Preliminary Analysis of Load Input into the Accumulation Varazdin by Rain Overflow

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Professional paper

Preliminary Analysis of Load Input into the Accumulation Varaždin by Rain Overflow

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Abstract: The wastewater treatment plant Varaždin upgrade project envisages the reconstruction of the rain overflow directly upstream of the plant. Physicochemical parameters of water quality (Biological Oxygen Demand, Chemical Oxygen Demand, Total Nitrogen, Total Phosphorus, Suspended Solids) in sewage/drainage system and in the accumulation were analyzed. In accordance with expected values of concentrations in overflow and in the accumulation, an analysis of the water quality in the accumulation after mixing was performed with certain assumptions. The results show that the ecological condition of the accumulation generally remains unchanged, classified as good condition, except for Chemical oxygen demand which is a critical parameter. Paper refers to the frequency and duration of possible exceedances of the Chemical oxygen demand limits and gives critical analysis of the realistically expected impacts. A proposal for conducting more detailed analysis with a larger database and by modelling pollution discharge by a complex three-dimensional model is given.

Keywords: accumulation Varaždin; agglomeration Varaždin; rain overflow; regulation on water quality standard; wastewater treatment plant

1 INTRODUCTION

The quantity and quality of wastewater is determined by many factors. Not all humans or industries produce the same amount of waste. The design of the sewer system affects the wastewater composition significantly [1]. In combined systems a part of the total wastewater is discharged to local water bodies, often without any treatment. There is no doubt that the overflow structures in combined sewage systems are large and difficult to control sources of water pollution, especially in populated areas. If they want to be controlled, then it is very expensive, complex, and generally rarely sufficiently effective. Combined sewage is characterized by the presence of overflows, through which during rainy periods untreated wastewater together with stormwater flows from the sewer system to the receivers. Main role of overflows in mixed sewers is essentially economic. Discharging large amounts of stormwater directly into the receivers reduces the flow of water in the sewer downstream of the overflow structure and thus significantly reduces the cost of construction and operation of the sewer, but also the costs of wastewater treatment plants (WWTP). With the increase in water pollution because of accelerated urban development that generates large amounts of wastewater and polluted stormwater, such a concept of sewage/drainage is becoming less and less acceptable. Namely, overflow waters are a source of uncontrolled environmental pollution that can cause aesthetic pollution, increased health risk of disease for all direct or indirect users of the receiver (bacteriological pollution), environmental damage in the receiver and the associated environment (various pollutants contained in stormwater and municipal wastewater) and a reduction in dissolved oxygen levels that may adversely affect the living world of the receiver [2].

Various studies provide a wide range of pollution parameters in the stormwater runoff. The characteristics of stormwater runoff quality, hydrology, retention and other issues have all been examined in the literature, and it has been found that significant quantities of organics, nutrients, and heavy metals are present in stormwater runoff. It has long been recognized that the pollutant build-up and wash-off processes are influenced by rainfall and catchment characteristics [3]. However, the pollution parameters are many times higher in sanitary wastewater than in the inflow. The two definitions used worldwide are that one Population Equivalent (PE) produces about 150 l/d and 60 g/Biological Oxygen Demand (BOD) [4]. The actual contribution from a person living in a sewer catchment, so-called the Person Load, can vary considerably (Tab. 1).

Table 1 Variations in person load [1]

Parameter	Unit	Range
COD	g/cap·d	25-200
BOD	g/cap·d	15-80
TN	g/cap·d	2-15
TP	g/cap·d	1-3

*BOD – Bilogycal Oxygen Demand; COD – Chemical Oxygen Demand; TN – Total Nitrogen; TP – Total Phosphorus

The concentrations found in wastewater are a combination of pollutant load and the amount of water with which the pollutant is mixed. The daily or yearly polluting load may thus form a good basis for an evaluation of the composition of wastewater. The composition of municipal wastewater varies significantly from one location to another. On a given location the composition will vary with time. This is partly due to variations in the discharged amounts of substances. However, the main reasons are variations in water consumption in households and infiltration and exfiltration during transport in the sewage system. Stormwater will further dilute the wastewater as most stormwater components have lower concentrations compared to very diluted wastewater [4].

