VODOHOSPODÁŘSKÉ TECHNICKO-EKONOMICKÉ INFORMACE
(WATER MANAGEMENT TECHNICAL AND ECONOMIC INFORMATION)

VTEI/2023/4

60 years ago in VTEI

The TECHNICAL INFORMATION FROM THE FIELD OF WATER MANAGEMENT (TECHNICKÉ INFORMACE Z OBORU VODNÍHO HOSPODÁŘSTVÍ) journal, in its third issue of 1959, addressed, among other things, pipeline installations for drilled wells.

When installing the final equipment of drilled wells, steel pipes are mainly used which are perforated in the part that is immersed in the groundwater. Steel material is suitable for equipping drilled wells with non-aggressive water. In our country, however, most groundwater is more or less aggressive.

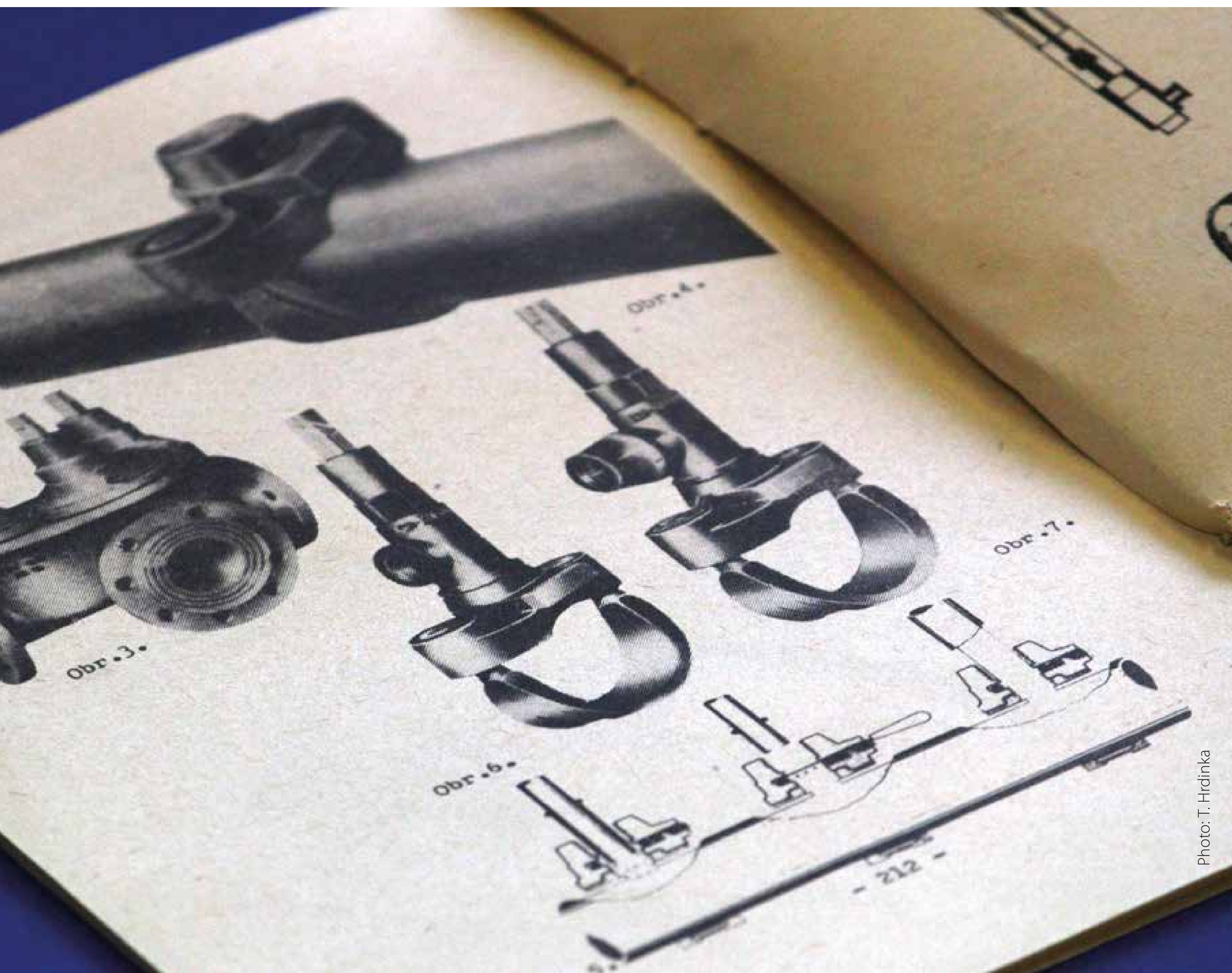
It damages the steel walls of the pipes. The pipes are protected by coatings; however, no coating can last more than three to five years without renewal in an aggressive environment. This protection is not suitable for wells as the requirement for their service life is much longer. It is necessary to look for new materials that would not be affected by aggressive water. That is why pipes made of stoneware and plywood joined with resin glue are introduced. At the testing stage, the new-dura pipeline is made of sheets and asbestos cement.

It would be possible to use other non-metallic materials for this purpose, which would safely resist water aggressiveness, would withstand the stress of lowering and landing the entire column to depths of up to 150 m, would not be fragile or harmful to health. At the same time, the appropriate joining of individual pipe pieces must be resolved.

Pipes of profiles between 200 and 650 mm are most often used for final equipment of drilled wells.

From TGM WRI archive.

VTEI Editorial office



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Contents

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Dear readers,

You are currently holding the August issue of our VTEI journal, which is varied in terms of content and full of interesting articles. The authors focused on various aspects of the pollution of watercourses, the development of ponds in the Poděbrady region, the issue of atmospheric deposition as a possible source of surface water pollution, and the use of artificial intelligence in our field with a focus on the visual area.

First, we would like to draw your attention to an article dealing with microbial pollution of the Vltava. Microbiological indicators of fecal pollution are among the most important in monitoring the quality of surface water from the point of view of protecting human health. Despite the implementation of the best available technologies, the biggest source of fecal pollution is treated and untreated municipal wastewater. The trend of the development of microbial contamination of the Vltava below Prague is described in detail in the article by Hana Zvěřinová Mlejnková (TGM WRI).

Another interesting contribution is an article by Jan Unucka (CHMI Ostrava) focused on an application developed by CHMI to support hydrological modelling with the primary use of the HEC-HMS model. The article briefly describes the current state of the application development and its functionality, even for readers without a professional background.

In his article, our colleague Pavel Richter (TGM WRI) introduces you to the results of research into landscape changes in the Polabí lowland from the Poděbrady region, where significant changes in the location of ponds have occurred over the centuries. His study provides a comprehensive view of the historical development of ponds in the Poděbrady region and their current importance for the landscape, and follows on from the "Development of pond location in the Polabí lowland since the mid-19th century – Part 1 – Pardubice" published in the previous issue of our journal.

In her article, Věra Očenášková (TGM WRI) provides information on the occurrence of selected drugs in wastewater in 2019–2022, with special attention on the period since the outbreak of the global health emergency caused by Covid-19. You will learn about how this situation affected drug consumption thanks to a comparison of the results of weekly sampling events.

We would also like to draw your attention to the informative article "Fundamental revision of the Urban Waste Water Treatment Directive provokes conflicting reactions from European Union member states", which was provided by Tomáš Gremlica (Ministry of Agriculture), and to the interview with Slavomír Vosika, head of the Secretariat of the International Commission for the Protection of the Elbe River, especially with regard to the upcoming Magdeburg Seminar on Water Protection 2023, which will take place on 11th and 12th in October Karlovy Vary under the title "Extreme hydrological phenomena and their impact in the Elbe basin".

The new VTEI issue brings you a number of current findings from research in the field of water management. We hope that the contributions of the August issue will not only provide you with new and interesting information, but will also become a stimulus for further research and professional discussion.

Enjoy the rest of the summer holidays.

VTEI Editorial office

The influence of wastewater on microbial contamination of the Vltava below Prague

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Keywords: microbial contamination — Vltava — CWWTP — fecal pollution

ABSTRACT

In terms of public health protection, the most important indicator in surface water monitoring is microbial fecal contamination. Despite the introduction of the best available technologies, their biggest source is treated and untreated municipal wastewater. Around 90 % of the Czech population use their local sewerage system, which is linked to a WWTP, treated, and discharged into recipient waters. Monitoring of microbial contamination of the Vltava below Prague CWWTP showed a level of fecal pollution in the 10 km section below the wastewater inflow in periods with different flow rates. Smaller tributaries of the Vltava, which bring treated wastewater from local WWTPs to the Vltava, were monitored as additional sources. From April 2022 to March 2023, the amount of *Escherichia coli*, enterococci, thermotolerant coliform bacteria, and *Clostridium perfringens* were monitored at ten sampling sites. The monitoring results showed relatively significant microbial pollution of the Vltava from Prague CWWTP discharge and, at the same time, the river's substantial self-cleaning ability in the following section. This creates good potential for the river's future utilization in the monitored area, with the exception of the section directly affected by the inflow of treated wastewater from Prague CWWTP. This study could be used to raise public awareness in order to minimize the health risk caused by the river's inappropriate utilization (possible presence of pathogenic microorganisms, including carriers of antimicrobial resistance).

INTRODUCTION

The Vltava is an important watercourse which, along its entire length, is the recipient of the inflow of a large volume of wastewater. Thanks to its high water bearing and cascades of water reservoirs, it can eliminate the pollution brought into it relatively effectively. The largest load on the Vltava comes from the capital city of Prague, not only from the Central Waste Water Treatment Plant (CWWTP), but also other smaller treatment plants. Municipal wastewater is one of the main sources of contamination of surface streams with microbial contamination, despite the obligation to use the best available wastewater treatment technologies at WWTPs. Some microorganisms significant for hygiene are not completely eliminated by treatment processes, and thus subsequently adversely affect the quality of water in watercourses, where they can represent an acute (viable microorganisms) or passive (e.g., spread of antibiotic resistance) health risk and a reduction in water usability, such as for recreation and irrigation. Despite this fact, the mechanisms for controlling microbial pollution of wastewater from WWTPs are not currently determined by legislation. In addition, the risk has increased with the current climate period, with the occurrence of extreme phenomena (drought and torrential rainfall). Both of these phenomena are critical for maintaining good microbial quality of surface waters. In periods of low flow rates, due to the low dilution of wastewater from WWTPs and other municipal sources, there is an increased concentration of microbial contamination in streams. In cities, torrential rain poses the risk of increased loading of streams by flood-ways, which bring untreated wastewater that the WWTPs are not able to manage. These facts have significantly contributed to the increased microbial load of watercourses in the long term [1, 2, 14]. Water quality in the Vltava is regularly monitored by the watercourse manager within the state surface water quality monitoring network for the ISVS (Informační systém veřejné správy, Public administration information system) – surface water quality records of the CHMI (Czech Hydrometeorological Institute). However, the sparse network of sampling sites (Vltava above Prague-Vrané nad Vltavou; Vltava below Prague-Zelčín) and the limited scope of monitoring cannot capture the risks associated with microbial contamination of the watercourse.

In our study, the Vltava in Prague and below the city was chosen for the purpose of a closer understanding of microbial contamination and its natural elimination in a large watercourse. Fecal pollution of the water in a recipient watercourse was assessed by determining standard indicator groups of microorganisms *Escherichia coli* (*E. coli*), thermotolerant (fecal) coliform bacteria, intestinal enterococci, and *Clostridium perfringens*, whose spores are highly resistant to external environmental factors and survive in wastewater and surface water for a long time [3, 4].

The aim of the study was to characterize microbial pollution in the longitudinal profile of the Vltava below Prague and to determine the degree of increase in health risk and decrease in the usability of water burdened by fecal pollution due to the inflow of wastewater from the WWTP in the monitored section, and to assess the development trend in comparison with historical data [5].

Fig. 1. Vltava in Podbaba below the wastewater inflow from the current and new water line of CWWTP Prague

Fig. 2. Inflow of the Klecanský stream into the Vltava in Klecánky

Fig. 3. Vltava in Řež (the last sampling site of the monitored section)

METHODOLOGY

A 10 km section of the Vltava (from Troja to the Vltava-Řež sampling site) was monitored to determine the influence of treated wastewater discharge from the WWTP on water quality in the researched section of the river's longitudinal profile *(Fig. 1–3)*. The descriptions and locations of the sampling sites are shown in *Tab. 1* and *Fig. 4*. Sampling sites on the Vltava were selected for monitoring where it is possible to assess the impact on its water quality by the inflow of treated wastewater from the Prague CWWTP and smaller WWTPs on the tributaries. The characteristics of these WWTPs are shown in *Tab. 2*. For technical reasons, the sampling sites capturing pollution input from the Prague-Bohnice, Nebušice, and Roztoky WWTPs were not included in the monitoring. Other tributaries in the monitored area have no WWTP inflow.

Tab. 1. Description and location of sampling sites

Site No.	Name of sampling site	Description of sampling sites
1	Vltava-Troja	control sampling site above CWWTP Prague; sampling carried out from Troja footbridge
2	Vltava-Podbaba	sampling below both outlets of the CWWTP Prague from the left bank at the end of Císařský ostrov; the water below the outlets is not sufficiently mixed
3	Vltava-Sedlec	sampling on the left bank of the Vltava in Sedlec near a small beach used for recreation about 2 km below the CWWTP
4	Vltava-Roztoky	sampling near the outlet of the Roztoky WWTP to the Vltava, about 5 km below the CWWTP; is not sufficiently representative due to the irregular WW discharge
5	Vltava-Klecany	sampling from the centre of the watercourse about 6 km below the CWWTP; carried out from the ferry
6	Vltava-Řež	sampling from the centre of the watercourse about 10 km below the CWWTP; carried out from the footbridge
7	Drahanský stream	right-hand tributary of the Vltava, outlet of the Prague--Čimice WWTP; sampling carried out about 1 km from the outlet to the Vltava
8	Přemyšlenský stream	right-hand tributary of the Vltava, outlet of the Zdiby WWTP; sampling carried out before the outlet to the Vltava
9	Klecanský stream	right-hand tributary of the Vltava, outlet of the Klecany WWTP; sampling carried out before the outlet to the Vltava
10	Podmoráňský stream	left-hand tributary of the Vltava, outlet of the Velké Přílepy WWTP; sampling carried out before the outlet to the Vltava
11	Únětický stream	left-hand tributary of the Vltava, outlet of the Horoměřice and Tuchoměřice WWTPs; sampling carried out from the road bridge about 150 m before the outlet of the Vltava

Fig. 4. Sampling site locations

Tab. 2. Basic WWTP characteristics

WWTP name	Category according to PE	WW recipient	Number of people connected to the WWTP (2021)	Amount of treated WW in total [thousand m³/year]
CWWTP Praha EWL	over 100,000	Vltava	491,633	44,989
CWWTP Praha NWL	over 100,000	Vltava	706,012	64,601
WWTP Roztoky	2,000–10,000	Vltava	7,869	773
WWTP Dolní Chabry	2,000–10,000	Drahanský stream	4,632	264
WWTP Zdiby	2,000–10,000	Přemyšlenský stream	3,000	166
WWTP Klecany	2,000–10,000	Klecanský stream	3,117	343
WWTP Velké Přílepy	2,000–10,000	Podmoráňský stream	2,935	190
WWTP Horoměřice	2,000–10,000	Horoměřický stream (Únětický stream)	3,450	274
WWTP Tuchoměřice	up to 2,000	Únětický stream	1,816	149

The amount of *E. coli*, intestinal enterococci, thermotolerant (fecal) coliform bacteria, and *Clostridia perfringens* were determined by standard culture methods. Determination of thermotolerant (fecal) coliform bacteria and *E. coli* was carried out according to ČSN 75 7835 standard, intestinal enterococci according to ČSN EN ISO 7899-2 standard, and *Clostridia perfringens* according to Decree 252/2004 Coll., Annex 6. For culture determination, methods according to the following procedures were used [6–8]. Plain samples were taken from April 2022 to March 2023 with a monthly frequency at the above-mentioned sampling sites.

The results were classified into quality categories according to ČSN 75 7221 [8] and compared with EQS limits (environmental quality standards) for surface waters according to Government Regulation No. 401/2015 Coll. [10]. For information, the results were compared with the limits for bathing waters according to Decree No. 238/2011 Coll. [11].

ČSN 75 7221 [8] uses the characteristic value C90 and, based on it, classifies flowing surface water into five classes according to quality (*Tab. 3*). The standard allows the so-called purposeful classification according to its own range of indicators, when the resulting class is determined according to the most unfavourable classification. In our case, the classification was used for indicators of thermotolerant (fecal) coliform bacteria and intestinal enterococci.

