in-sewer storage in large sewer Polesie XV prior the WWTP with the RTC system. The detention would be forced by 4 pairs of gates installed in the sewer. Exemplary effects of such a solution are presented in Fig. 4.

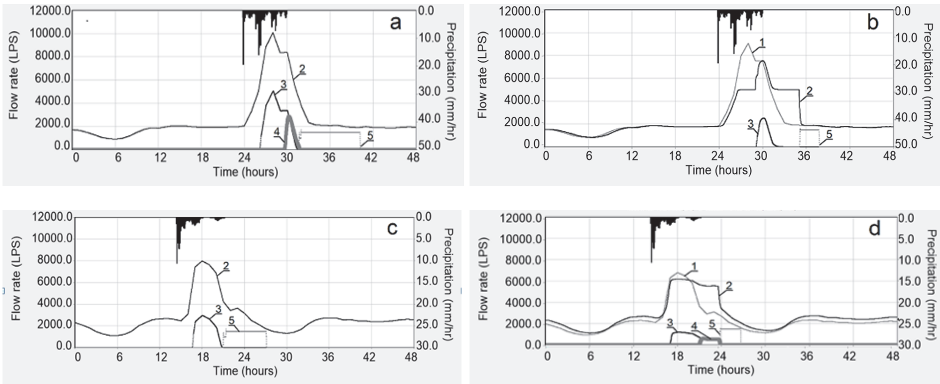

Fig. 4. Example of simulation of WWTP operation with the storage tanks, flow (l/s)
a, b – example of a rainfall with overflow in case of sewage storage in tanks (a) and without overflow in case of additional storage in the sewer Polesie XV (b);
c, d – example of a rainfall without overflow in case of sewage storage in tanks (c); and with overflow in case of additional storage in the sewer Polesie XV (d)
1 – inflow to the sewer Polesie XV; 2 – inflow to WWTP; 3 – inflow to storage tank;
4 – overflow from storage tank; 5 – storage tank emptying; right axis – precipitation (mm/hr)

3.3. Quality of wastewater in sewer system

Quality of wastewater flowing into WWTP may also change significantly during wet weather. Strormwater, which in this period may constitute the majority of the entire inflow volume (depending on precipitation parameters) may carry a significant amount of pollutants washed out from the catchment and leached from the sewer deposits, hindering the treatment process. In wet weather, as well as during snowmelt, inflows to WWTP are often characterized by the occurrence of the first flush phenomena. This means that in the beginning of precipitation in the mixture of municipal wastewater and stormwater much larger amount of pollutants may flows to WWTP than in the further runoff.

The inflow of a large amount of pollutants in very short time, even if there are no toxic substances among them, can cause significant difficulties in the treatment process. Changes in the quality and quantity of sewage flowing into WWTP are not repeatable, they depend primarily on rainfall characteristic and the length of the dry weather period before precipitation, which determines the amount of pollution built-up on the catchment and wash-off during rainfall. Even on the same catchment, in the case of different precipitation, the first flush phenomenon may not be observed, it may be pronounced or the so-called the last flush phenomenon may occur, moreover, the flow of pollutants may be different for basic quality parameters of sewage (Fig. 5).