Tab. 2 provides a comparative presentation of the mean values of the concentrations of individual pollution parameters in the inflow and sanitary wastewater. Additionally, the limit values for wastewater emissions are stated, depending on the degree of treatment according to the Ordinance on Limit Values for Wastewater Emissions (NN 26/20) [5].

Table 2 Comparison of composition of raw municipal wastewater with minor contributions of industrial wastewater with pollution concentrations in stormwater from mixed residential-commercial urban watersheds (mean values) and wastewater emission limit values depending on the degree of treatment

Parameter	Unit	Raw municipal wastewater [4, 6-8]	Stormwater [3, 9-19]	Emission limit values depending on the degree of treatment [5]	
				II.	III.
BOD_5	mg/l	260.50	18.60	25	-
COD	mg/l	600.50	107.08	125	-
TN	mg/l	39.00	4.34	-	15 (10)**
TP	mg/l	7.75	1.09	-	2 (1)**
SS	mg/l	219.50	99.43	35	-

* SS – Suspended Solids
** WWTP capacity 10,000-100,000 PE (or over 100,000 PE)

Therefore, when discharging untreated mixed inflows into the environment, such water pollution is no longer acceptable to the public nor is it legally allowed, so it is necessary to control overflows, i.e. reduce or completely eliminate the negative impact on water resources, and the first step in this process is to analyse the impact of individual overflows on the water quality of the receiver. This paper provides an example of such preliminary analysis.

2 DESCRIPTION OF THE LOCATION AND TECHNICAL CHARACTERISTICS OF THE ANALYZED EXAMPLE

The wastewater and drainage system of the city of Varaždin is a combined system, which means that wastewater from households, industrial wastewater and rainwater is collected by a single collector network. The total length of the collectors is over 100 km. The total amount of mixed wastewater is discharged by the main collector profile DN3000, which is dimensioned for a flow of Q = 13.2 m³/s. Main rain overflow was built on the system, at the end of the main collector, and before mechanical and biological treatment within WWTP. As part of the actual project of the agglomeration Varaždin, it is planned to upgrade and reconstruct the WWTP, which will have a capacity of 127,000 PE with the 3rd stage of purification. The hydraulic capacity of the WWTP is calculated as Q_{max} = 716 l/s which will be transported by the inlet pumping station towards the mechanical pre-treatment. Wastewater inflow greater than 716 l/s will be directed via rain overflow into a retention basin with a volume of 2,500 m³. The retention basin should retain inflows up to $4Q_{dry}$ (1,440 l/s), which will prevent the overflow of wastewater of higher pollution into the recipient and ensure its additional protection. Wastewater inflows greater than 1.4 m³/s will activate rain overflow, which will gravitationally transport overflow waters to the right drainage channel of the hydro power plant (HPP) Čakovec accumulation. The maximum amount discharged by the gravitational part of overflow (overflow 1 in Fig. 1) is 7.36 m³/s (8.8-1.44 m³/s).

In the event of a flow of more than 8.8 m³/s, it will activate other part of the rain overflow (overflow 2 in Fig. 1) through which a maximum of 11.2 m³/s will be transported to pumping station with a useful volume of 400 m³. Pumping station will be equipped with vertical pumps (five pumps) that will transport overflow waters by the pressure pipeline through the right embankment into the accumulation of HPP Čakovec. In front of the rain overflow, automatic chain coarse grid of 5 cm openings, with a total capacity of 20 m³/s, will be installed in three parallel lines (6.67 m³/s each). Large automatic grates will remove large waste from wastewater, which will ensure the smooth operation of pumps in the pumping station for overflow waters and protect the recipient, i.e., the accumulation of HPP Čakovec.