Government Regulation No. 401/2015 Coll., on indicators and values of permissible pollution of surface waters and wastewater, requirements for permits for discharge of wastewater into surface waters and into sewers, and on sensitive areas from 2016 [10] specifies EQS values for microbiological indicators as P90 for *E. coli*, intestinal enterococci, and thermotolerant (fecal) coliform bacteria (*Tab. 3*).

Decree No. 238/2011 Coll., on the establishment of hygiene requirements for swimming pools, saunas, and hygiene limits of sand in sandpits of outdoor playgrounds from 2011 [11] differentiates between intestinal enterococci and *E. coli* indicators based on P90 and P95 into three quality levels (*Tab. 3*).

Tab. 3. Classification of microbial parameters

	Thermotolerant (fecal) coliform bacteria	Intestinal enterococci	*Escherichia coli*
		[CFU/100 ml]	
		ČSN 75 7221 (C90)	
Class 1 = unpolluted water	< 2,000	< 600	-
Class 2 = slightly polluted water	< 10,000	< 1,300	-
Class 3 = polluted water	< 20,000	< 2,500	-
Class 4 = heavily polluted water	< 40,000	< 4,600	-
Class 5 = very heavily polluted water	≥ 40,000	≥ 4,600	-
		Government Regulation No. 401/2015 Sb.	
EQS (P90)	4,000	2,000	2,500
		Decree No. 238/2011 Sb.	
excellent quality	-	200 (P95)	500 (P95)
good quality	-	400 (P95)	1,000 (P95)
acceptable quality	-	330 (P90)	900 (P90)
unsatisfactory quality			

Notes: C90 = characteristic value (value with a probability of not exceeding 90 %); P90 and P95 (95% and 90% percentile); EQS = environmental quality standard

RESULTS

The results of microbial pollution monitoring from April 2022 to March 2023 are shown in the graphs in *Fig. 6–15*.

The assessment according to ČSN 75 7221 (*Fig. 5*) showed the best quality at the Vltava-Troja control sampling site, which was classified as slightly polluted water (quality class 2). The outlet of treated wastewater from the CWWTP changed the water quality in Vltava-Podbaba to quality class 5 (very heavily polluted water). Thanks to the intensive dilution of microbial pollution and the active watercourse self-cleaning, the water in the other monitored locations of the longitudinal profile of the Vltava already corresponded to quality class 3 (polluted water). The discharge from heavily polluted tributaries (i.e., Drahanský, Klecanský, Podmoráňský, and Únětický streams) did not contribute to the significant deterioration of water microbial quality. Of the monitored streams, Přemyšlenský stream showed the best quality, on which the apparently well-functioning WWTP from the village of Zdiby-Přemyšlení is located.

The water quality at the monitored sampling sites was compared with EQS for microbiological indicators, expressing the surface water status (*Tab. 3*). The results for all monitored indicators are presented in *Figs. 6–13* and in *Tab. 4*. Both the graphs and the table show significant differences between the individual sampling sites, not only in the Vltava but also in its tributaries below Prague. Indicators of thermotolerant (fecal) coliform bacteria and *E. coli* were exceeded at 60 % of the sampling sites in the Vltava and in 80 % of the tributaries; the indicator of intestinal enterococci was exceeded at only 20 % of the sampling sites in the Vltava, but in 80 % of the tributaries. The control sampling sites on the Vltava above the CWWTP and the Vltava-Klecany met the requirements of Government Regulation No. 401/2015 Coll. for all three indicators. Despite the inflow of pollution from many sources during its flow through Prague (including the significantly polluted Botič and Rokytka streams), the results showed that the Vltava in Troja has unexpectedly good water quality. According to the original assumptions, a significant increase in the number of microbial indicators occurs in the next section, where wastewater treated on two water lines of the Prague CWWTP flow into it. This is despite the fact that the CWWTP is equipped with modern treatment technology that meets the requirements for the best available wastewater treatment technologies and is actively taking other steps to improve the quality of discharged water, such as UV disinfection of treated wastewater (which was put into trial operation in October 2021). As the graphs in *Fig. 6–14* show, intensive dilution and self-cleaning occur in the Vltava, thanks to which there are already significantly fewer microbiological indicators in the section from Sedlec, namely about 2 km below the CWWTP.

Surprising differences were found in the microbial quality of the water of the Vltava tributaries below Prague into which wastewater from local WWTP is fed (*Fig. 6–14*, *Tab. 4*). Critical pollution was brought by the Klecanský and Podmoráňský streams, to which the Klecany and Velké Přílepy WWTPs are connected, i.e., around 6,000 connected inhabitants. In contrast, Přemyšlenský stream (Zdiby WWTP; 3,000 connected inhabitants) showed the lowest pollution throughout the monitoring period. Thanks to the relatively low water bearing of the polluted tributaries, the influence on the Vltava below their inflow is not significant (*Fig. 14*). According to ČSN 75 7143, Vltava water is "conditionally suitable" for irrigation at most sampling sites, i.e., the numbers of thermotolerant (fecal) coliform bacteria and enterococci range between 1,000 and 10,000 CFU/100 ml [15].

Tab. 4. Classification of microbiological parameters

Sampling site	Thermotolerant (fecal) coliform bacteria		Intestinal enterococci		*Escherichia coli*	
	P90/ average [CFU /100 ml]	min./max. [CFU/100 ml]	P90/ average [CFU/100 ml]	min./max. [CFU/100 ml]	P90/ average [CFU/100 ml]	min./max. [CFU/100 ml]
Vltava-Troja	2,870/1,252	60/5,400	1,300/567	48/4,800	1,940/992	50/5,400
Vltava-Podbaba	**27,800**/17,167	800/79,000	**9,610**/5,258	80/2,800	**19,800**/10,758	200/36,000
Vltava-Sedlec	**8,800**/4,145	600/20,000	1,800/1,045	130/5,200	**4,800**/2,655	400/13,000
Vltava-Klecany	3,790/2,575	130/11,000	1,640/691	90/2,100	2,490/1,668	110/6,000
Vltava-Řež	**7,820**/2,837	200/12,000	1,990/763	90/2,400	**4,540**/2,006	110/9,000
Drahanský stream	**12,000**/19,245	500/180,000	**3,700**/4,363	190/34,000	**12,000**/19,245	500/180,000
Únětický stream	**9,410**/5,981	110/32,000	**6,020**/2,177	200/7,400	**8,440**/4,501	990/22,000
Přemyšlenský stream	2,090/1,146	70/5,800	1,990/1,478	20/9,600	1,730/907	70/3,800
Klecanský stream	**117,000**/59,492	600/520,000	**76,200**/19,108	600/120,000	**93,600**/42,808	500/360,000
Podmoráňský stream	**37,900**/23,625	2,000/39,000	**20,800**/12,033	800/52,000	**27,700**/16,142	1,700/30,000

Note: P90 values exceeding EQS Government Regulation No. 401/2015 Coll. are marked in bold

The results were further evaluated according to Decree No. 238/2011 Coll., which assesses water quality after the end of the bathing seasons (ideally 4) based on its determination according to the indicators listed in *Tab. 3*. Water is classified as "unsuitable" for bathing if the values of any of the indicators are higher than the values for "acceptable" quality. According to the above assessment, in the observed period, none of the Vltava's sampling sites achieved a quality acceptable for bathing. However, at the Vltava-Troja sampling site, in the period suitable for recreation (i.e., from May to September), the numbers of CFU in both indicators were found to be 100 % corresponding to the limits for "acceptable" quality. The sampling site is located near Troja slalom channel, where canoeists often come into contact with water. In the next section of the watercourse, below the inflow of the CWWTP, values below the limit for unacceptable quality appeared only sporadically. The situation was better with intestinal enterococci. At the Vltava-Řež sampling site, about 10 km from the CWWTP, in the period suitable for recreation (May to September), the numbers of CFU in both indicators were found to be already 70 % corresponding to the limits for "acceptable" quality. Some sampling was carried out after heavy rain, which negatively affected the water quality (*Fig. 15*).

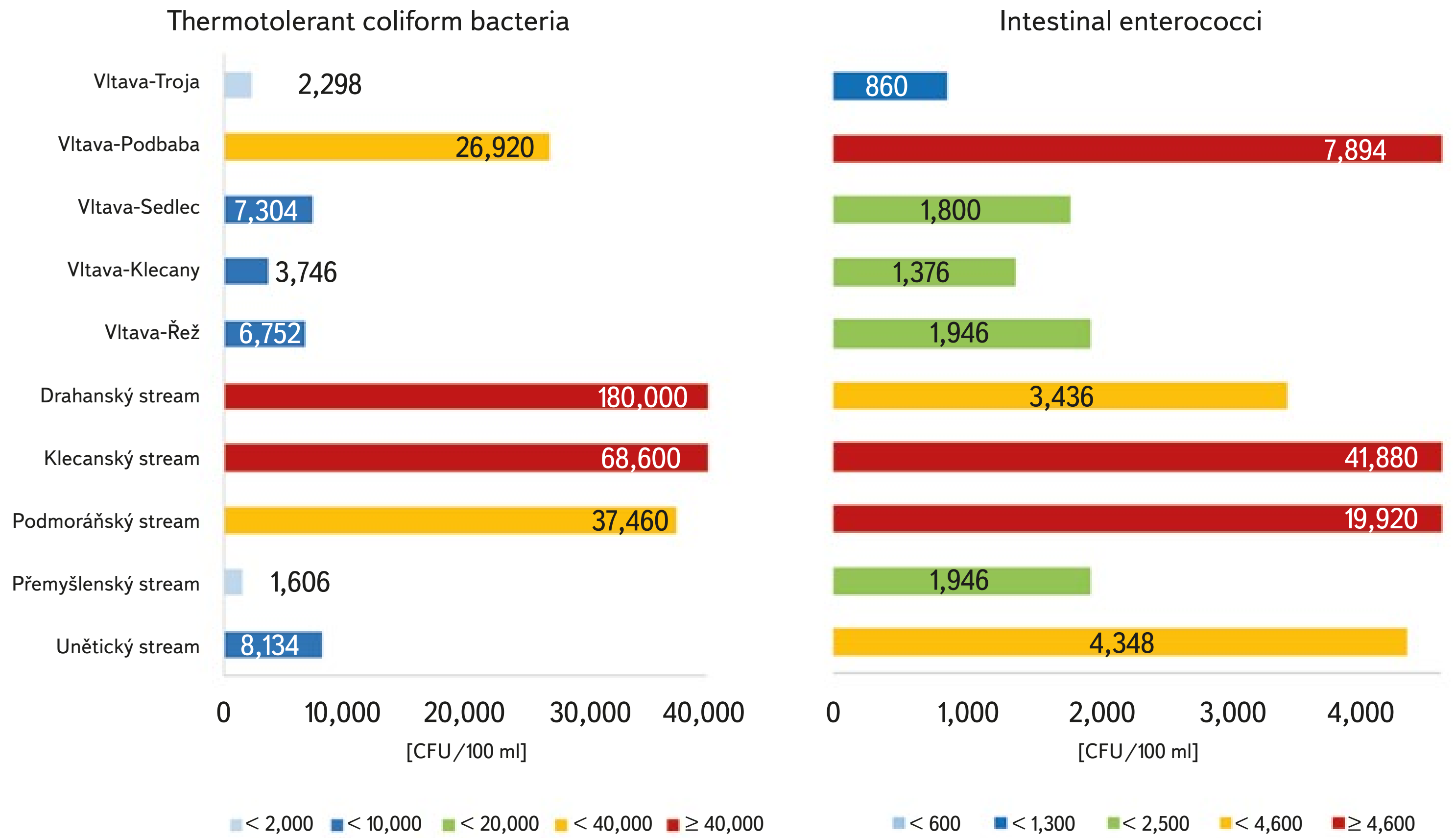
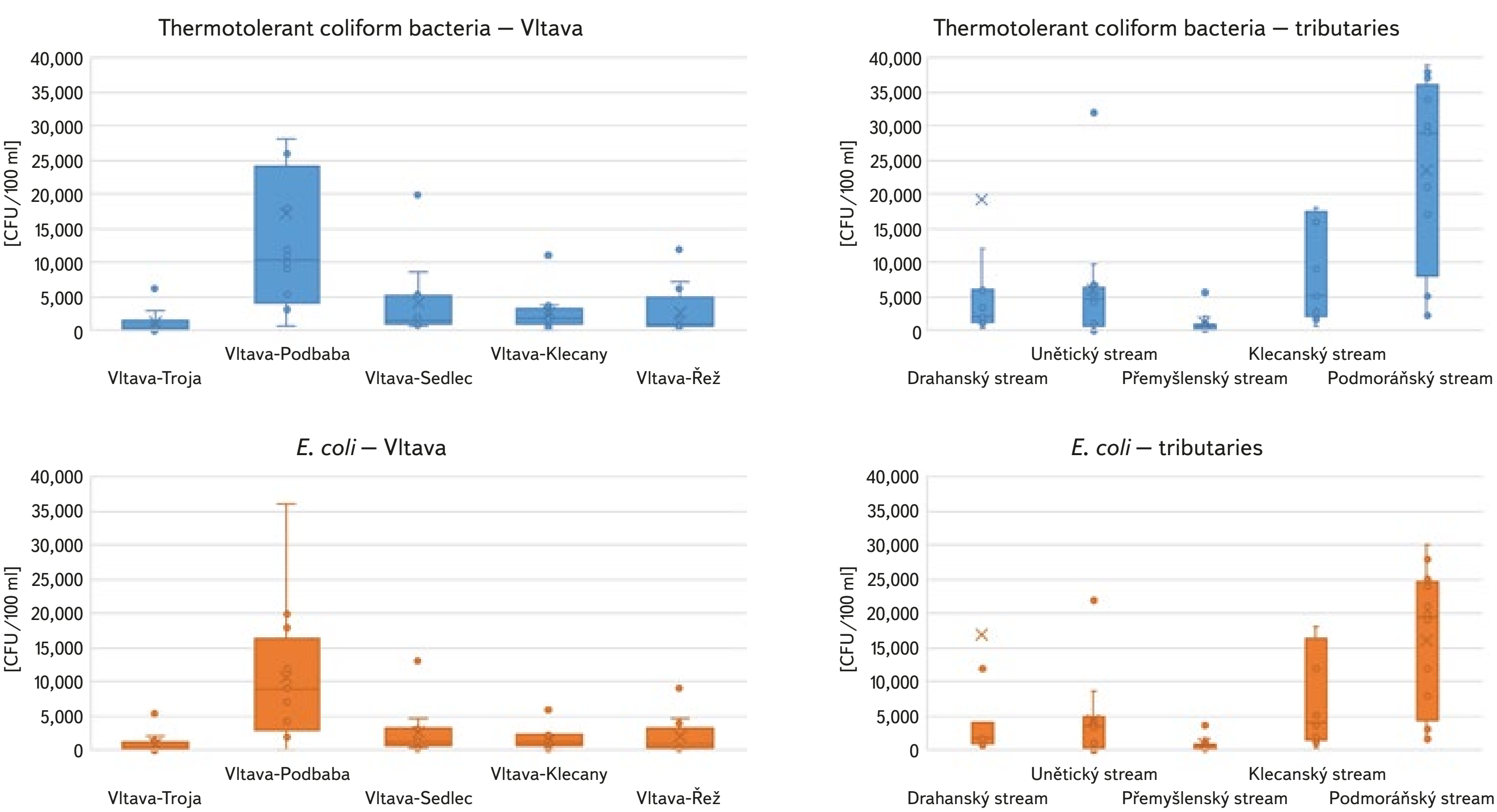


Fig. 5. Sampling site pollution rates for thermotolerant (fecal) coliform bacteria and intestinal enterococci according to Czech technical norm ČSN 75 7221