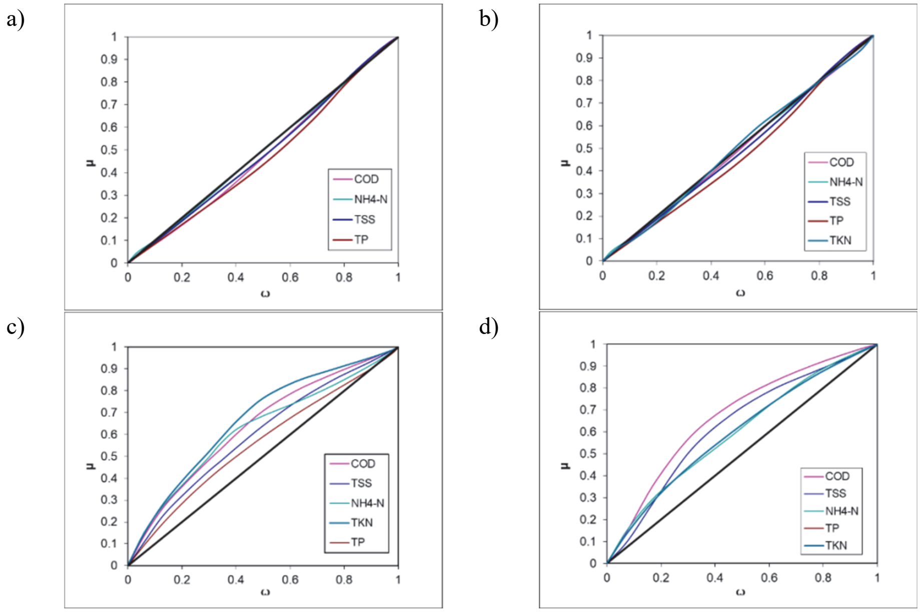

Fig. 5. Analysis of the first flush phenomena in inflow to GOŚ ŁAM: a) storm with a high intensity of precipitation; b) long rainfall of low intensity; c) long-lasting heavy rainfall; d) snowmelt combined with rainfall. COD – chemical oxygen demand; TSS – total suspended solids; NH_4-N – ammonium nitrogen; TKN – total Kjeldahl nitrogen; TP – total phosphorus; ω – cumulative wastewater volume; μ – cumulative load

An important threat to the WWTP is the inflow of toxic substances that can cause inhibition of biological treatment processes. Such situations took place in September 2011 and April 2019, when as a result of the inflow of unidentified substances to Lodz WWTP, inhibition of the nitrification process was found, which resulted in limiting the reduction of nitrogen concentration, a significant increase in the emission of nutrients to the environment, and the threat of non-compliance with legal requirements. The process collapse was associated with the destruction of the nitrifying bacterial population, which is most sensitive to the effects of toxic agents. Restoration of the relevant nitrification process parameters is possible after the termination of toxic substances inflow, and taking action to accelerate the recovery of the bacterial population. This can be done by inoculating the activated sludge with sludge from other treatment plants and dosing preparations containing nitrifying bacteria. Regardless of chosen solutions, the reconstruction can take up to several weeks. This time depends on many factors, including the parameters of treatment process and the nitrogen load in sewage inflowing to WWTP.

Research on wastewater quality in the Lodz sewage system conducted in recent years have shown considerable variability in its composition. Sudden increse in parameters such as BOD, COD, and suspended solids were sometimes observed, which may indicate illegal sewage discharge (Table 2, Fig. 6).

Table 2. Variability of wastewater composition in example points of the sewage system

Parameter	Unit	1. Sanitary sewer		2. Large sanitary sewer		3. Large combined sewer	
		range	CV	range	CV	range	CV
pH	(-)	7.12-8.65	0.04	7.1-7.62	0.02	7.13-8.5	0.04
Conductivity	(µS/cm)	257-4648	0.66	1582-2750	0.19	803-2915	0.19
Suspended solids	(mg/l)	296-11500	2.53	194-858	0.25	80-5004	1.36
BOD	(mg O_2/l)	200-9600	2.28	260-875	0.27	20-1450	0.56
COD	(mg O_2/l)	649-17955	2.16	459-1854	0.25	77-4041	0.68
NH_3	(mg/l)	26.9-76	0.26	28-56	0.16	18.1-99.1	0.26
H_2S	(mg/l)	<0.01-0.1	2.07	<0.1-0.4	0.58	<0.01-0.7	1.47

CV – coefficient of variation

4. Concept of the monitoring, early warning and sustainable management system

In order to improve WWTP functioning, two storage tanks of the volume 15,000 m^3 and 25,000 m^3. are being built in Lodz WWTP. Tanks volume was determined on the basis of many years of observation of inflows to the WWTP and computer simulations (Zawilski & Sakson 2008). The total useful capacity of the tanks (40,000 m^3) is to ensure the capture of most of the runoff after low and medium rainfall and the most polluted first flush of large runoff, exceeding the volume of the tanks.