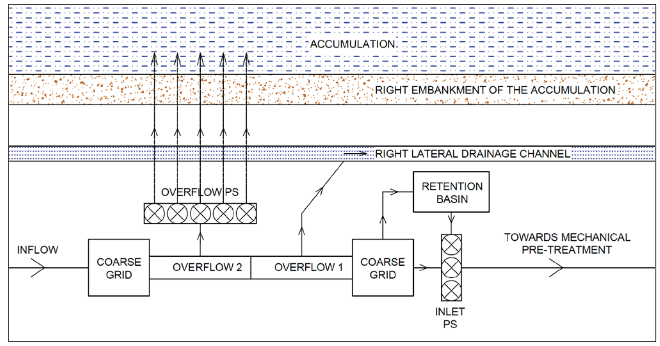

Figure 1 Schematic concept of the designed solution with rain overflow at the entrance to WWTP Varaždin

The receiver of the effluent from the WWTP Varaždin is the right drainage channel of the accumulation lake, which inflows downstream into the old Drava riverbed. It is envisaged that in the future project, the receiver of overflow quantities from the rain overflow in front of the WWTP will be the right drainage channel and the accumulation lake of HPP Čakovec (in case of heavier precipitation). Given that the accumulation has been identified as a sensitive part of this system, and the legislation generally restricts the discharge of wastewater into this type of water bodies, even if it is extremely rare and limited in time, as in this case, the impact of overflow on the quality of water in the accumulation will be analyzed below. Preliminary analysis of load input into the accumulation was performed in relation to the available input data. Due to the lack of continuous data during the calendar year, i.e. several years, data on minimum and maximum values of concentrations of water quality indicators of the influent and accumulation, and minimum and maximum values of flow through the accumulation were used. These data were used as input parameters for the calculation of concentrations after mixing of overflow waters and accumulation, and the determination of concentration limits of the ecological status of the water body for the basic physicochemical quality parameters.

3 ANALYSIS OF WASTEWATER AND ACCUMULATION OF HPP ČAKOVEC

3.1 Relevant Overflow Quantities and Accumulation Flow

The planned reconstruction of the rain overflow envisages the discharge into the recipient - the HPP Čakovec accumulation only in the case of precipitation resulting in higher total inflows (more than 8.8 m³/s). This roughly corresponds to precipitation of return period of 3 years, which was confirmed by using a hydraulic mathematical model of the sewage/drainage system (Fig. 2 - first graph).

The model was created using the EPANET software package, version 2.2.

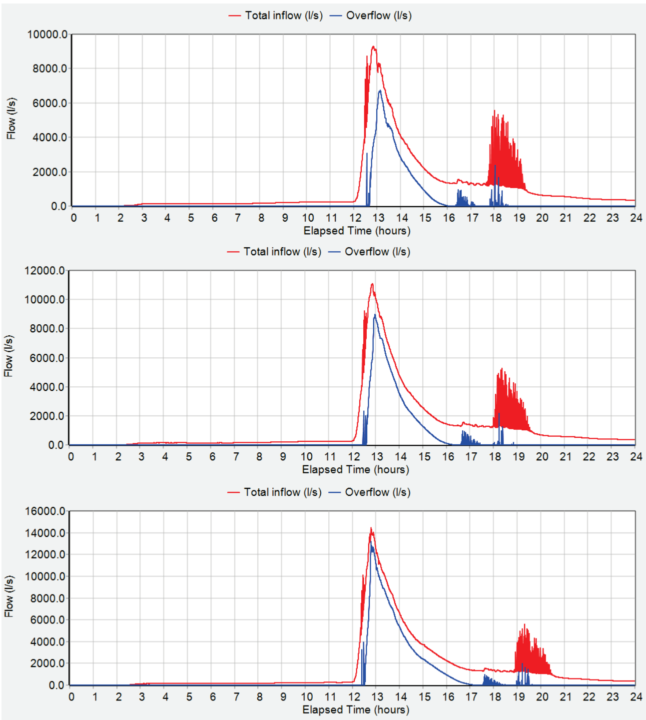

Figure 2 Results of the hydraulic model (EPANET, version 2.2) at the location of the analyzed rain overflow for the relevant precipitation of the RP 3, 5 and 10 years