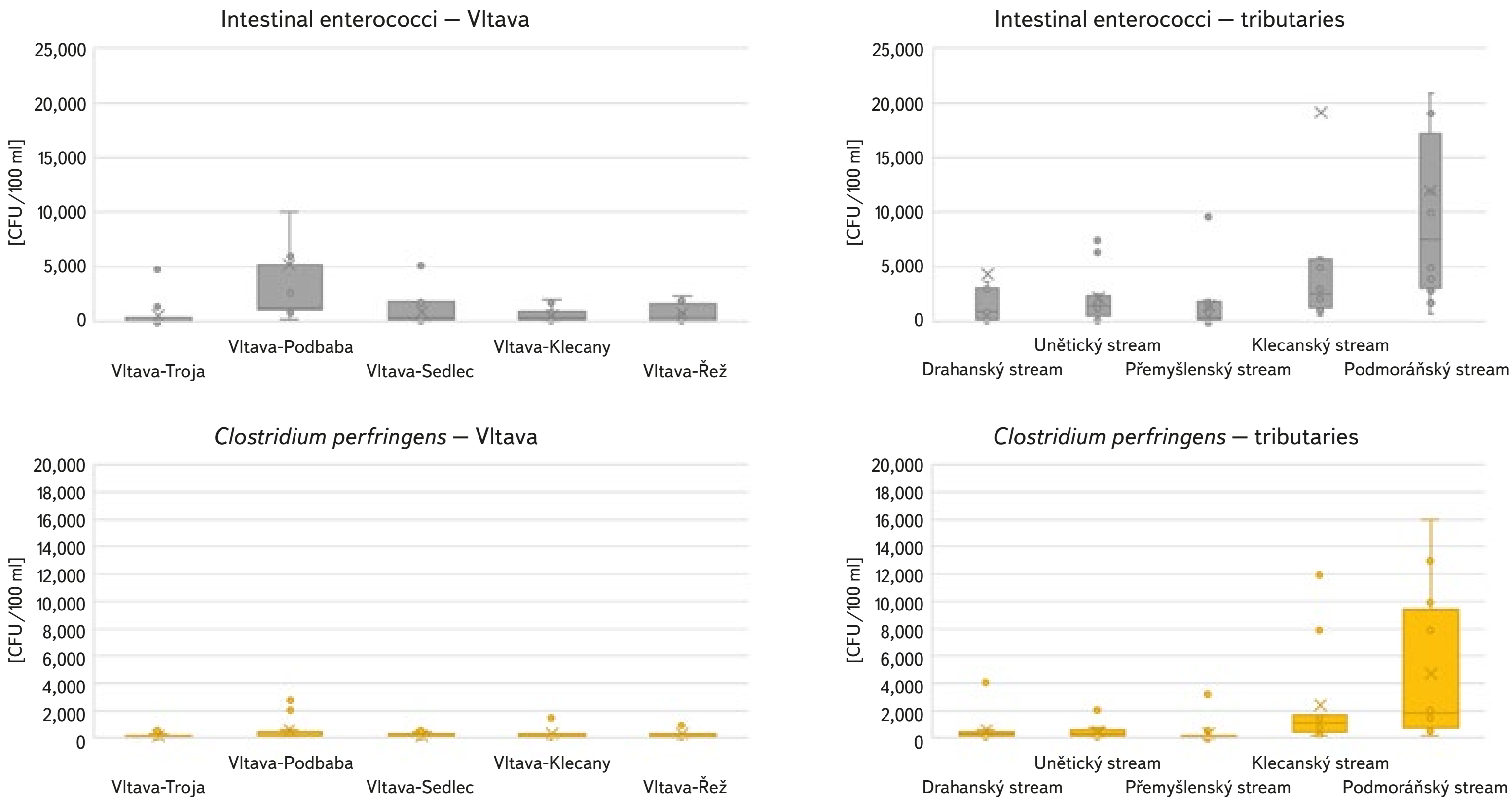


Fig. 6–13. Microbial water quality of monitored sites of the Vltava and its tributaries

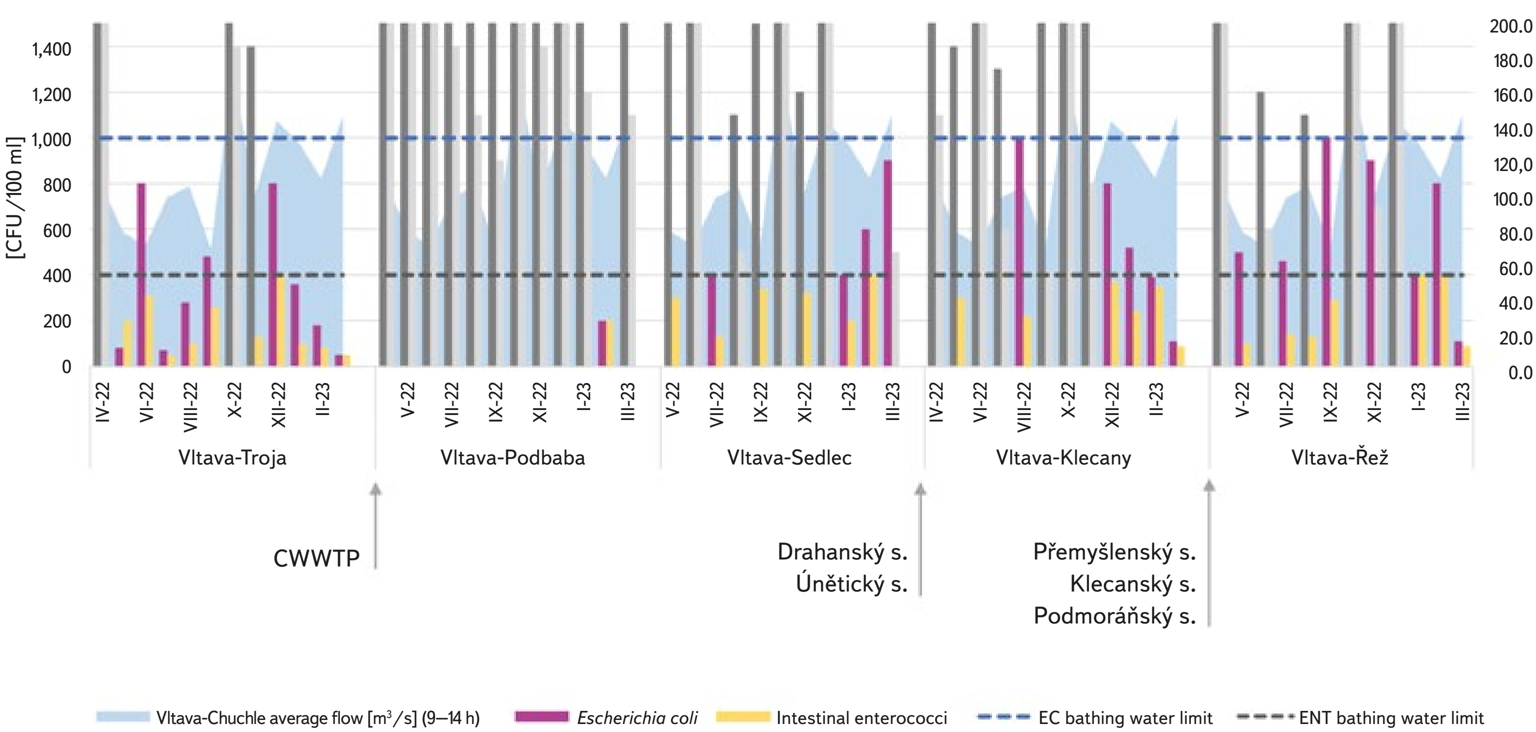


Fig. 14. Seasonal progress of selected microbial indicators in the Vltava; columns with values exceeding the bathing water limits are represented in grey – dark grey for *E. coli*, light grey for enterococci

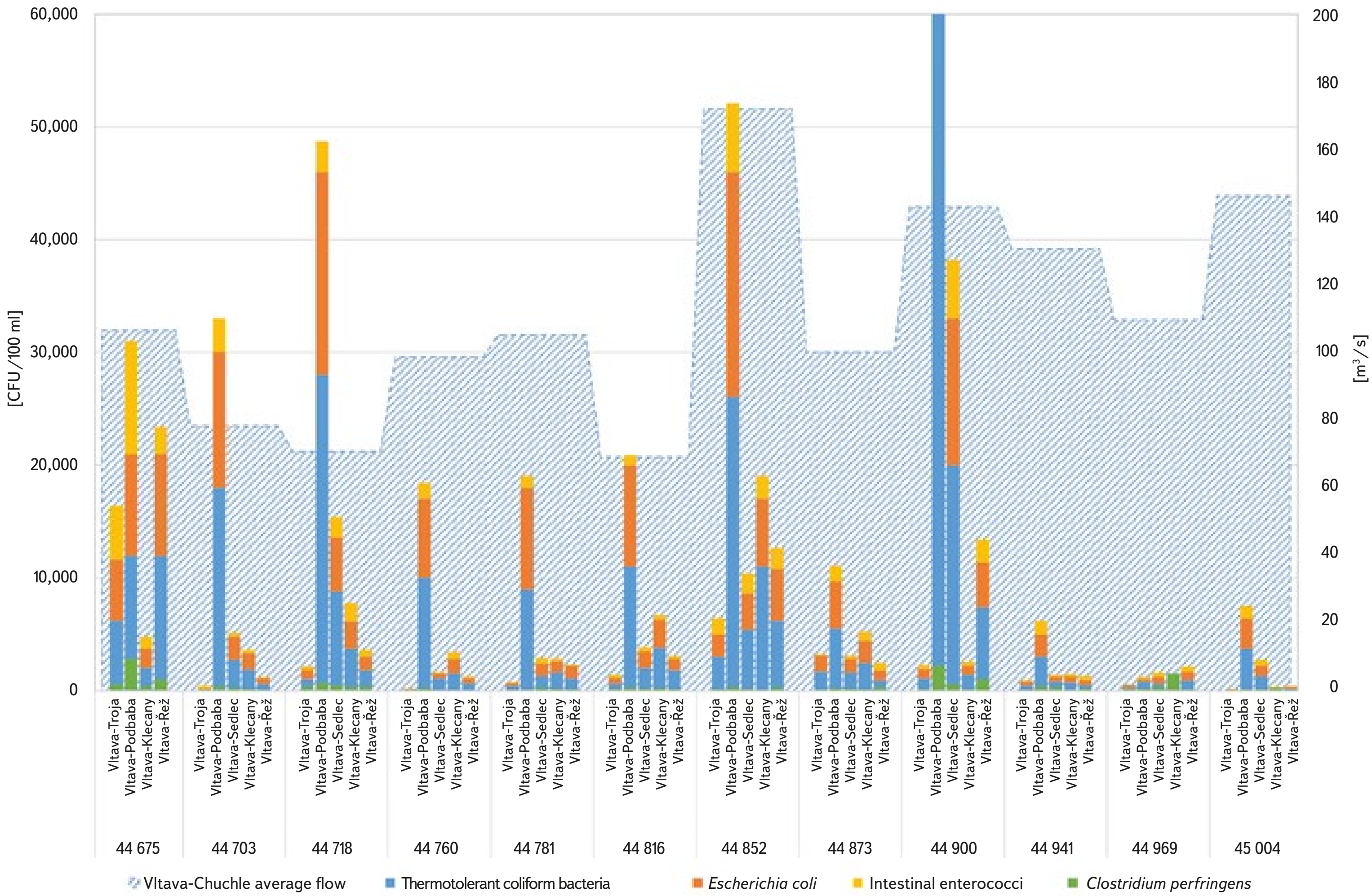


Fig. 15. Sum of selected microbial indicators during the monitoring in comparison with Vltava flow rate

DISCUSSION

The aim of this study was to monitor the current state of water quality in the Vltava from Troja to the footbridge in Řež, along with several important tributaries with an inflow from local WWTPs. Water quality in this part of the Vltava is not systematically monitored and suggests very strong pollution, both from the many sources below Prague and from the discharge of treated wastewater from the Prague CWWTP on Císařský ostrov. Annual monitoring of this area was aimed at identifying limitations in the usability of the Vltava water for its further use (e.g., recreation and irrigation). The results showed that the Vltava has huge capacity to absorb pollution and eliminate it. However, the use of water for recreation is completely limited in a relatively short section below the CWWTP inflow. After a few kilometres, however, the watercourse regenerates from the point of view of microbial contamination, probably due to strong dilution, sedimentation, and active self-cleaning processes. Although the study was not focused on monitoring changes due to climatic episodes, it was found that both extreme conditions (drought with low flows and heavy torrential rains) have a negative effect on water quality. Low flows will limit the possibility of diluting the incoming pollution, which was already visible at the control Troja sampling site; on the other hand, torrential rain worsens water quality in the Vltava and its tributaries due to the effect of surface pollution flushes and the inflow of flood-ways directly into the recipient watercourses.

The microbial quality of the water in the Vltava below Prague has not been systematically monitored in recent years or the data has not been published. The sampling sites monitored as part of the surface water monitoring programme are relatively less dense in the section of the Vltava below Prague due to the larger size of the water bodies. The Vltava is regularly monitored at the representative sampling sites of Vrané nad Vltavou and Zelčín. In Prague, water quality is monitored in detail at the Vltava-Podolí sampling site, and basic physico-chemical and microbiological indicators are monitored at the Prague-Troja sampling site. Pražské vodárny a kanalizace, a. s. also monitors the Prague-Podolí sampling site.

The first, completely unique bacteriological study of the Vltava was carried out in 1931 by Kredba and Dvořák [5, 12]. In this study, a one-time monitoring of the presence of microorganisms was performed. Sampling was done in a short time interval (3 days) in April to be as little affected by climatic and other factors as possible. Samples were taken from both banks in the marked section, which started above Prague at the Zbraslav bridge and ended below Prague under the weir in Roztoky. Sampling sites were chosen so that each source of pollution could be captured. In accordance with the methods of the time, "*bact. coli* numbers in 1 l" (modified Ficker-Partiš method on Endo agar) and "number of germs in 1 ml" were determined. We assume that the method of determining *bact. coli* could be comparable to today's method of determining coliform bacteria on Endo agar [4]. A comparison of historical and current data is shown in *Tab. 5.*

Another source of older data was the study by Baudišová [13, 14] in 1997, which dealt with the water microbial quality in the Labe and the lower Vltava. The study was focused on the quality of the water before the Vltava meets the Labe, and coliform bacteria and thermotolerant (fecal) coliform bacteria were monitored in it. The values found at the Podolí, Troja, Roztoky and Zelčín sampling sites are shown in *Tab. 5*. A comparison of the values of coliform bacteria in 1 l of water from the three periods indicated a significant decrease in microbial contamination since 1931 at the Podbaba and Roztoky sampling sites. In all three periods, an increase in microbial contamination below the CWWTP inflow is evident, while the current state is the most favourable thanks to advanced treatment technologies.

Tab. 5. Comparison of present fecal pollution situation with historical data

	1931 (Kredba)	**1996 (Baudišová)**		**2022–2023**
Sampling point	*Bact. coli* (left/right bank) – one-time sampling	Coliform bacteria (annual average)	Thermotolerant (fecal) coliform bacteria (annual average)	Thermotolerant (fecal) coliform bacteria (annual average)
			[CFU/1 000 ml]	
Podolí	-	77,000	22,000	-
Troja	-	57,000	23,000	12,500
Stromovka ferry	30,000/64,000	-	-	-
Podbaba	94,000/1,200,000	-	-	171,670 (left bank)
Roztoky above the weir	550,000/630,000	2,384,000	922,000	2,000*
Roztoky below the weir (Klecany)	400,000/450,000	-	-	25,750 (left bank)
Zelčín (before the Vltava meets the Labe)	-	1,309,000	576,000	-

* One-time sampling on 25th April 2022

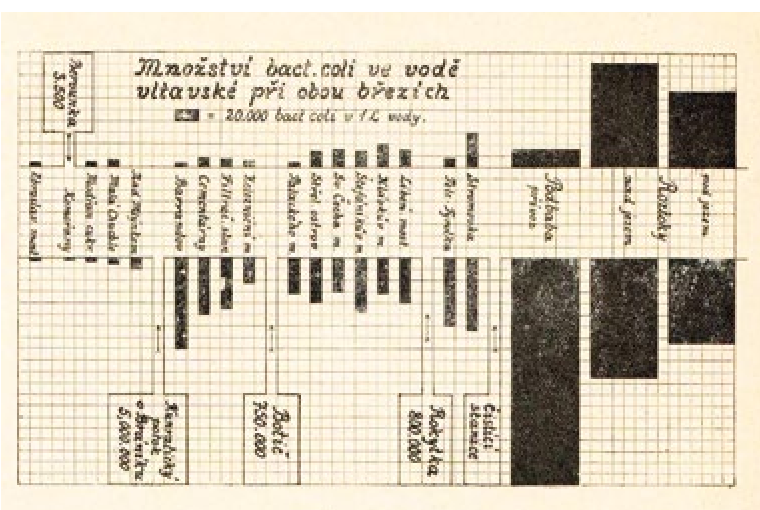


Fig. 16. Amount of bact. coli in the Vltava in 1931

CONCLUSIONS

The updating of historical data describing microbial contamination of water in the Vltava below Prague showed a favourable trend in development, which is a consequence of improving technological processes of wastewater treatment.