Filling of tank I (Fig. 1) is foreseen after preliminary settling tanks – from the distribution channel to activated sludge chambers (ASC) or after grit chambers (GC), from the distribution channel to preliminary settling tanks (PST), through the designed channel valve. The maximum sewage inflow to the preliminary settling tanks was assumed to be about 30,000 m^3/h (above this inflow the excess sewage will be directed to tank I). It was assumed that the sewage inflow to ASC will not exceed the value of 18,200 m^3/h. Excess wastewater after PST, in the amount of approx. 12,000 m^3/h, will be directed through channel valves designed in the distribution channel on the ASC to the storage tank I. The tank chambers will be filled in cascade. After filling the first chambers, excess sewage will overflow to the common channel between tanks I and II, and then to tank II or to the bypass channel. Tank I will be emptied into PST distribution channel, while wastewater from tank II will be directed to distribution channel to ASC through a system of designed pump systems.

Optimal use of storage tanks requires information on quality and quantity of wastewater flowing into the WWTP and the forecast of their changes. If the excess volume of wastewater after rainfall is taken over by the tanks, it will be possible to fully clean it after the increased inflow stops. Also, if significant changes in sewage quality are identified that may affect their biological treatment, it will be possible to divert this type of inflow to tanks. Therefore, having information on the current composition of sewage in the sewer system and forecasting inflow to the treatment plant will facilitate optimal use of the technological possibilities of WWTP. The above premises, analysis of the current state of knowledge and technical capabilities, as well as experience in the field of monitoring and modelling of the Lodz sewage system constitute the basis for the development by Lodz University of Technology, Institute of Environmental Engineering and Building Installations, and Wastewater Treatment Plant of Lodz, Ltd. the prototype of monitoring, early warning and sustainable management system for WWTP in Lodz. The system will be based on measurement data from three main sources, these are:

- existing pluviometric system in the city, consisting of 18 raingauges, of which 5 are located on the combined catchment,
- flow measurement system in sewers next to 18 combined sewer overflows,
- newly constructed 4 stations (Fig. 6) for qualitative monitoring of wastewater in the sewage system with on-line sensors measuring min. 8 parameters on each station (pH, conductivity, organic substances, ammonium nitrogen, suspended solids/turbidity, chlorides, BTX, hydrogen sulphide). Research on sewage quality with on-line probes conducted on the J1 CSO since 2011, as well as previous tests on the inflow to WWTP (Brzezinska et al. 2016). showed that these types of stations can be successfully used for assessment of sewage quality and amount of pollutant emissions from the sewage system.

The system will enable receiving, well in advance, reliable information by sewage treatment plant employees on anticipated significant quantitative and qualitative changes in inflowing sewage and the possibility of a threat to biological treatment processes. This creates the opportunity to optimally control the treatment plant, both the parameters of the treatment process and flows. In a situation where there is a suspicion of the inflow of hazardous substances, part of the wastewater may be direct into the tanks, which will allow for their storage, collection of sewage samples and their analysis as well as determination of the way to proceed (referring to biological treatment or neutralization). Optimal use of storage tanks will allow reducing the bypass channel operation. According to the conducted analyses (Zawilski et al. 2017) limiting the operation of the bypass channel and the volume of discharges by 70% will allow reducing the emissions of basic pollutants by approx. 2.7-6.8% depending on the parameter (BOD_5, COD, TSS, TN, and TP).