As mentioned above, the maximum overflow expected into pumping station is projected at 11.2 m^3 /s. The project envisages a pumping station with 5 parallel pumps, each with a capacity of 2,240 l/s. This means that the maximum possible overflow into the accumulation is 11.2 m^3/s and this occurs when all 5 pumps are activated. However, from the graphs shown above, even in the case of precipitation for return period (RP) 10 years not all 5 pumps are activated, but only 3. Namely, with precipitation of 10 years RP total inflow at the location is approximately 14.2 m^3/s (Fig. 2 – third graph). This means that about 5.4 m^3/s of the total inflow remains for transfer into the accumulation (since 8.8 m^3/s goes downstream, towards the WWTP and the gravitational part of the overflow ending in the right drainage channel), which is easily covered by three pumps (Fig. 3 – Q3). Therefore, it can be concluded that the designed solution was made with an extremely high degree of safety and that the activation of all 5 pumps in the overflow pumping station is expected only in the event of precipitation of significantly higher RP (over 10 years). Fig. 3 shows the possible amounts of overflow water into the accumulation depending on the number of active pumps. For example, to activate all 5 pumps, the total inflow should be around 17.8 m^3/s (8.8 m^3/s going downstream and the amount of overflow 2 (from Fig. 1) greater than the capacity of 4 pumps, i.e. 8.96 m^3/s.

Another important amount for the subject analysis relates to the flow through the accumulation. Fig. 4 shows the measured data on accumulation flows for the period 2017-2019, where the values marked in red represent the absolute minimum, i.e., the maximum in the observed period.

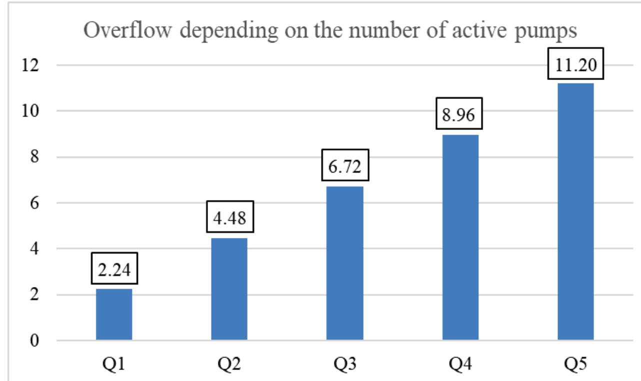

Figure 3 Possible variations of overflow into the accumulation

The presented results to be used in further analyses are summarized in Tab. 3. In the conducted analyses, the so-called constant accumulation volume is neglected, thus the results obtained will be on the safe side. Namely, the analyses below shows that the concentrations of individual pollution parameters in the accumulation are far below their values within the sewerage/drainage system, so mixing additional amounts of less polluted water would further contribute to dilution and reduction of total pollution concentrations.

Table 3 Recorded flows through the accumulation of HPP Čakovec for the period 2017-2019.

Flow	Min	Mean	Max
Q (m^3/s)	141	309	625

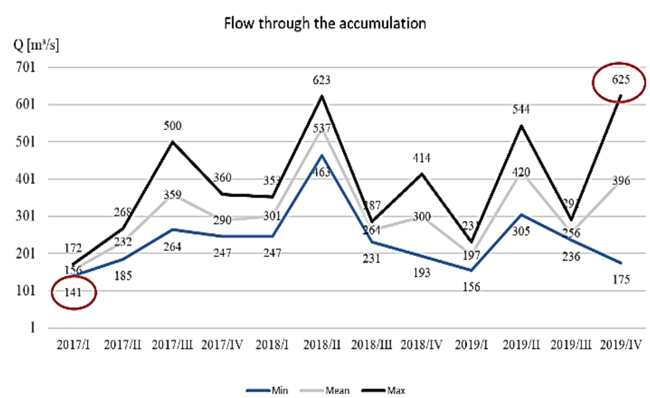

Figure 4 Flow changes through the accumulation for the period 2017-2019 with highlighted absolute minimum and maximum in the observed period

3.2 Water Quality in the HPP Čakovec Accumulation

Sampling of water quality in the HPP Čakovec accumulation is performed according to the Technical Observations Project, which is performed quarterly throughout the current year at specific, fixed control points, and for further analysis, four control points were taken as relevant for this analysis. The data taken for analysis at these points are the concentrations of water quality indicators [mg/l] BOD_5, COD, TN, TP, and SS in the period 2017 – 2019 (Tab. 4).