It was found that fecal contamination at the Vltava-Troja control sampling site is unexpectedly low, despite the fact that it receives pollution from many sources in Prague. In the period when it could be used for recreation, the water showed "acceptable" quality according to Decree No. 238/2011 Coll.

Water quality at the other sampling sites was strongly affected by discharged purified wastewater from both CWWTP water lines, and in the area near the sampling site, its further usability was strongly reduced, especially for recreation.

However, the condition quickly improved in the next section of the Vltava thanks to dilution, sedimentation, and cleaning processes; the water quality at more distant sampling sites already showed "acceptable quality" during some samplings during the period of possible summer recreation.

Although the study was not focused on monitoring changes due to climatic episodes, it was found that both extreme conditions (drought with low flows and heavy torrential rains) have a negative effect on water quality. Low flows will limit the possibility of diluting the incoming pollution, which was already visible at the Troja control sampling site; on the other hand, torrential rain worsens water quality in the Vltava and its tributaries due to the effect of surface pollution flushes and the inflow of flood-ways directly into the recipient watercourses.

The study showed relatively good potential for the possible use of the Vltava in Prague and below Prague, with the exception of the section strongly affected by the inflow of treated wastewater from the Prague CWWTP. In general, it would be advisable to focus on increasing awareness with a help of this and similar studies, so that water can be used more efficiently and, conversely, so that it does not represent a significant health risk when used inappropriately (possible presence of pathogenic microorganisms, including antibiotic resistance carriers).

With regard to the growing requirements for the protection of the health of the human population and improvement of water quality in streams to the level of the standards of European directives, it is necessary to focus more attention on the monitoring microbiological indicators of water quality than is ensured by the current routine monitoring system.

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Photo: H. Zvěřinová Mlejnková

Application for the parametrization and automatic running of the HEC-HMS rainfall-runoff model

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Keywords: hydrologic modelling — HEC-HMS — HEC-RAS — GIS — automatic launching — parametrization of models

ABSTRACT

This article presents an application developed in the Czech Hydrometeorological Institute (CHMI) to support hydrologic modelling using the HEC-HMS model as the primary used rainfall-runoff model. The application enables group editing of selected parameters of the model schematization, automatic running of simulations, display of selected simulation results, and communication of the HEC-HMS model with GIS and other selected models, e.g., HEC-RAS or MIKE 11. The application is designed to use only freeware and open source libraries and is capable of operating under both Windows OS and UNIX/Linux OS. This article briefly describes the current state of the application development and its functionality, even for readers without major IT background. Further development is outlined in the last part of the article. Further development of the application is aimed at higher support for hydraulic modelling at the level of communication between the HEC-HMS and HEC-RAS models, as well as at the level of automatic parameterization and launching of the HEC-RAS model and its communication with other tools, e.g. hydraulic model MIKE 11 or GIS post-processing of the results.

INTRODUCTION

The HEC-HMS (Hydrologic Engineering Center Hydrologic Modeling System) software for rainfall-runoff modelling is one of the most widely used worldwide and its popularity is growing. One of the main reasons is the fact that it is distributed as freeware, including rich documentation [7]. Other reasons include the ever-expanding palette of methods for hydrological and hydraulic transformation in semi- and fully distributed solutions (e.g., SCS-CN, Green-Ampt, SAC-SMA, kinematic wave approximation, Muskingum-Cunge, linear reservoir) and also the fact that it is validated and listed as a FEMA/NFIP industry standard [8]. Last but not least, it is also the possibility to communicate with the HEC-RAS hydraulic model and the HEC-ResSim model for operational simulation and optimization of water management systems, while the integration possibilities are significantly increased by the HEC-WAT (Watershed Analysis Tool) and HEC-RTS (Real Time Simulation) platforms. Another significant advantage is the possibility of operation on multiple operating systems, namely Windows, UNIX/Linux, and macOS. This software is used in CHMI for assessment activities, hydrological analyses and, at the Ostrava branch, together with the HYDROG rainfall-runoff model, for operational hydrological forecasting within the framework of the Flood Warning and Forecasting Service (FWFS) of the Czech Republic. Other aspects are also important for operational hydrological forecasting; the most fundamental ones include the possibility of automatic or semi-automatic adjustment of selected parameters, calibration and optimization, as well as automatic launching. The HEC-HMS software has an advanced API (Application Programming Interface) in the new versions based on the Java, Python, and Jython languages. For this reason, an application that makes these automatic and semi-automatic functions of HEC-HMS available to users and expands them was gradually created at CHMI Ostrava. The basic motivation was to shorten the processing time of the input and output data of rainfall-runoff modelling, as well as the full or partial automation of some steps within the rainfall-runoff modelling itself, for example updating the parameters of the runoff loss methods according to the indicator of previous rainfall, or conversion of schematics between the SCS-CN and Green-Ampt methods.

Operation of the HEC-HMS model at CHMI Ostrava

The HEC-HMS rainfall-runoff model has been gradually introduced and tested at the CHMI Ostrava branch since 2013. It has been routinely operated to predict flows on selected flood warning profiles on watercourses within the branch's territorial jurisdiction since 2017, and serves as a support system that is used during the decision-making process when issuing warning information on flood phenomena within the Integrated Warning Service System [5]. Data for rainfall-runoff modelling are exported from the CLIDATA database system, specifically from the SOMDATA module [3] in the required format and structure, and subsequently imported into the HEC-DSSVue database system [6], which uses the HEC-HMS model along with other USACE/HEC tools as well. After the actual calculation in the HEC-HMS model, the results are then exported from the HEC-DSSVue database, and then again, in the required format, imported back into the CLIDATA database for further use in operational practice.

For the actual prediction of flows in the HEC-HMS model, the Forecast Alternatives module (hereafter Forecast) is available in which the date and time of simulation and prediction are set; subsequently, the module is connected to a specific basin model (Basin), the meteorological model is specified, and the configurations are set that can be used to adjust (calibrate) model parameters (set methods of hydrological and hydraulic transformation of rainfall and base runoff) [7]. The advantages of using it in everyday operation are a clear user environment, the speed of the calculation itself, and the possibility of calibrating individual parameters. Due to the steps described above, automation of individual parts of the calculation is a next step to make the work more efficient and quicker. The result should be the acceleration of data export as well as the simplification and acceleration of the actual setting of the Forecast module, especially changes of parameters for calibration and automatic changes of simulation and prediction time.

Description of the interface and application functionalities

As HEC-HMS itself is multi-platform, the application was also created in a variant for OS Windows and OS Linux (tested on openSUSE, Mageia, and Ubuntu distributions). Another requirement was modularity, where the addition or change of functions does not have to mean an intervention in the basic code of the application. The programming languages and development environments used were Microsoft Visual Studio NET Enterprise 2022 (C++ and some Visual Basic modules), Java (Apache NetBeans), Python and Jython (Visual Studio Code or IronPython). The accompanying scripts and batch files were created in Windows PowerShell or Bash (Bourne Again Shell) for Linux.

The basic functionalities of the application include:

1. Automatic launching of the HEC-HMS model including automatic rewriting of time parameters of control files (Control or Forecast).
2. Automatic update of scripts for downloading data from DBS ORACLE (CLIDATA) according to the time of launching imports and simulation.
3. Automatic or semi-automatic adjustment of the parameters of the selected methods according to the indicator of previous rainfall (currently for the SCS-CN and Green-Ampt methods).
4. Conversion of model schematizations between the SCS-CN and Green-Ampt methods.
5. Automatic and mass editing of selected parameters in Forecast files (i.e., setting of parameters, zones and forecast alternatives).
6. Viewing and basic editing of GIS data by schematization (using GDAL, SharpMap, and MapWindow GIS libraries).
7. Statistical evaluation of simulated hydrographs (e.g., according to the Nash-Sutcliffe coefficient).
8. Display of simulation results (dispatch window for running hydrographs and hyetographs).
9. Connection with HEC-RAS and DHI MIKE 11 hydraulic models (transmission of hydrographs for selected computing nodes and update of simulation time parameters for continuous flow).
10. Data exports to MS Excel or ASCII formats (CSV).

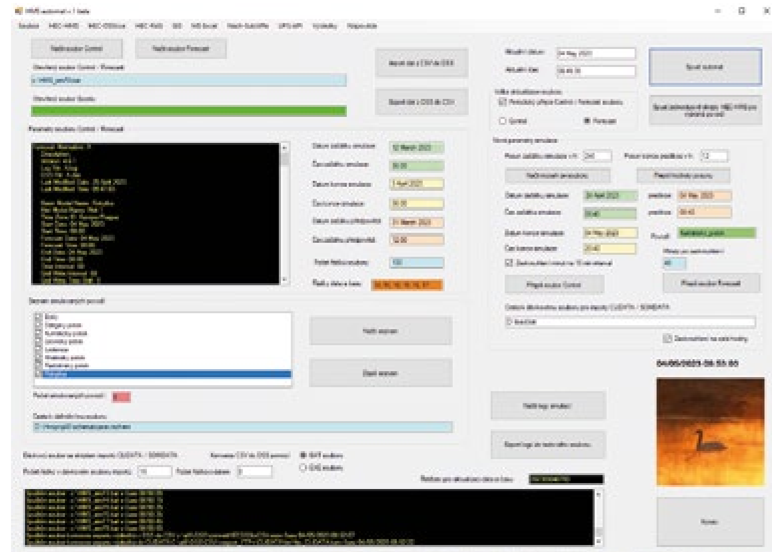

Fig. 1. Basic user interface and the main window of the application

The basic interface and main window of the application is shown in *Fig. 1*, while other functionalities and windows are run from the main menu.

The window for editing parameters of schematizations based on the SCS-CN and Gren-Ampt methods is illustrated in *Fig. 2*. The schematization editing function loads key parameters from the Basin file, for example in the case of the SCS-CN method, initial loss values and CN curves for individual basins. These can then be adjusted according to the indicator of previous rainfall or with a conversion coefficient. In the case of the SCS-CN method, it is an adjustment according to AMC (Antecedent Moisture Conditions) [1, 4, 7]; in the case of the Green-Ampt method, it is again a parameter of initial loss, suction buoyancy and hydraulic conductivity [1, 7]. Schematization conversion between the SCS-CN and Green-Ampt methods also works on these principles. This conversion is independent of the used method of hydraulic transformation and basic outflow, so it works only with selected parameters of outflow loss (Loss method) [7].

Given that HEC-HMS in versions 4.x has strong support for GIS functions and data types (ESRI shapefile, ASCII raster, GeoTIFF, etc.) and it can be expected that the schematization of models takes place dominantly in a GIS environment, the application as such has an input GIS data browser (both raster and ESRI shapefile support). For this functionality, it is necessary to have the GDAL libraries installed; the other libraries are included directly in the application. All libraries for GIS support are open source, so it is not necessary to install commercial GIS software on a computer. The GDAL libraries are installed together with HEC-HMS for both Windows OS and Linux OS (also GRASS GIS or QGIS). Path setting for both operating systems is most often done automatically, so no further user intervention is required. The scripts for running the HEC-HMS simulations themselves use these default directory paths.

The application at the level of automatic running of imports and conversions of data and running of HEC-HMS scripts enables continuous operation, where the user only sets the intervals at which individual steps are repeated. During this automated run, it is possible to work interactively in other user windows, such as GIS, schematization update, dispatcher window for simulation results, or statistical evaluation of simulations.

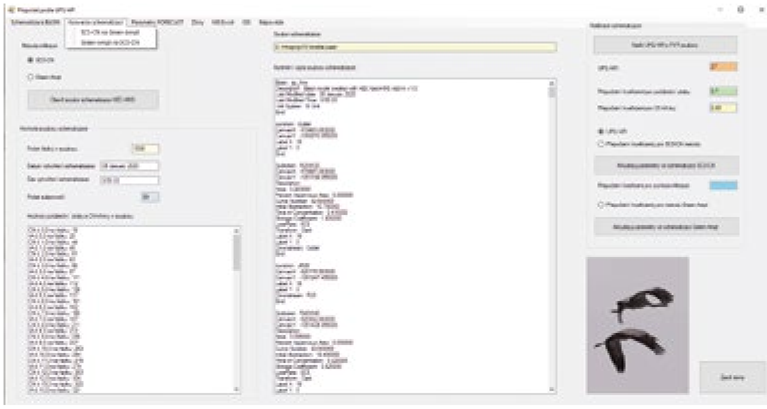

Fig. 2. Graphical interface for the automatic update and conversion of HEC-HMS schematizations

Fig. 3. Window for the result viewing of HEC-HMS simulations for the decision making

Further application development

The goal of the development and subsequent operation of this application is not to duplicate the functions of complex interfaces, such as FEWS or HEC-RTS, but to support parameterization and automation of rainfall-runoff and hydraulic modelling for users who do not have experience in programming scripts and only have basic knowledge of the structure of data and files of HEC-HMS and HEC-RAS models. Since the support of the HEC-RAS model for OS UNIX/Linux is still being developed and its existing scripting options have been based on the VBA (Visual Basic for Applications) language [2], further development of the application's functionalities is planned mainly in this direction. Support documentation for the current version of HEC-RAS for OS Linux can be found on its website [9].

Another scope for development is represented by the simulation logs of the HEC-HMS model and the system for logging errors (Error), warnings (Warning) and notifications (Note) [7]. This, together with the report system, creates a complex structure of files and information, which may seem confusing, especially to novice users.

Therefore, work on a log filtering function is currently underway for the user to be able to choose which information is relevant to them, and this will then be displayed either in a dialog box or exported to a text file.

The last major area is the support of the MIKE 11/1D hydraulic model and the EPA SWMM urban hydrology model. The reason is the current absence of the ability to simulate flow in pipes and closed profiles at the level of the HEC-HMS model.

So the basic motivation remains the same – the development of a functional application that simplifies and accelerates work with HEC-HMS and HEC-RAS models and streamlines their communication with the HEC-DSSVue data set manager, database systems, GIS, or other modelling tools for interactive user work and automatic running of simulations.

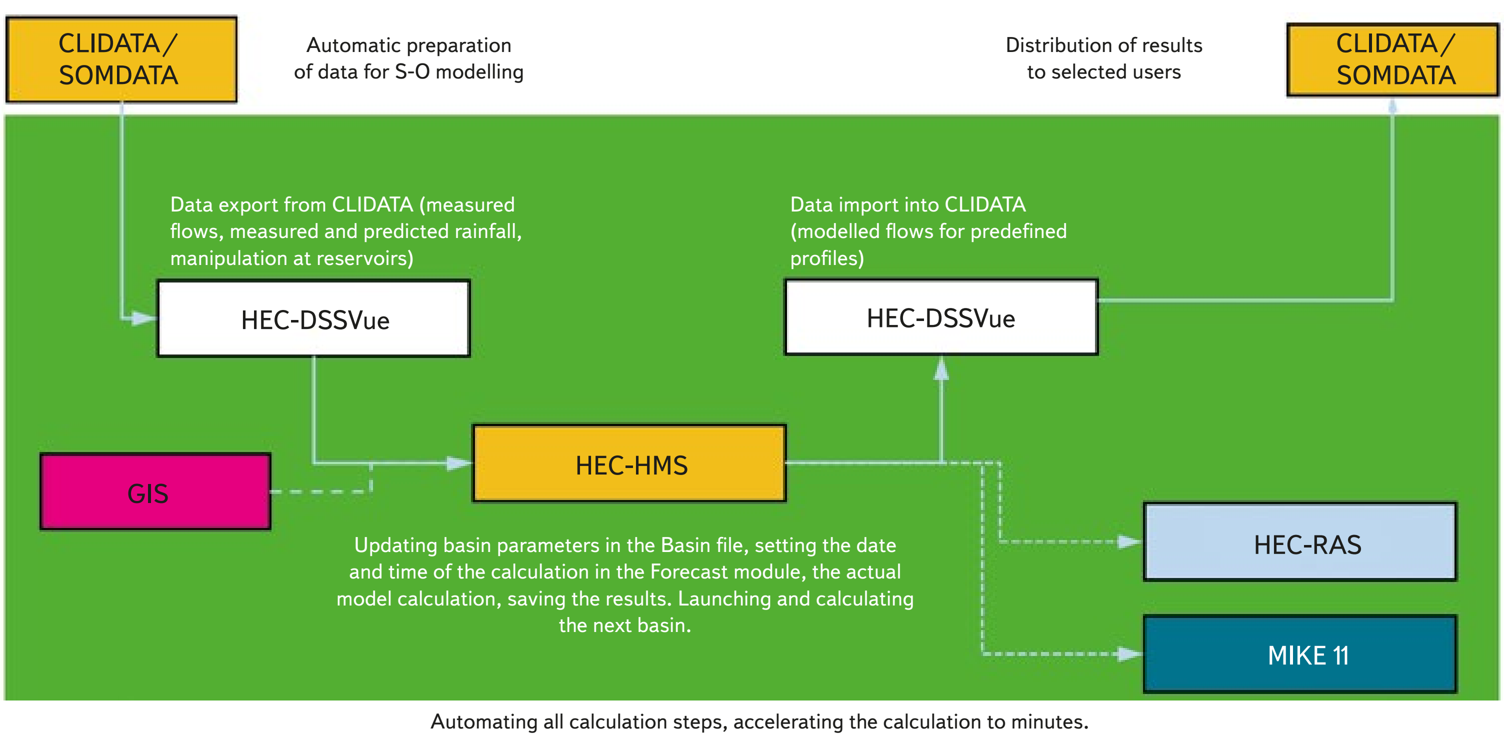

Fig. 4. Data flow in the application

CONCLUSION

At this time, the goal of streamlining and accelerating partial steps within the entire cascade of operational hydrological forecasting, including the automation of selected processes at the level of data processing and rainfall-runoff modelling itself, has been fulfilled, with the development of other functionalities continuing. The basic diagram of the data flow in the application is illustrated in *Fig. 4*. The connectors with a solid line show the basic data flows that are repeated at each iteration of the calculation, the connectors with a dashed line show the optional data flows that are controlled by the user manually or within the parameterization of the automatic calculation.
The application was created for the needs of the CHMI operational hydrological forecast; however, since the HEC-HMS and HEC-RAS models are used in the Czech Republic by other institutions and experts, the basic version for OS Windows (with the limitation of selected functionalities for the needs of operational forecasting of FWFS CR) will be available for download in the future, or it is possible to contact the authors of the application and the article.