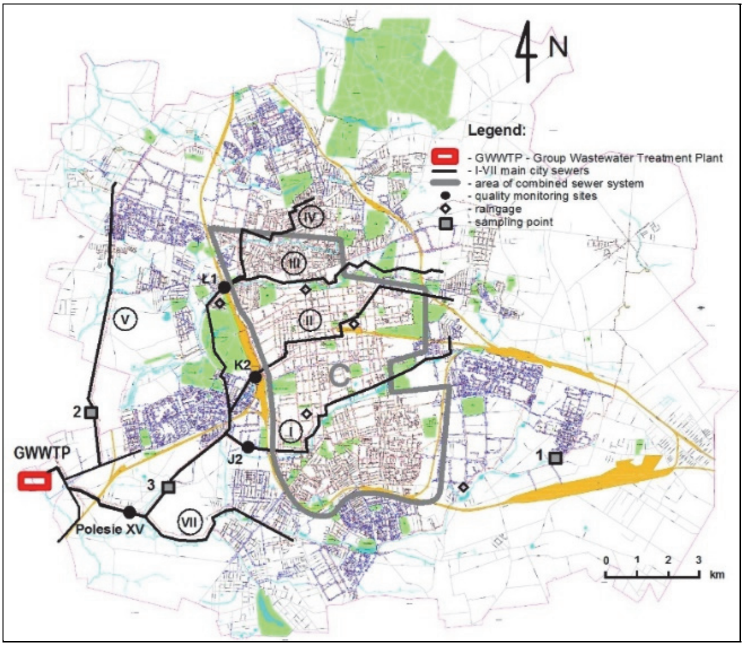

Fig. 6. Location of sewage quality monitoring stations in the Lodz sewage system

The system, based on only 4 stations for monitoring the quality of sewage, will not yet allow full control of the inflow to WWTP due to the existing sewer system layout in the city. Current research on sewage quality (including toxicity) in the entire sewer system should allow to determine the quality characteristics of sewage discharged from the whole catchment, which will allow more accurate inflow forecasting, but this will not take into account uncontrolled pollutant discharges into not monitored sewers. For this reason, the system will probably need to be expanded in the future. The use of quantitative and qualitative on-line monitoring of the sewage system is a very convenient and promising tool that facilitates solving many operational and modernization problems, however it creates many operational difficulties. There may be gaps in measurements or the measurement data is of poor quality. However, it can be assumed that the rapid progress in the development of on-line measurement methods and the expansion of experience in the field of operation of this type of equipment will contribute to the improvement of the efficiency and reliability of such solutions.

5. Conclusions

WWTP in Lodz is exposed to sudden changes in the inflow quantity, which now sometimes necessitates discharging part of sewage through a bypass channel without required biological treatment. The analysis of rainfall data shows that these phenomena may intensify. Significant changes in the composition of wastewater are also observed, and even the inflow of toxic substances inhibiting the biological treatment process. Research on wastewater composition in the sewer system shows that illegal discharges of concentrated sewage into the sewerage may occur. Introducing wastewater detention in WWTP can prevent the negative effects of rapid changes in inflow quality and quality. Optimal use of the storage tanks will be possible thanks to introducing the monitoring, early warning and sustainable management system for WWTP. The system will be based on data from raingauges, flowmeters and online quality sensors and will forecast the sewage inflow to the treatment plant and the concentration and loads of pollutants.

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Abstract

Municipal WWTP are exposed to the inflow of toxic substances, which may impede their proper functioning, especially of the biological part. In the case of combined or hybrid sewer systems, additionally, in wet weather, there may appear a rapid inflow of a mixture of domestic and industrial sewage, and stormwater in an amount exceeding the capacity of the devices, causing the need to discharge parts of not fully treated wastewater through the bypass channel. In such situations, the receivers are exposed to an inflow of increased amounts of pollutants. The article presents the concept of a monitoring, early warning and sustainable management system for the Lodz wastewater treatment plant, which will allow minimizing pollutant emissions to the aquatic environment.

Keywords:
sewer system, sewage treatment, water protection, predictive model, toxicity

Zagrożenia dla oczyszczalni ścieków w systemie ogólnospławnym – analiza problemów i możliwych rozwiązań na przykładzie Łodzi

Streszczenie

Miejskie oczyszczalnie ścieków są narażone na napływ substancji toksycznych, które mogą utrudniać ich prawidłowe funkcjonowanie, zwłaszcza części biologicznej. W przypadku ogólnospławnych lub mieszanych systemów kanalizacyjnych dodatkowo w czasie pogody mokrej może pojawić się gwałtowny dopływ mieszaniny ścieków bytowo-gospodarczych i przemysłowych oraz wód opadowych w ilości przekraczającej przepustowość urządzeń, powodując konieczność zrzutu części nie w pełni oczyszczonych ścieków przez kanał ominięcia. W takich sytuacjach odbiorniki są narażone na napływ zwiększonych ilości zanieczyszczeń. W artykule przedstawiono koncepcję systemu monitorowania, wczesnego ostrzegania i zrównoważonego zarządzania łódzką oczyszczalnią ścieków, który pozwoli zminimalizować emisję zanieczyszczeń do środowiska wodnego.

Słowa kluczowe:
kanalizacja, oczyszczanie ścieków, ochrona wód, model prognostyczny, toksyczność