Table 4 Concentrations of water quality indicators in the accumulation for the period 2017-2019

Parameter	Unit	1	2	3	4	Min/Max	Mean
BOD_5 (min/max)	mg/l	0.50/ 2.00	0.50/ 2.70	0.60/ 1.70	0.50/ 2.00	0.50/ 2.70	1.15
COD (min/max)	mg/l	< 4.00/ 5.80	< 4.00/ < 4.00	< 4.00/ < 4.00	< 4.00/ < 4.00	< 4.00/ 5.80	4.83
TN (min/max)	mg/l	0.60/ 1.50	0.80/ 1.80	1.10/ 1.60	1.00/ 1.70	0.60/ 1.80	1.30
TP (min/max)	mg/l	0.01/ 0.17	0.02/ 0.11	0.02/ 0.10	0.02/ 0.13	0.01/ 0.17	0.07
SS (min/max)	mg/l	< 5.00/ 19.00	< 5.00/ 20.40	< 5.00/ 22.70	5.90/ 35.90	< 5.00/ 35.90	14.10

According to the Decree on Water Quality Standards (NN 96/19), the condition of a water body is assessed according to the value of the 50th percentile for rivers, transitional and coastal waters, i.e. the average annual concentration for lakes. These values are called the relevant values and are calculated on the basis of all measurement results, measured in different periods during the calendar year. Given the limited data available for this preliminary analysis, the mean values from the data presented above will be used for this classification, since these are estimated to be approximately relevant.

Table 5 Limit values of ecological status for basic physicochemical parameters for the water body of the HPP Čakovec accumulation

Panonska ecoregion		BOD_5 (mg/l)	COD (mg/l)	TN (mg/l)	TP (mg/l)
HR-R_5b	very good condition	1.50	2.50	1.20	0.05
	good condition	3.50	5.50	2.50	0.20

The analysis of water quality in the HPP Čakovec accumulation, based on the basic physicochemical quality parameters (Tab. 5), shows the characteristics of the category of good ecological condition.

3.3 Wastewater Quality

Sampling of wastewater, i.e. influent quality, the company Varkom d.d. performs on 24-hour composite samples that are tested and determined on the basis of the Ordinance on waste water emission limit values (NN 26/20). The summary results of these tests for the period 2017-2019 are shown in Tab. 6.

Table 6 Concentrations of wastewater quality indicators at the inlet of the WWTP for the period 2017-2019.

Parameter	Unit	Min	Mean	Max
BOD_5	mg/l	120.94	240.06	365.00
COD	mg/l	317.45	590.04	960.00
TN	mg/l	12.91	20.06	25.97
TP	mg/l	1.71	3.32	4.64
SS	mg/l	8.29	13.56	20.03

The analysis of wastewater quality in front of the WWTP (influent), shows that the concentrations are far above the emission limit values for pollutants in wastewater that are allowed to be discharged into the environment, and which are determined according to the Ordinance on wastewater emission limit values (NN 26/20, Annex I). The reason for this is that the analyzed wastewater is raw, and as mentioned before, result of 24-hour composite samples that were not diluted with large amounts of precipitation water and that were not taken instantly, during higher precipitation (and this is the time when the rain overflow is activated). Thus, taking these values for the calculation of the concentrations of the analyzed parameters in the accumulation after the inflow of overflow waters, obtained results are expected to be on the safe side, i.e. the conducted scenario assumes a hypothetical worst case.

4 ANALYSIS OF THE INFLUENCE OF OVERFLOW WATERS ON WATER QUALITY IN THE ACCUMULATION

Possible consequences of overflow water generally in relation to the parameters analyzed, are reflected in the following [2]:

- BOD_5 (COD) - reduction of the dissolved oxygen and mortality of wildlife
- TN and TP - eutrophication and algal blooms and deterioration of aesthetic values.