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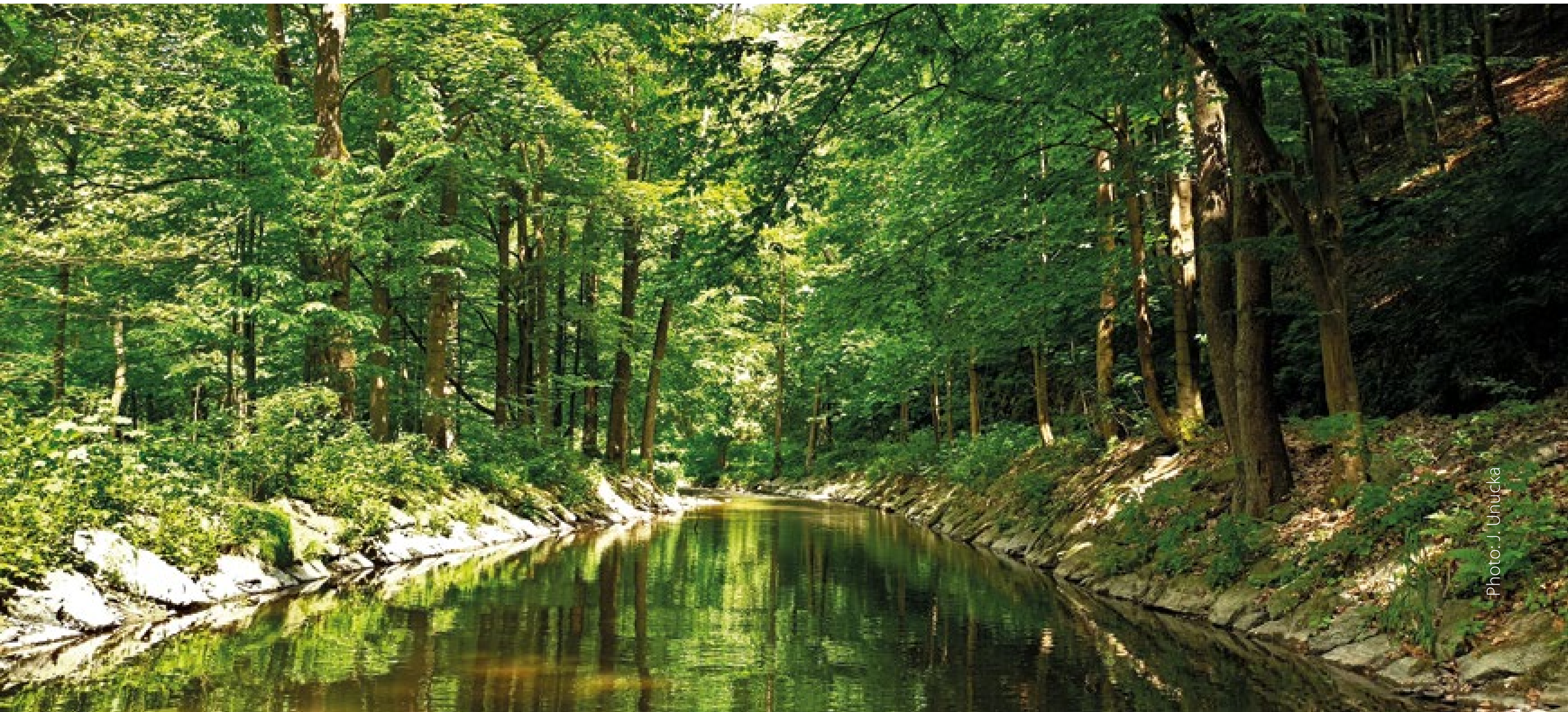

Atmospheric deposition as a possible source of surface water pollution

(Results of the project, part 2. – polycyclic aromatic hydrocarbons)

FRANTIŠEK SÝKORA, TOMÁŠ MIČANÍK, SILVIE SEMERÁDOVÁ, IVAN SUCHARA, NIKOLA VERLÍKOVÁ, JULIE SUCHAROVÁ

Keywords: atmospheric deposition — surface water — pollution sources — polycyclic aromatic hydrocarbons

ABSTRACT

From October 2020 to September 2021, in two forest micro-catchments in the Czech Republic, the quality of wet atmospheric deposition (bulk and throughfall) was monitored simultaneously with the surface water quality in the local watercourse, humus, and the moss species *Pleurozium schreberi*. An evaluation is presented of the 15 polycyclic aromatic hydrocarbons (PAHs) burden of the above-mentioned matrices. The first site was chosen in the Beskid Mountains in the Moravian-Silesian region, in the cadastre of the village of Bystřice in the upper basin of the Suchý stream (altitude 590 to 835 m a.s.l.). This area is affected by industrial activities. The second reference site was chosen in the Bohemian-Moravian Highlands near Košetice observatory (altitude 520 m a.s.l.). A significant PAHs burden was confirmed at the Bystřice site. The concentration of Σ15 PAH during the monitored period in the bulk deposition was 0.785 ± 0.579 $mg.l^{-1}$ at the Bystřice site and 0.114 ± 0.110 $mg.l^{-1}$ at the Košetice site. In throughfall deposition, the concentration of Σ15 PAHs was slightly higher: 0.824 ± 0.670 $mg.l^{-1}$ in Bystřice and 0.203 ± 0.141 $mg.l^{-1}$ in Košetice. Significantly higher PAHs concentrations were found in the cold half of the year. The amount of atmospheric deposition of Σ15 PAHs in Bystřice was calculated at 1,098.7 $g.km^{-2}.year^{-1}$; in Košetice it is 10 times lower at 102.7 $g.km^{-2}.year^{-1}$. The topsoil and vegetation cover PAHs sorb. PAHs enter surface waters through erosion. The concentration of Σ15 PAHs in the Suchý stream at the Bystřice site was 0.026 ± 0.049 $mg.l^{-1}$, while in the Lesní stream at the Košetice site it was 0.033 ± 0.038 $mg.l^{-1}$. Total Σ15 PAHs flux by the Suchý stream (upper basin) accounts for only 1 % of the atmospheric bulk deposition in Bystřice and 2.8 % by the Lesní stream in Košetice. The ratio of fluoranthene and pyrene in the precipitation indicates the origin of PAHs pollution from combustion processes (FLT/PYR > 1) at both sites. In bulk deposition, this FLT/PYR ratio was 1.6 in Bystřice and 1.5 in Košetice, and 1.5 (Bystřice) and 1.6 (Košetice) in the throughfall. The river sediment burden with Σ15 PAHs in the Lesní stream (1.498 ± 0.138 $mg.kg^{-1}$) was more than in the Suchý stream (0.340 ± 0.109 $mg.kg^{-1}$) due to the different granularity with a significantly higher proportion of fine soil particles, although the content of Σ15 PAHs in the upper soil layer was 3.2 to 3.7 times lower in Košetice than in Bystřice. Similarly, the content of Σ15 PAHs in *Pleurozium schreberi* was 3 times lower at Košetice than at the exposed Bystřice site.

INTRODUCTION

Polycyclic aromatic hydrocarbons (PAHs) form an important group of substances, most of which show adverse effects on aquatic organisms and humans. Due to their persistence, they have the ability to remain in the aquatic environment for a long time. Directive 2008/105/EC of the European Parliament and of the Council [1], as amended by Directive 2013/39/EU [2], included selected PAH substances in the list of priority substances, of which anthracene, benzo[a]pyrene, benzo[b]fluoranthene, benzo[k]fluoranthene, benzo[g,h,i]perylene, and indeno[1,2,3-cd]pyrene are identified as priority hazardous substances. According to Framework Directive 2000/60/EC establishing the framework for Community action in the field of water policy [3], Article 16 (Strategy against pollution of water) there is a need to reduce discharges, emissions, and leaks of these substances in a targeted manner; in the case of priority dangerous substances it is even a matter of stopping or gradual elimination of input into the environment. The requirements of the above Directives were implemented in Czech Government Radulation No. 401/2015 Coll. [4].

Polycyclic aromatic hydrocarbons are ubiquitous substances found in all components of the environment. They are one of the most common reasons for failure to achieve good chemical and ecological status of surface waters (note: PAHs specified as priority substances are currently subject to chemical status assessment, other PAHs belong to the group of specific pollutants, which are one of the components of the ecological status assessment of surface water bodies). The environmental quality standard expressed as an annual average is the strictest for benzo[a]pyrene (0.17 $ng.l^{-1}$), followed by fluoranthene (6.3 $ng.l^{-1}$) [4].

This was also the reason for the inclusion of the group of PAH substances in the TA CR project SS01010231 *"Impacts of atmospheric deposition on the aquatic environment with consideration of climatic conditions"*, which was realized from March 2020 to December 2022. The aim of this project was to verify the level of pollution in selected components of the environment, or to investigate the link between them with the impact on surface water quality in order to be able to better quantify this impact in the future, and to propose effective measures for achieving a good chemical status of surface waters in terms of PAH pollution. Two different forest micro-catchment sites were chosen: one with significant anthropogenic influence (the upper part of the Suchý stream basin in the cadastre of Bystřice municipality in the Moravian-Silesian Beskids) and the other in the reference area (the Lesní stream in the cadastre of Košetice municipality near Košetice climatological station).

POLYCYCLIC AROMATIC HYDROCARBONS IN THE ENVIRONMENT

Polycyclic aromatic hydrocarbons (PAHs) can be found in all components of the environment. This is due to the fact that the dominant source of pollution is combustion processes, which are of both natural and anthropogenic origin. The most important natural sources of PAHs are volcanic activity, vegetation cover fires, and some sedimentary rocks. Anthropogenic emissions of PAHs of a non-industrial nature arise from the targeted burning of vegetation, from domestic heating, and smoking. In industry, the dominant sources of pollution are the production of coke, electric and thermal energy, smelters, selected branches of chemical industry (tar processing, catalytic cracking, soot production), and also food industry [5].

The rate of PAH production depends on the combustion process and the type of fuel used. It is highest during incomplete combustion, which happens mostly in local domestic heating. The mechanism of PAH formation involves two processes: pyrolysis and pyrosynthesis. Pyrolysis produces PAH precursors, which recombine at temperatures of 500 to 800 °C to form relatively stable aromatic hydrocarbons [5]. In the case of incomplete combustion, the emissions of primary PAHs contained in the fuel can also occur. The primary emissions of PAHs into the air are predominantly in the gaseous phase, but their condensation and sorption to fine dust particles occurs relatively quickly during the cooling of flue gases. The rate of sorption depends on the molecular weight. According to selected characteristics of physico-chemical properties (Henry's constant, partition coefficients K_{ow}, K_{oc}) we can divide PAHs into:

- low molecular weight (152 to 178 $g.mol^{-1}$) – acenaphthene, acenaphthylene, anthracene, phenanthrene and fluorene (consisting of 2 to 3 aromatic nuclei),
- medium molecular weight (202 $g.mol^{-1}$) – fluoranthene, pyrene (consisting of 4 aromatic nuclei),
- high molecular weight (228 to 278 $g.mol^{-1}$) – benzo[a]anthacene, benzo[b]fluoranthene, benzo[k]fluoranthene, benzo[a]pyrene, benzo[g,h,i]perylene, dibenzo[a,h]anthracene, chrysene, indeno[1,2,3-c,d]pyrene (consisting of 5 or more aromatic nuclei) [6].

This division is important because the above-mentioned groups of PAHs behave differently in the environment. We can show the differences, for example, using Henry's constant, which states the partial pressure of the gas above the solution, expressed in the unit $Pa.m^3.mol^{-1}$. For naphthalene it is 43.00, acenaphthene 12.17, pyrene 0.919, and benzo[k]fluoranthene 0.044 $Pa.m^3.mol^{-1}$ [7]. The difference is within several orders of magnitude; the higher the molecular weight, the easier and faster the binding to fine particles.

When burning coal, mainly phenanthrene (over 50 %), anthracene, and fluoranthene to a lesser extent, and a small amount of benzo[a]pyrene (0.5 to 2.4 %) are produced [6]. Combustion products are also PAH derivatives, mainly nitroaromatics.

In the atmosphere, mainly low molecular weight PAHs are broken down by sunlight. High molecular weight PAHs are sorbed to particles of different sizes. The smaller the particles, the longer the degradation time is needed to break down the PAH (up to several weeks), and the longer the PAHs remain in the atmosphere. From the atmosphere, PAHs are introduced into other components of the environment by dry and wet deposition. Due to their longer lifetime, high-molecular-weight PAHs are transported from the source over long distances, depending on climatic conditions and the time of year. In winter, the concentration of PAH in the air is significantly higher than in summer. This is due to higher emissions from combustion processes combined with lower efficiency of photodegradation processes in the cold part of the year.

From the atmosphere, PAHs reach vegetation and the earth's surface through dry and wet deposition. On agricultural soils, PAHs penetrate into deeper soil layers due to ploughing, while in other cases they remain in surface layers. Low molecular weight PAHs partially volatilize back into the atmosphere or are decomposed by photochemical processes. Biodegradation by microorganisms is also present, which is the predominant factor in the decomposition of primary PAHs. The rate of degradation depends on the soil type and organic carbon content. S. Thiele-Bruhn studied the kinetics of PAH degradation in soils contaminated by industrial activity (gas industry, coke plants) [8]. Fine soil with a particle size below 2 mm from 11 sites with a predominance of loamy-sandy soils was placed in Mitscherlich containers and fertilized with equal amounts of phosphorus and potassium in order to stimulate microbial processes. The experiment took place for 168 weeks in natural conditions. The result was the determination of the degradation rate constant "k" and the decrease of individual PAHs expressed as DT_{50} (disappearance time). In the case of naphthalene and acenaphthene, the median DT_{50} was units of weeks (6.1 and 9.5, respectively), for anthracene and phenanthrene tens of weeks (70 and 92, respectively), for other high molecular weight PAHs it was over 100 weeks with a maximum of 522 weeks for benzo[k]fluoranthene. Thus, high molecular weight PAHs remain in the soil for a long time.

Particularly low molecular weight PAHs with 2 to 3 aromatic nuclei, which make up to 80 % of total PAHs, pass into the vegetation from the soil and the atmosphere through the root system and leaves. The relatively high concentration of naphthalene in crops is due to its higher solubility in water [9]. High molecular weight PAHs are sorbed on the surface of vegetation. PAHs reach surface waters through erosional washes from soils, vegetation, and from the paved surfaces of roads and urban agglomerations. This type of transfer in terrestrial systems dominates over bulk deposition. High molecular weight PAHs preferentially bind to fine particles of undissolved substances in water, and sediment in suitable places depending on the nature of the flow. In well-oxygenated streams, the process of PAH degradation is faster, both in the water column and in river sediment. The rate of microbial revival of the aquatic environment also plays a positive role in the process of their degradation. The present dissolved organic matter (DOM) accelerates the photodegradation of low molecular weight PAHs by facilitating the formation of reactive intermediates and, conversely, inhibits the photodegradation of high molecular weight PAHs (e.g., benzo[a]pyrene) by binding their molecules [10].

In surface waters, PAHs are a long-term cause of failure to achieve good chemical status. In the last evaluated three-year period from 2016 to 2018, a total of 54.7 % of surface water bodies failed or were not classified in the fluoranthene indicator and 99.3 % in the benzo[a]pyrene indicator [11]. The latter indicator is also problematic from the point of view of the difficulty of achieving a sufficiently low limit of determination by laboratory techniques in relation to the value of the environmental quality standard (EQS) expressed as an annual average.

The ubiquity of PAHs in the environment, the failure to achieve good water quality, and the danger to human health are the reasons why it is necessary to pay attention to these substances. The International Agency for Research on Cancer (IARC) has classified 60 polycyclic aromatic hydrocarbons into groups according to their potential carcinogenic effects to humans. Of the 15 PAHs monitored as part of the ATMDEP project, benzo[a]pyrene belongs to group 1 – "proven carcinogen". Group 2A – "probably carcinogenic to humans" includes dibenzo[a,h]anthracene. Group 2B – "suspected human carcinogen" includes benzo[a]anthracene, benzo[b]fluoranthene, benzo[k]fluoranthene, chrysene, indeno[1,2,3-c,d]pyrene. Group 3 – "unclassifiable" includes acenaphthene, anthracene, benzo[g,h,i]perylene, fluoranthene, fluorene, phenanthrene and pyrene. Benzo[a]pyrene is currently the only PAH representative in Group 1. In the human body, it metabolizes to PaP-7,8-diol 9,10-epoxide, which can damage DNA. For Group 3, there is still insufficient evidence of their carcinogenic effects [12]. It has to be noted that PAHs act in the mixture. Therefore, a number of authors have developed toxic equivalent factors (TEFs) for individual PAHs, which are related to the toxicity of benzo[a]pyrene (BAP = 1). Nisbet and LaGoy did so in 1992 [13]. They applied a higher TEF than for BAP in the case of DBA (TEF = 5). In the case of the other four PAHs (BAA, BBF, BKF, INP), TEF = 0.1. For ANT, BGP, and CHRY they applied TEF = 0.01. For other PAHs, the TEF is equal to 0.001. (The abbreviations used to denote PAHs are listed in *Tab. 2*.) Multiplying the concentration of each determined PAH by this factor and adding them up gives the equivalent concentration with respect to the toxic potential of benzo[a]pyrene.

METHODOLOGY

In the project, PAHs were investigated and evaluated which cause a failure to achieve good water status and, at the same time, which are expected to be transmitted through the air even at great distances from the sources of pollution.
In order to compare the presence of polycyclic aromatic hydrocarbons in individual components of the environment, samples of the following matrices were selected at the two sites:

- bulk, (monthly precipitation*),
- throughfall, (monthly rainfall*),

— surface water (monthly),
— river sediment (twice during the year),
— humus – a biologically stable humification layer (H, Oh horizon), after removal of forest fallout (Ol) and fermentation horizon (Of) (2x during the year – samples represent accumulated PAH deposition over a longer period of time – age of the forest),
— red-stemmed feathermoss (*Pleurozium schreberi*) (twice during the year – samples represent the average PAH deposition over the last three years of moss growth).

* For the analytical determination of polycyclic aromatic hydrocarbons in atmospheric deposition, it was necessary to obtain a sufficient volume of samples. At the Košetice site, there were three cases of insufficient amount of sample for analytical determination due to the low monthly rainfall total; therefore, in these cases, the rainfall samples were taken after a two-month exposure.

In aqueous samples, PAHs were analysed on an Agilent 1260 Infinity II liquid chromatograph with fluorescence detection. A Pinnacle II PAH 4 µm column, 150 x 4.6 mm (Restek), and a mobile phase with the composition A: methanol, B: water + 5 % methanol were used for separation. Sediments were lyophilized and sieved through a 2 mm sieve prior to extraction.

Polycyclic aromatic hydrocarbons in moss and humus samples were analysed on a Bruker EVOQ GC-TQ gas chromatograph by MS/MS. Red-stemmed feathermoss samples were collected in the autumn of 2020 and 2021 at three sites in the upper parts of the Suchý stream basin and in the vicinity of the Lesní stream in bulk (unaffected by throughfall deposition) in aluminium bags. After being transported to the laboratory in a cooling box, the moss samples were stored in a freezer and, after thawing, manually cleaned of unwanted impurities. For PAH determination, the upper green parts of the moss were torn off. The moss was then homogenized in a vibrating mill using liquid nitrogen and dried by lyophilization. PAHs were extracted with n-hexane. After evaporation, the extract was purified by gel permeation chromatography. Bio-Beads SX-3 styrenedivinylbenzene polymer gel was used. Humus samples were simultaneously collected in aluminium bags from the visually undisturbed Oh horizon at three sites in each micro-catchment and transported and stored like the moss samples. After drying by lyophilization, they were sieved to a size of 0.25 mm. PAHs were extracted with dichloromethane with the addition of Al_2O_3 and diatomaceous earth. PAH extractions from both moss and humus samples were performed at elevated temperature and pressure with a Dionex ASE 350 extractor.

For the project, model forest micro-catchments were selected that met the following criteria:
— proximity to CHMI monitoring points to monitor the amount of precipitation,
— sufficient number of places with red-stemmed feathermoss (*Pleurozium schreberi*),
— detection of anthropogenic influence on selected sites,
— sufficient water level throughout the sampling period (even in the case of low flows in the summer),
— minimizing the risk of theft or damage to rain gauges by strangers,
— suitability of the sites in terms of prevailing wind direction and landscape relief,
— integrated micro-catchment for monitoring the quality of atmospheric precipitation, surface water, and other environmental matrices.

Fig. 1. Location of the selected pilot sites

The following micro-catchments were selected as pilot areas on the basis of the above-mentioned criteria:
— The model basin of the Suchý stream is located in the Moravian-Silesian Beskids east of the Ostrava and Třinec agglomerations (between Třinec and Jablunkov), which, due to the prevailing air flow, is heavily loaded by exposures to polycyclic aromatic hydrocarbons from the local metallurgical and power engineering industries. In Jablunkovská brázda, local heating plants from concentrated and scattered buildings are also an important source of emissions. The share of long-distance transmission in the total load of PAHs in the Třinec area, characterized by suspended PM2.5 particles, is up to 10 % [14]. In its upper part, the Suchý stream valley is closed from the south by Javorový hill (627 m a.s.l.), which, towards the east, creates a ridge connected to the main ridge formed by the peaks of Polední (672 m a.s.l.) – Hrbel (727 m a.s.l.) – Loučka (835 m a.s.l.) and Filipka (771 m a.s.l.). The Suchý stream valley is open to the west towards the Třinec and Bystřice agglomeration. About 70 % of the upper part of the Suchý stream basin is made up of forests, the rest is meadows. Mixed forests prevail, with spruce in the highest parts. Beech stands make up to 85 % in and above the selected site. There is no direct source of pollution in the original upper part of the Suchý stream model area. The area of the model part of the basin is 0.462 km^2. The Suchý stream is part of the basin of the HOD_750 – Hluchová water body from the spring to the confluence with the Olše, which, in the third planning cycle, does not reach good status due to higher PAH concentrations. In the text, the Suchý stream basin (*Fig. 2*) is referred to as BY after the name of the nearest village, Bystřice.

Fig. 2. Suchý stream site, Bystřice (Source: HEIS TGM WRI)

— The Lesní stream model basin, located in the Bohemian-Moravian Highlands northwest of the village of Košetice in the Borek forest near the middle part of the Anenský stream, river km 0.7, which then flows into the Martinický stream at 23.1 river km. The Lesní stream basin is part of the long-term integrated monitoring of environmental components of the Košetice National Atmospheric Observatory. The monitored basin is located 1 km south of the observatory; its area is 0.292 km^2. Approximately 90 % of the basin is forested, the rest is agricultural land. The forested part is mostly covered with spruce monocultures; the predominant stands are around 90 years old with a mixture of pine, beech, larch, and birch. The Lesní stream is the only permanent tributary of the Anenský stream. The stream is part of the DVL_0440 Martinický stream basin, which achieved good chemical status in the second and third planning cycles, and environmental quality standards according to Government Regulation No. 401/2015 Coll., were not exceeded in terms of PAH indicators. The site is not in an area with a significant PAH deposition; it is outside continuous settlements and outside the direct reach of significant sources of pollution. Therefore, it was chosen as a suitable reference site for comparison with the selected more anthropogenically loaded site of Bystřice. In the text, the Lesní stream basin (*Fig. 3*) is designated KO after the nearest village of Košetice.

Fig. 3. Lesní stream site, Košetice (Source: HEIS TGM WRI)

In October 2020, monitoring of atmospheric precipitation in monthly campaigns was started at both sites (*Tab. 1*). In the case of insufficient rainfall, a two-month rainfall sample was used (sample volume required was 2,000 ml). Rain gauges were installed at the sites to capture bulk precipitation, and in the forest stand to capture throughfall precipitation. For the collection of precipitation for PAH determination, a rain gauge was made for a stainless steel container with a collection area of 52.4 cm^2 (*Fig. 4*). The upper part of the rain gauges was equipped with a stainless steel bowl with holes so that the fall of coarse solid particles and insects did not get into the collected precipitation sample. A conifer (spruce in both cases) was chosen for the throughfall exposure, because precipitation was also collected in winter. The amount of precipitation recorded in individual campaigns was measured and compared with data on the total precipitation for the same period from the nearest climatological station of the Czech Hydrometeorological Institute (CHMI). At the same time, spot sampling of surface water from a nearby watercourse was carried out during the precipitation sampling. The average monthly flow for the Suchý stream was derived according to the flows at the nearest CHMI gauging station from the ratio of the areas of the given sub-basins. The average monthly flow of the Lesní stream was taken from regular measurements carried out by CHMI.

Tab. 1. Monthly precipitation amount and flows in sampling campaigns at the Bystřice and Košetice sites

Campaign	Campaign start date		Precipitation [mm]		verage monthly flow [$m^3.s^{-1}$]	
	BY	KO	BY	KO	BY	KO
1	06.10.2020	07.10.2020	197.3	85.2	0.0224	0.0009
2	05.11.2020	06.11.2020	22.1	9.2	0.0050	0.0007
3	07.12.2020	08.12.2020	59.5	25	0.0059	0.0004
4	06.01.2021	07.01.2021	149.9	70.2	0.0088	0.0010
5	05.02.2021	06.02.2021	90.3	14.3	0.0140	0.0021
6	05.03.2021	06.03.2021	96.3	23.5	0.0099	0.0010
7	06.04.2021	07.04.2021	148.1	42.2	0.0151	0.0007
8	06.05.2021	07.05.2021	179.2	86.2	0.0176	0.0029
9	07.06.2021	08.06.2021	75.4	100.7	0.0031	0.0008
10	07.07.2021	08.07.2021	198.8	126.3	0.0041	0.0014
11	06.08.2021	07.08.2021	224.8	30.1	0.0148	0.0007
12	06.09.2021	07.09.2021	83.4	32.1	0.0047	0.0003
Total precipitation [mm]			1,525.1	645.0	-	-
Average flow rate [$m^3.s^{-1}$]			-	-	0.0105	0.0011


Fig. 4. Rain gauge for precipitation capture for PAH analysis

Fig. 5. Rain gauges for capturing bulk and throughfall precipitations at the Bystřice site (5th November 2020)

Fig. 6. Rain gauge for capturing bulk precipitation at the Košetice site (8th February 2021)

On the basis of field data, i.e., the amount of precipitation and the detected concentrations of monitored parameters of 15 PAHs in precipitation, an estimate of the total deposition for a given experimental basin was calculated according to the following formula:

$$RS = \sum Sx*Cx$$

Where: RS is the annual precipitation in a given basin
Sx amount of precipitation in a given month converted to the basin area
Cx concentration of the pollutant in the throughfall sample of a given month

The results of PAH concentrations in throughfall deposition were used in the calculation, which is considered the best possible estimate of total atmospheric deposition and is used in particular for determining the input of substances when balancing the circulation of substances in small basins [15].

The estimate of the annual substance ratio of watercourses for a given pollutant was calculated on the basis of the derived flow rate and the detected concentrations according to the following formula:

$$LOD = \sum Qx*Cx*d$$

Where: LOD is riverine load
Qx average flow rate in the campaign
Cx concentration of the substance in the spot sample
D period

Values of concentration below the detection limit were not included.
Note: The usual procedure of using half the limit of determination was not chosen because the results of the two procedures show large differences.

RESULTS

In the following tables and graphs, the abbreviations listed in *Tab. 2* are used for individual PAH compounds.

Tab. 2. Abbreviations used to designate individual PAH compounds

Compound	Abbreviation	Compound	Abbreviation
Naphthalene	NAP	Chrysene	CHRY
Acenaphthalene	ACN	Benzo[b]fluoranthene	BBF
Fluorene	FLU	Benzo[k]fluoranthene	BKF
Phenanthrene	FEN	Benzo[a]pyrene	BAP
Anthracene	ANT	Dibenzo[a, h]anthracene	DBA
Fluoranthene	FLT	Benzo[g, h, i]perylene	BGP
Pyrene	PYR	Indeno[1, 2, 3-c, d]pyrene	INP
Benzo[a]anthracene	BAA		

For information, the PAH results in precipitation and in surface water are compared with the limits of good surface water status according to Government Regulation No. 401/2015 Coll. [4]. These limits are environmental quality standards (EQS) expressed as an annual average value of AA-EQS and as the highest permissible concentration of MAC-EQS. *Tab. 3* shows the result of the evaluation of surface water bodies where good chemical or ecological status was not achieved in terms of individual PAH indicators. The evaluation was carried out in 2016–2018 for the third river basin management plans. From the total of 1,118 surface water bodies, PAHs were measured in 53 to 65 % of them. The number of insufficient water bodies indicates the importance of these substances in terms of determining measures to achieve good surface water status.

Tab. 4 and *5* show the results of PAH measurements in surface water and precipitation (bulk and throughfall) at Bystřice and Košetice. Values that are higher than the values of environmental quality standards for good surface water status are marked in red. The measurement results in individual sampling campaigns are compared with the MAC-EQS value, the calculated average annual value is compared with the AA-EQS value. The results are shown in *Fig. 5–10*. They show a high load of PAHs in precipitation at the Bystřice site.

In *Fig. 7, 8, 10*, and *11*, the trend in PAH pollution in winter and summer precipitation can be observed. The increase in concentrations in the winter period is most probably influenced by the local heating stations and meteorological conditions (*temperature inversion?*) during the colder part of the year. Of the individual PAH compounds, concentrations prevail in atmospheric precipitation in the Suchý stream – Bystřice in the following order: fluoranthene, pyrene, bezo[a]anthracene, phenanthrene, chrysene, and benzo[b]fluoranthene, and in the Lesní stream – Košetice in the following order: fluoranthene, phenanthrene, pyrene, benzo[a]anthracene, chrysene and benzo[b]fluoranthene.

Although high molecular weight PAHs are more easily sorbed onto fine dust particles in the air, it was not confirmed that the content of these PAHs was unequivocally predominant in the throughfall deposition in Bystřice; it was mainly observed in winter and spring. In contrast, at the minimally loaded site at Košetice, a higher PAH load in the throughfall deposition was the rule.

For comparison, the highest concentration of fluoranthene in throughfall precipitation in Bystřice was 0.306 $\mu g.l^{-1}$ and in Košetice 0.076 $\mu g.l^{-1}$.

The PAH representation in surface water is significantly lower compared to atmospheric deposition. The upper soil layers and the vegetation cover capture the majority of these non-polar organic substances, which are easily sorbed to fine dust and humus particles.

The highest concentration of monitored PAHs in the surface water of the Suchý stream in Bystřice (*Fig. 9*) was found for naphthalene (January and September). A larger spectrum of PAHs occurs as a result of large precipitation episodes. In winter, the concentrations of naphthalene, phenanthrene, fluoranthene, and pyrene dominate. In October, November, December, April, and August, PAH values were below the limit of determination. The highest concentration of naphthalene was found in the Lesní stream in Košetice (*Fig. 12*) in April. In winter, the concentrations of fluoranthene, phenanthrene, pyrene, and benzo[a]anthracene dominate. The composition of individual PAHs in surface water also correlates with higher precipitation episodes.