The calculation of the concentrations of physicochemical parameters in the accumulation after discharging the overflow waters was made within the following assumptions:

1) Instantaneous mixing of total quantities
2) The "constant" volume of the accumulation is neglected - only the flow through the accumulation is taken into account (this gives results on the safe side). Namely, there is always a certain amount of water in the accumulation, defined as a "constant" volume, while additional quantities flow through the accumulation and further through the engine room of the HPP. Since the concentrations of the observed pollution parameters are far lower in the accumulation compared to the wastewater, by mixing them the accumulation water actually lowers the concentrations of the mixture, and analysis that considers only the quantities flowing through the accumulation yields results on the safe side.

The calculation of concentrations in the accumulation after the discharge of overflow was calculated according to Eq. (1):

$$c_{\mathrm{m}} = \frac{c_{\mathrm{a}} \cdot Q_{\mathrm{a}} + c_{\mathrm{o}} \cdot Q_{\mathrm{o}}}{Q_{\mathrm{m}}}. \tag{1}$$

Where are: c_m - concentration of the observed parameter in the accumulation after discharge of overflow (mg/l); c_a - concentration of the observed parameter in the accumulation before discharge of overflow (mg/l); c_o - concentration of the observed parameter in the overflow (i.e., inflow) (mg/l); Q_a - flow through the accumulation (m^3/s); Q_o - overflow (m^3/s); Q_m - total flow as the sum of the flow through the accumulation and overflow (m^3/s).

Two extreme hypothetical cases were defined:

1. Best case scenario: $Q_{a,max}$ and $c_{a,min} + Q_{o,min}$ and $c_{o,min}$
2. Worst case scenario: $Q_{a,min}$ and $c_{a,max} + Q_{o,max}$ and $c_{o,max}$.

Although both scenarios defined are unlikely (it is to be expected that at higher overflows the flow through the accumulation will be higher because this is a moment of significant precipitation, and it is also to be expected that the concentrations in overflow waters due to dilution will be lower at higher overflows and vice versa), the actual range of concentrations of the analyzed parameters that can be expected in the accumulation, after overflow is discharged, is in the range between the values obtained for these two scenarios (Tab. 7). Still, expected concentrations in real conditions are much closer to lower presented values.

Table 7 Concentrations of water quality indicators in the accumulation after discharge of the overflow

Parameter	Unit	Best case scenario	Worst case scenario	Good condition limits
BOD_5	mg/l	0.93	29.36	3.50
COD	mg/l	2.20	76.02	5.50
TN	mg/l	0.64	3.58	2.50
TP	mg/l	0.02	0.50	0.20
SS	mg/l	4.91	34.73	-

Based on the results in Tab. 7, it is concluded that, if the overflow pumping station would be active all year round, the condition of the accumulation would meet the limits good condition in relation to the analyzed parameters for the best case scenario, while for the worst case scenario these values would be significantly exceeded for all analyzed parameters, especially organic load, i.e. oxygen demand in water (expressed as BOD_5 and COD).

With the same assumptions adopted previously, the so-called realistic scenario was defined so that mean values were taken for the relevant flow through the accumulation and for the concentrations of each pollution parameter in the accumulation. Overflow quantities are defined depending on the number of active pumps (Fig. 3) in the range of 2.24-11.20 m^3/s. Concentrations of pollution parameters in overflow are taken as minimum values based on wastewater sampling in front of the WWTP (Tab. 6) for the flow of the first pump (Q_1 = 2.24 m^3/s). Namely, in the conditions when the overflow pumping station is activated, a significant dilution is already present in the sewage/drainage system, and since the values shown in Tab. 6 are result of 24-hour composite samples, it is logical to choose minimum concentration values. For the values of concentrations in overflow resulting from pumps Q_2-Q_5, the average of mean values of individual pollution parameters in stormwater were chosen based on a literature review (Tab. 8).