Tab. 6 shows the results of the measured PAH values in the monitored solid matrices. These are average values from two to three measurements in the case of stream sediment and from three sites in each micro-catchment in the case of moss and humus. The detected PAH content is higher in sediment than in surface water. The content of the fine fraction of the Suchý stream sediment was very low because the morphology of the river bed, the slope of the mountain stream bed, and the dynamics of the flow do not allow the deposition of the fine fraction as in the case of the Lesní stream. Therefore, the content of PAHs in the river sediment of the Lesní stream is many times higher, despite the fact that it is a low-exposed reference area. At the same time, the PAH content in humus was more than three times higher at Bystřice than Košetice due to the high load from atmospheric deposition. The highly exposed PAH load of the Bystřice site was also manifested in red-stemmed feathermoss, which receives nutrients for its growth exclusively from the atmosphere (which is why it is used as a suitable marker of atmospheric load). The analysed parts of the moss represent an approximately three-year period of PAH exposure. The concentration ratio of the amount of PAH between the two monitored sites in moss and humus is approximately the same (3.0 and 3.5, respectively).

Tab. 7 and *Fig. 13* provide a summary of the calculated atmospheric deposition and substance ratio both absolutely and relatively per unit area at both experiment sites.

The calculated results confirm (*Tab. 7*) that in the case of PAH, rainfall pollution is many times higher than surface water pollution (*Fig. 13*). The Ostrava--Třinec industrial agglomeration is one of the areas with the highest concentration of PAH in the Czech Republic. This is also confirmed by the results from Bystřice.

For the concentrations of individual PAH compounds in the atmospheric deposition per area ($g.km^{-2}.year^{-1}$), the following order applies:

Bystřice: FLT > FEN > PYR > BAA > INP > CHR > BBF > BGP > BAP > FLU > NAP > BKF > ANT > DBA > ACN

Košetice: FLT > FEN > PYR > BAA > CHR > INP > BBF > NAP > BGP > BAP > BKF > FLU > DBA > ANT > ACN

For the concentrations of individual PAH compounds in the ratio of substance to area ($g.km^{-2}.year^{-1}$), the following order applies:

Bystřice: NAP > FEN > FLT > PYR > BAA > BBF > BAP > CHR > BGP > INP > BKF > ACN, FLU, ANT, DBA

Košetice: NAP > FLT > PYR > BAA > FEN > BGP > BBF > BAP > INP > CHR > BKF > ACN, FLU, ANT, DBA

Tab. 3. Assessment of surface water body status 2016–2018 in PAH parameters for the third planning cycle

Compound	EQS [$\mu g.l^{-1}$]		Number of water bodies		
	RP	NPK	Evaluated	Unsuitable	Not classified
Naphthalene	2	130	728	0	50
Fluorene	0.1	-	601	5	0
Phenanthrene	0.03	-	601	37	0
Anthracene	0.1	0.1	688	3	49
Fluoranthene	0.0063	0.12	690	351	48
Pyrene	0.024	-	601	59	0
Benzo[a]anthracene	0.03	-	601	7	0
Chrysene	0.024	-	601	59	0
Benzo[b]fluoranthene	-	0.017	689	167	45
Benzo[k]fluoranthene	-	0.017	689	68	46
Benzo[a]pyrene	0.00017	0.27	689	274	413
Dibenzo[a, h]anthracene	0.016	-	601	1	0
Benzo[g, h, i]perylene	-	0.0082	689	223	40

Tab. 4. Results of measurements of individual PAHs in surface water and precipitation, Bystřice site

Campaign		PAH compound [$\mu g.l^{-1}$]															15 PAU
		NAP	ACN	FLU	FEN	ANT	FLT	PYR	BAA	CHRY	BBF	BKF	BAP	BGP	DBA	INP	
1	watercourse	< 0.0300	< 0.0050	< 0.0050	< 0.0030	< 0.0020	< 0.0020	< 0.0020	< 0.0020	< 0.0020	< 0.0020	< 0.0020	< 0.0020	< 0.0020	< 0.0020	< 0.0050	< MS
	bulk	0.0535	< 0.0050	0.0098	0.0662	0.0124	0.1077	0.0888	0.0725	0.0521	0.0399	0.0231	0.0339	0.0405	0.0084	0.0455	0.6543
	throughfall	< 0.0300	< 0.0050	< 0.0050	0.0339	0.0049	0.0608	0.0503	0.0563	0.0316	0.0365	0.0201	0.0359	0.0452	0.0048	0.0559	0.4361
2	watercourse	< 0.0300	< 0.0050	< 0.0050	< 0.0030	< 0.0020	< 0.0020	< 0.0020	< 0.0020	< 0.0020	< 0.0020	< 0.0020	< 0.0020	< 0.0020	< 0.0020	< 0.0050	< MS
	bulk	0.0317	< 0.0050	0.0097	0.1214	0.0133	0.2096	0.1425	0.1236	0.1098	0.0986	0.0491	0.0729	0.0890	0.0154	0.1170	1.2036
	throughfall	0.0496	< 0.0050	0.0057	0.0645	0.0087	0.1102	0.0805	0.0836	0.0593	0.0540	0.0320	0.0531	0.0777	0.0074	0.0809	0.7671
3	watercourse	< 0.0300	< 0.0050	< 0.0050	< 0.0030	< 0.0020	< 0.0020	< 0.0020	< 0.0020	< 0.0020	< 0.0020	< 0.0020	< 0.0020	< 0.0020	< 0.0020	< 0.0050	< MS
	bulk	0.0482	< 0.0050	0.0218	0.1633	0.0321	0.3062	0.2470	0.2314	0.2010	0.1836	0.0961	0.1504	0.1929	0.0167	0.2332	2.1238
	throughfall	0.1193	< 0.0050	0.0092	0.1465	0.0253	0.2735	0.2185	0.2068	0.1659	0.1545	0.0803	0.1233	0.1631	0.0133	0.2040	1.9036
4	watercourse	0.0387	< 0.0050	< 0.0050	0.0058	< 0.0020	0.0024	0.0016	< 0.0020	< 0.0020	< 0.0020	< 0.0020	< 0.0020	< 0.0020	< 0.0020	< 0.0050	0.0485
	bulk	0.0811	< 0.0050	0.0191	0.1855	0.0136	0.2383	0.1427	0.1405	0.0953	0.0812	0.0370	0.0509	0.0565	0.0106	0.0735	1.2258
	throughfall	0.0671	< 0.0050	0.0245	0.2530	0.0300	0.3510	0.2420	0.1692	0.1545	0.1355	0.0641	0.0955	0.1086	0.0107	0.1465	1.8521
5	watercourse	< 0.0300	< 0.0050	< 0.0050	0.0078	< 0.0020	0.0028	0.0019	< 0.0020	< 0.0020	< 0.0020	< 0.0020	< 0.0020	< 0.0020	< 0.0020	< 0.0050	0.0125
	bulk	0.0451	< 0.0050	0.0211	0.2281	0.0077	0.2269	0.1252	0.1144	0.0741	0.0697	0.0298	0.0429	0.0602	0.0103	0.0723	1.1278
	throughfall	0.0624	< 0.0050	0.0215	0.3160	0.0158	0.3150	0.1782	0.1569	0.0884	0.0802	0.0357	0.0497	0.0678	0.0068	0.0825	1.4769
6	watercourse	< 0.0300	< 0.0050	< 0.0050	0.0063	< 0.0020	0.0018	< 0.0020	< 0.0020	< 0.0020	< 0.0020	< 0.0020	< 0.0020	< 0.0020	< 0.0020	< 0.0050	0.0081
	bulk	0.0360	< 0.0050	0.0127	0.1893	0.0107	0.2328	0.1368	0.1352	0.0919	0.0993	0.0474	0.0668	0.0812	0.0155	0.1000	1.2555
	throughfall	0.0591	< 0.0050	0.0106	0.1960	0.0171	0.3066	0.2023	0.1899	0.1123	0.1171	0.0587	0.0880	0.0956	0.0106	0.1213	1.5849
7	watercourse	< 0.0300	< 0.0050	< 0.0050	< 0.0030	< 0.0020	< 0.0020	< 0.0020	< 0.0020	< 0.0020	< 0.0020	< 0.0020	< 0.0020	< 0.0020	< 0.0020	< 0.0050	< MS
	bulk	0.0300	< 0.0050	0.0084	0.0883	0.0023	0.1106	0.0468	0.0463	0.0437	0.0400	0.0190	0.0240	0.0388	0.0105	0.0397	0.5483
	throughfall	0.0349	< 0.0050	0.0142	0.1422	0.0077	0.1822	0.1030	0.0927	0.0615	0.0524	0.0253	0.0354	0.0483	0.0072	0.0570	0.8640
8	watercourse	< 0.0300	< 0.0050	< 0.0050	0.0045	< 0.0020	0.0018	< 0.0020	< 0.0020	< 0.0020	< 0.0020	< 0.0020	< 0.0020	< 0.0020	< 0.0020	< 0.0050	0.0063
	bulk	0.0300	< 0.0050	0.0059	0.0381	0.0017	0.0569	0.0378	0.0461	0.0281	0.0376	0.0157	0.0224	0.0343	0.0152	0.0369	0.4065
	throughfall	< 0.0300	< 0.0050	0.0059	0.0424	< 0.0020	0.0699	0.0438	0.0441	0.0309	0.0438	0.0194	0.0247	0.0410	0.0250	0.0413	0.4319
9	watercourse	< 0.0300	< 0.0050	< 0.0050	0.0051	< 0.0020	0.0018	< 0.0020	< 0.0020	< 0.0020	< 0.0020	< 0.0020	< 0.0020	< 0.0020	< 0.0020	< 0.0050	0.0070
	bulk	0.0300	< 0.0050	< 0.0050	0.0081	0.0017	0.0152	0.0079	0.0075	0.0047	0.0059	< 0.0020	0.0020	0.0119	0.0084	0.0088	0.1121
	throughfall	0.0330	< 0.0050	< 0.0050	0.0153	< 0.0020	0.0390	0.0227	0.0190	0.0134	0.0129	0.0023	0.0077	0.0125	0.0057	0.0112	0.1947
10	watercourse	< 0.0300	< 0.0050	< 0.0050	0.0090	< 0.0020	0.0094	0.0068	0.0058	0.0040	0.0053	0.0021	0.0040	0.0037	< 0.0020	< 0.0050	0.0502
	bulk	0.0300	< 0.0050	< 0.0050	0.0119	0.0017	0.0245	0.0173	0.0263	0.0122	0.0162	0.0048	0.0119	0.0151	0.0067	0.0142	0.1927
	throughfall	< 0.0300	< 0.0050	< 0.0050	0.0143	< 0.0020	0.0197	0.0141	0.0169	0.0088	0.0111	0.0048	0.0113	0.0099	0.0025	0.0111	0.1243
11	watercourse	< 0.0300	< 0.0050	< 0.0050	< 0.0030	< 0.0020	< 0.0020	< 0.0020	< 0.0020	< 0.0020	< 0.0020	< 0.0020	< 0.0020	< 0.0020	< 0.0020	< 0.0050	< MS
	bulk	0.0300	< 0.0050	< 0.0050	0.0164	0.0017	0.0289	0.0216	0.0394	0.0172	0.0224	0.0100	0.0136	0.0236	< 0.0020	0.0261	0.2508
	throughfall	< 0.0300	< 0.0050	< 0.0050	0.0097	< 0.0020	0.0131	0.0101	0.0160	0.0067	0.0123	0.0068	0.0122	0.0139	< 0.0020	0.0167	0.1177
12	watercourse	0.1138	< 0.0050	< 0.0050	0.0050	< 0.0020	0.0111	0.0090	0.0081	0.0052	0.0064	0.0034	0.0056	0.0050	< 0.0020	0.0066	0.1791
	bulk	0.1449	< 0.0050	< 0.0050	0.0073	0.0017	0.0375	0.0236	0.0436	0.0146	0.0127	0.0040	0.0057	0.0098	< 0.0020	0.0100	0.3154
	throughfall	0.1102	< 0.0050	< 0.0050	0.0058	< 0.0020	0.0055	0.0035	0.0037	0.0067	0.0018	< 0.0020	< 0.0020	0.0020	< 0.0020	< 0.0050	0.1392
Average	watercourse	0.0127	< 0.0050	< 0.0050	0.0036	< 0.0020	0.0026	0.0016	0.0012	0.0008	0.0058	0.0005	0.0008	0.0007	< 0.0020	0.0006	0.0309
	bulk	0.0492	< 0.0050	0.0090	0.0937	0.0084	0.1329	0.0865	0.0856	0.0620	0.0589	0.0305	0.0414	0.0545	0.0098	0.0648	0.7872
	throughfall	0.0446	< 0.0050	0.0076	0.1030	0.0091	0.1455	0.0974	0.0879	0.0617	0.0593	0.0318	0.0447	0.0571	0.0078	0.0690	0.8265

Tab. 5. Results of measurements of individual PAHs in surface water and precipitation, Košetice site