Table 8 Literature range of pollution concentrations in stormwater from mixed residential-commercial urban watersheds [3, 9-19]

Parameter	Unit	Min	Mean	Max
BOD_5	mg/l	1.08	18.60	270.67
COD	mg/l	6.01	107.08	880,00
TN	mg/l	0.02	4.34	42.93
TP	mg/l	0.03	1.09	13.70
SS	mg/l	2.00	99.43	3,577.00

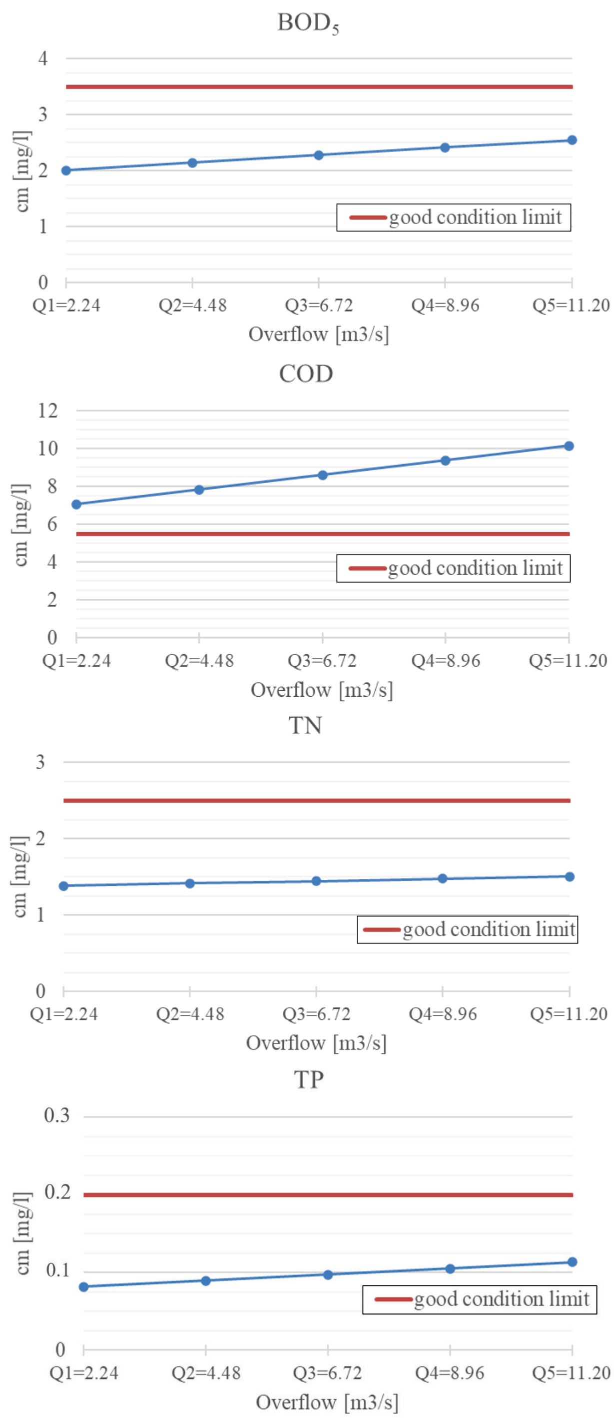

Figure 5 Concentrations of water quality indicators in the accumulation after discharge of overflow in relation to the amount of overflow water (number of active pumps) – realistic scenario

Results of this analysis are shown in the Fig. 5 from which exceeding the limit values of good condition of the water body of the accumulation (based on the analyzed parameters) occurs only regarding COD, while the other considered parameters are within limits regardless of the number of active pumps.

The presented results show that with a larger number of active pumps, the input of pollution into the accumulation also increases, although in these conditions the dilution is significant. Again, the COD has been identified as a critical parameter, moreover, when operating more than one overflow pump, regardless of the concentration in the overflow waters of pump Q_1, it is not possible to meet the limits of good water body condition in a short term (Tab. 9). The reason for this is that the assumed concentration in the overflow waters Q_2-Q_5 (stormwater inflow) is already high enough to exceed the maximum allowable values. What needs to be emphasized is that these are extremely rare moments when more than one pump will be activated at all. Namely, with the precipitation of RP 3 years, only short-term activation of the first pump is expected, which based on the presented results may, depending on the actual concentration of COD in the sewage/drainage system, result in only short-term exceeding of good condition criteria. Based on the other analyzed parameters, good condition is always satisfied, regardless of the inflow and the number of active pumps. For the COD parameter, the risk of exceeding the good condition criteria increases with the increase in the number of active pumps and the amount of overflow water. Even for this criterion, these are extremely short-term effects (which occur only during the extreme precipitation) at a frequency level of an average of once in about 3 years or even less.

Table 9 Maximum allowable concentration of analysed pollution parameters in Q_1 overflow to maintain good condition of the accumulation

Parameter	Unit	Number of active pumps				
		1	2	3	4	5
BOD_5	mg/l	327.67	312.57	297.47	282.37	262.27
COD	mg/l	97.92	X	X	X	X
TN	mg/l	168.04	166.20	164.36	162.52	160.68
TP	mg/l	18.13	17.24	16.35	15.46	14.57

*X – not possible to meet the criterion of good condition

Table 10 Load input into the accumulation in the event of relevant precipitation of a RP of 3, 5 and 10 years

Parameter	Unit	RP 3 years	RP 5 years	RP 10 years
Overflow duration*	min	14.0	34.0	62.5
Average overflow*	l/s	321.5	1,148.6	2,601.9
Total overflow into the accumulation	m^3	270	2,343	9,757
BOD_5	kg/event	64.82	562.50	2,342.25
COD	kg/event	159.33	1,382.57	5,756.98
TN	kg/event	5.42	47.00	195.72
TP	kg/event	0.90	7.78	32.39
SS	kg/event	3.66	31.77	132.30

*Overflow above 8.8 m^3/s - since it is the part of the total overflow that goes into the accumulation (results of hydraulic model)

Concentrations of individual parameters in the accumulation are not the only parameter important for defining the impact of overflow quantities, and it is certainly necessary to have data on total amounts of pollution (mass inflow) that enter the accumulation during a certain period, for example at the annual level. It is necessary to know the data in the total time of overflow activation according to the accumulation in the observed period, which requires long series of historical data on precipitation. It is recommended to examine the above in the context of further analyzes. In relation to the available data set, Tab. 10 estimates the amounts of pollution that are introduced into the accumulation in the event of relevant precipitation of a RP of 3, 5 and 10 years and for mean concentrations of wastewater quality indicators at the inlet of the WWTP for the period 2017-2019 (Tab. 6). These are, especially in the case of organic load, significant absolute amounts, but it is still necessary to consider the frequency of occurrence of the analyzed events, i.e., on average once in 3, 5 or 10 years.

After conducting more comprehensive analysis using complete input parameters and preferably a 3D model of pollution discharge that would include all influential parameters, it is possible to apply additional measures to improve the condition of the accumulation, for example by introducing artificial aeration of the accumulation by surface aerators as aesthetically and environmentally acceptable solutions.

5 CONCLUSION

Paper presents preliminary analysis of load input by overflow in front of the WWTP Varaždin into HPP Čakovec accumulation. The impact on available oxygen (BOD_5 and COD parameters) and nutrient concentrations (TN and TP parameters) in the accumulation were analyzed. The results indicate that only in extremely short and rare periods deterioration in good condition of the accumulation could be expected. Such situations are expected at the level of an average of once in 3 years or less and in the maximum duration of extreme precipitation. In these extreme cases, the critical parameter is the content of dissolved oxygen in the accumulation expressed as COD.

With the aim to define the impact of load input in the accumulation using a comprehensive analysis the data on actual measured concentrations of pollution in the overflow in real time should be used, and with the rest of the data incorporated into complex 3D model which would include all influential parameters. In case of deterioration of the accumulation condition regarding dissolved oxygen levels, it is possible to consider additional measures to improve the water quality.

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