Campaign		PAH compound [µg.l⁻¹]															15 PAU
		NAP	ACN	FLU	FEN	ANT	FLT	PYR	BAA	CHRY	BBF	BKF	BAP	BGP	DBA	INP	
1	watercourse	< 0.0300	< 0.0050	< 0.0050	0.0056	< 0.0020	0.0170	0.0134	0.0106	0.0063	0.0062	0.0039	0.0078	0.0069	< 0.0020	0.0091	0.0866
	bulk	0.0354	< 0.0050	< 0.0050	0.0167	< 0.0020	0.0143	0.0124	0.0126	0.0059	0.0064	0.0036	0.0050	0.0110	0.0018	0.0105	0.1356
	throughfall	< 0.0300	< 0.0050	< 0.0050	0.0172	< 0.0020	0.0179	0.0138	0.0120	0.0074	0.0067	0.0038	0.0055	0.0083	0.0019	0.0094	0.1039
2	watercourse	< 0.0300	< 0.0050	< 0.0050	0.0050	< 0.0020	< 0.0020	< 0.0020	< 0.0020	< 0.0020	< 0.0020	< 0.0020	< 0.0020	< 0.0020	< 0.0020	< 0.0050	0.0050
	bulk	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	throughfall	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
3	watercourse	< 0.0300	< 0.0050	< 0.0050	< 0.003	< 0.0020	0.0038	0.0032	0.0030	0.0018	0.0025	< 0.0020	0.0020	0.0024	< 0.0020	< 0.0050	0.0187
	bulk	0.0382	< 0.0050	< 0.0050	0.0283	0.0015	0.0325	0.0244	0.0244	0.0209	0.0189	0.0087	0.0116	0.0189	0.0021	0.0233	0.2536
	throughfall	0.0422	< 0.0050	< 0.0050	0.0455	0.0035	0.0575	0.0448	0.0427	0.0351	0.0267	0.0133	0.0187	0.0283	0.0022	0.0334	0.3939
4	watercourse	< 0.0300	< 0.0050	< 0.0050	0.0068	< 0.0020	0.0039	0.0030	0.0027	< 0.0020	0.0017	< 0.0020	0.0015	0.0020	< 0.0020	< 0.0050	0.0218
	bulk	0.0458	< 0.0050	0.0063	0.0488	0.0020	0.0441	0.0258	0.0244	0.0194	0.0147	0.0067	0.0073	0.0112	0.0018	0.0148	0.2731
	throughfall	0.0443	< 0.0050	0.0061	0.0603	0.0028	0.0584	0.0371	0.0350	0.0249	0.0192	0.0091	0.0125	0.0161	0.0020	0.0216	0.3492
5	watercourse	< 0.0300	< 0.0050	< 0.0050	0.0054	< 0.0020	0.0019	< 0.0020	< 0.0020	< 0.0020	< 0.0020	< 0.0020	< 0.0020	< 0.0020	< 0.0020	< 0.0050	0.0073
	bulk	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	throughfall	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
6	watercourse	< 0.0300	< 0.0050	< 0.0050	< 0.003	< 0.0020	0.0022	0.0016	0.0017	< 0.0020	< 0.0020	< 0.0020	< 0.0020	< 0.0020	< 0.0020	< 0.0050	0.0056
	bulk	< 0.0300	< 0.0050	< 0.0050	0.0337	< 0.0020	0.0506	0.0310	0.0285	0.0283	0.0289	0.0125	0.0134	0.0215	0.0023	0.0261	0.2767
	throughfall	< 0.0300	< 0.0050	0.0121	0.0720	0.0024	0.0789	0.0512	0.0465	0.0330	0.0352	0.0147	0.0192	0.0263	0.0023	0.0339	0.4276
7	watercourse	0.1260	< 0.0050	< 0.0050	< 0.003	< 0.0020	0.0023	0.0017	0.0020	< 0.0020	0.0017	< 0.0020	< 0.0020	0.0017	< 0.0020	< 0.0050	0.1355
	bulk	< 0.0300	< 0.0050	< 0.0050	0.0196	< 0.0020	0.0269	0.0183	0.0141	0.0091	0.0089	0.0038	0.0046	0.0070	< 0.0020	0.0093	0.1216
	throughfall	< 0.0300	< 0.0050	0.0100	0.0390	< 0.0020	0.0430	0.0265	0.0190	0.0136	0.0141	0.0066	0.0088	0.0128	0.0019	0.0170	0.2123
8	watercourse	< 0.0300	< 0.0050	< 0.0050	< 0.003	< 0.0020	0.0023	0.0017	< 0.0020	< 0.0020	0.0018	< 0.0020	< 0.0020	0.0018	< 0.0020	< 0.0050	0.0075
	bulk	< 0.0300	< 0.0050	< 0.0050	0.0104	< 0.0020	0.0094	0.0055	0.0040	0.0032	0.0032	< 0.0020	0.0016	0.0025	< 0.0020	< 0.0050	0.0399
	throughfall	< 0.0300	< 0.0050	< 0.0050	0.0104	< 0.0020	0.0316	0.0190	0.0166	0.0107	0.0110	0.0053	0.0081	0.0093	< 0.0020	0.0107	0.1326
9	watercourse	< 0.0300	< 0.0050	< 0.0050	0.0054	< 0.0020	0.0023	0.0017	0.0015	< 0.0020	< 0.0020	< 0.0020	< 0.0020	< 0.0020	< 0.0020	< 0.0050	0.0110
	bulk	< 0.0300	< 0.0050	< 0.0050	0.0061	< 0.0020	0.0027	0.0018	< 0.0020	< 0.0020	< 0.0020	< 0.0020	< 0.0020	< 0.0020	< 0.0020	< 0.0050	0.0106
	throughfall	< 0.0300	< 0.0050	< 0.0050	0.0103	< 0.0020	0.0119	0.0067	0.0032	0.0029	0.0025	< 0.0020	0.0018	0.0023	< 0.0020	< 0.0050	0.0414
10	watercourse	< 0.0300	< 0.0050	< 0.0050	0.0047	< 0.0020	0.0029	0.0024	0.0021	< 0.0020	< 0.0020	< 0.0020	< 0.0020	< 0.0020	< 0.0020	< 0.0050	0.0121
	bulk	< 0.0300	< 0.0050	< 0.0050	0.0050	< 0.0020	< 0.0020	< 0.0020	< 0.0020	< 0.0020	< 0.0020	< 0.0020	< 0.0020	< 0.0020	< 0.0020	< 0.0050	0.0050
	throughfall	< 0.0300	< 0.0050	< 0.0050	0.0087	< 0.0020	0.0170	0.0108	0.0082	0.0074	0.0054	0.0025	0.0045	0.0046	< 0.0020	0.0054	0.0747
11	watercourse	< 0.0300	< 0.0050	< 0.0050	< 0.003	< 0.0020	0.0077	0.0064	0.0061	0.0032	0.0042	0.0021	0.0042	0.0038	< 0.0020	0.0046	0.0422
	bulk	< 0.0300	< 0.0050	< 0.0050	< 0.003	< 0.0020	0.0015	< 0.0020	< 0.0020	< 0.0020	< 0.0020	< 0.0020	< 0.0020	< 0.0020	< 0.0020	< 0.0050	0.0015
	throughfall	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
12	watercourse	< 0.0300	< 0.0050	< 0.0050	< 0.003	< 0.0020	0.0090	0.0070	0.0080	0.0030	0.0030	0.0020	0.0030	0.0030	< 0.0020	0.0050	0.0430
	bulk	< 0.0300	< 0.0050	< 0.0050	0.0047	< 0.0020	0.0041	0.0028	0.0026	0.0015	0.0016	< 0.0020	< 0.0020	0.0016	< 0.0020	< 0.0050	0.0189
	throughfall	0.0297	< 0.0050	< 0.0050	0.0093	< 0.0020	0.0147	0.0090	0.0060	0.0047	0.0041	0.0018	0.0045	0.0038	< 0.0020	0.0045	0.0921
Average	watercourse	0.0105	< 0.0050	< 0.0050	0.0027	< 0.0020	0.0046	0.0035	0.0031	0.0012	0.0018	0.0007	0.0072	0.0018	< 0.0020	0.0016	0.0387
	bulk	0.0099	< 0.0050	0.0005	0.0144	0.0003	0.0155	0.0102	0.0092	0.0074	0.0069	0.0029	0.0036	0.0061	0.0007	0.0070	0.0946
	throughfall	0.0097	< 0.0050	0.0024	0.0227	0.0007	0.0276	0.0182	0.0158	0.0116	0.0104	0.0048	0.0070	0.0093	0.0009	0.0113	0.1524

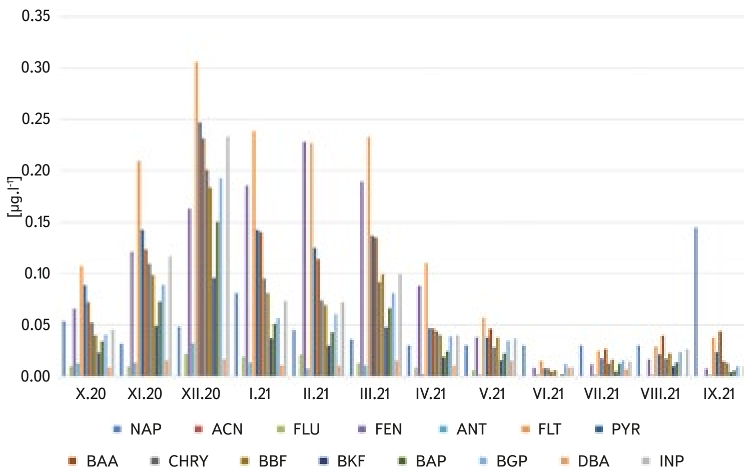

Fig. 7. Suchý stream, Bystřice – PAHs concentration in precipitation: BULK

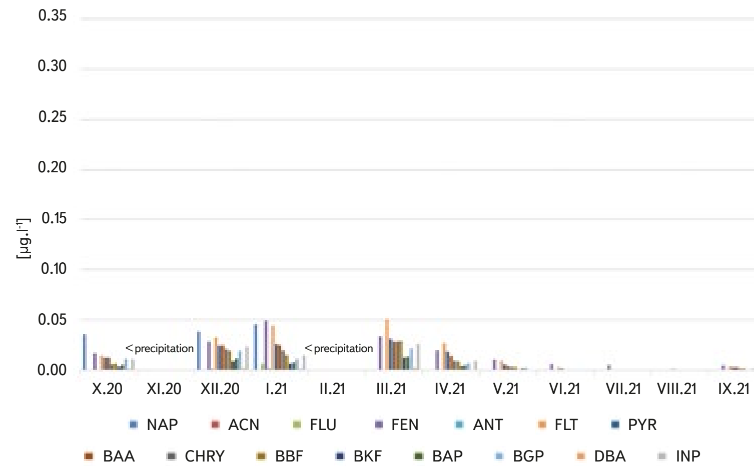

Fig. 10. Lesní stream, Košetice – PAHs concentration in precipitation: BULK

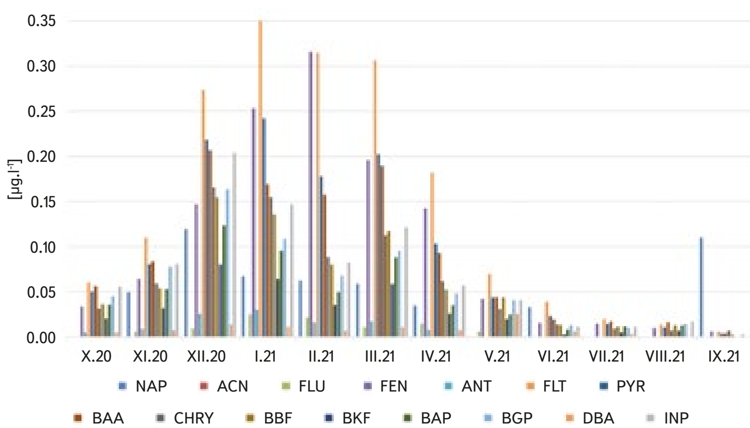

Fig. 8. Suchý stream, Bystřice – PAHs concentration in precipitation: THROUGHFALL

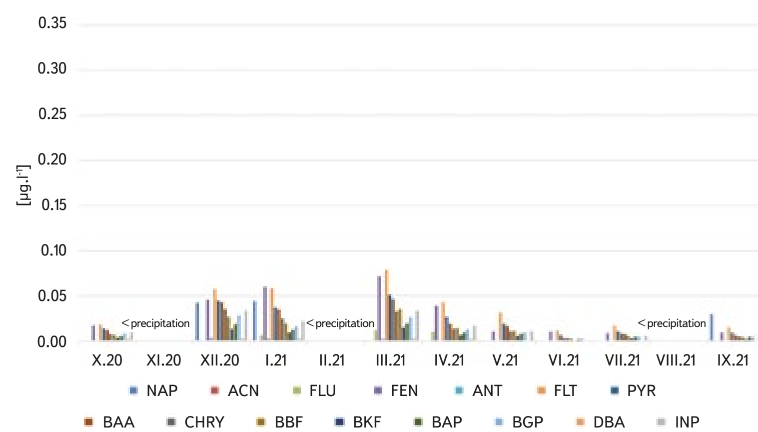

Fig. 11. Lesní stream, Košetice – PAHs concentration in precipitation: THROUGHFALL

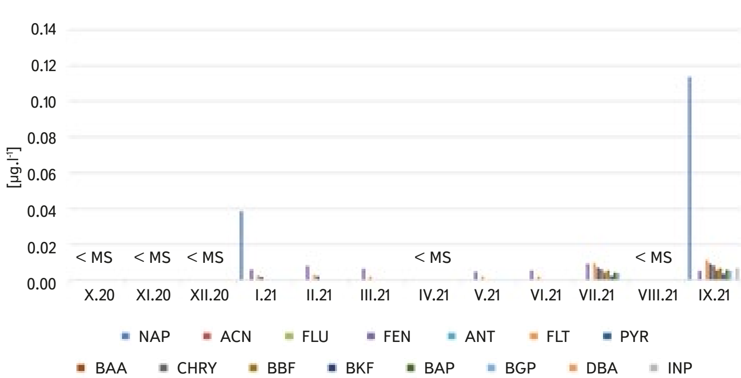

Fig. 9. Suchý stream, Bystřice – PAHs concentration in surface water

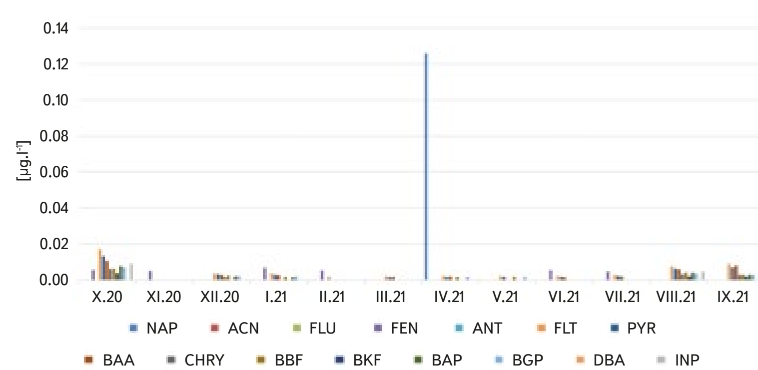

Fig. 12. Lesní stream, Košetice – PAHs concentration in surface water

Tab. 6. Indicative comparison of PAH concentrations in other monitored matrices in 2020 and 2021

Substance [mg.kg⁻¹]	**Site – year**											
	Stream sediment				**Moss**				**Humus**			
	BY – 2020	BY – 2021	KO – 2020	KO – 2021	BY – 2020	BY – 2021	KO – 2020	KO – 2021	BY – 2020	BY – 2021	KO – 2020	KO – 2021
Naphthalene	0.0130	0.0140	0.0410	0.0910	0.0755	0.0664	0.0507	0.0527	0.1580	0.1710	0.1120	0.1060
Acenaphthalene	< 0.0020	0.0040	0.0060	0.0080	0.0037	0.0054	0.0025	0.0034	0.0169	0.0314	0.0123	0.0143
Fluorene	< 0.0020	0.0040	0.0070	0.0080	0.0094	0.0088	0.0056	0.0061	0.0315	0.0482	0.0135	0.0199
Phenanthrene	0.0160	0.0340	0.0810	0.1010	0.0326	0.0389	0.0103	0.0216	0.4000	0.5020	0.1400	0.1440
Anthracene	0.0020	0.0040	0.0130	0.0080	0.0028	0.0025	0.0018	0.0016	0.0403	0.0509	0.0124	0.0201
Fluoranthene	0.0390	0.0700	0.2100	0.2670	0.0560	0.0754	0.0120	0.0256	0.7130	0.8680	0.2850	0.2770
Pyrene	0.0280	0.0500	0.1660	0.2060	0.0360	0.0517	0.0113	0.0178	0.4850	0.5740	0.2100	0.1990
Benzo[a]anthracene	0.0330	0.0720	0.1770	0.2600	0.0178	0.0228	0.0040	0.0052	0.3350	0.3520	0.0915	0.0782
Chrysene	0.0160	0.0320	0.0760	0.1070	0.0330	0.0523	0.0088	0.0112	0.6670	0.8930	0.1160	0.1550
Benzo[b]fluoranthene	0.0210	0.0390	0.1110	0.1120	0.0736	0.1105	0.0088	0.0181	0.7920	1.0551	0.1770	0.1959
Benzo[k]fluoranthene	0.0100	0.0170	0.0640	0.0690	0.0195	0.0367	0.0056	0.0059	0.2510	0.3690	0.0723	0.0849
Benzo[a]pyrene	0.0160	0.0310	0.1320	0.1280	0.0185	0.0363	0.0058	0.0078	0.3760	0.3900	0.1260	0.1250
Dibenzo[a, h]anthracene	0.0160	0.0310	0.1160	0.1180	0.0091	0.0090	0.0053	0.0015	0.1144	0.1093	0.0299	0.0268
Benzo[g, h, i]perylene	0.0020	0.0040	0.0230	0.0110	0.0243	0.0309	0.0082	0.0080	0.4470	0.4100	0.1450	0.1160
Indeno[1, 2, 3-c, d]pyrene	0.0190	0.0430	0.1370	0.1420	0.0239	0.0345	0.0077	0.0082	0.6010	0.5530	0.1440	0.1380
15 PAH	0.2310	0.4490	1.3600	1.6360	0.4355	0.5822	0.1481	0.1946	5.4281	6.3769	1.6869	1.7001

Tab. 7. Calculation of atmospheric deposition and riverine load at pilot sites

Substance	**Atmospheric deposition [g.rok⁻¹]**		**Atmospheric deposition per area [g.km⁻².rok⁻¹]**		**Riverine load [g.rok⁻¹]**		**Riverine load per area [g.km⁻².rok⁻¹]**		**Ratio of load and deposition [%]**	
	Location									
	BY	KO	BY	KO	BY	KO	BY	KO	BY	KO
Naphthalene	21.443	1.868	46.414	6.396	2.309	0.232	4.998	0.794	10.8	12.4
Acenaphthalene	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.0	0.0
Fluorene	4.832	0.382	46.414	1.308	0.000	0.000	0.000	0.000	0.0	0.0
Phenanthrene	65.513	4.448	137.475	15.231	1.001	0.099	2.166	0.340	1.5	2.2
Anthracene	5.254	0.120	11.372	0.410	0.000	0.000	0.000	0.000	0.0	0.0
Fluoranthene	88.267	5.655	191.055	19.367	0.547	0.132	1.185	0.451	0.6	2.3
Pyrene	58.552	3.678	126.735	12.595	0.290	0.095	0.628	0.326	0.5	2.6
Benzo[a]anthracene	52.394	3.115	113.407	10.666	0.164	0.074	0.355	0.253	0.3	2.4
Chrysene	36.414	2.291	78.818	7.846	0.109	0.026	0.235	0.089	0.3	1.1
Benzo[b]fluoranthene	36.083	2.011	78.101	6.888	0.137	0.050	0.297	0.170	0.4	2.5
Benzo[k]fluoranthene	17.471	0.915	37.816	3.132	0.064	0.015	0.140	0.052	0.4	1.6
Benzo[a]pyrene	26.837	1.404	58.088	4.809	0.113	0.036	0.254	0.122	0.4	2.6
Dibenzo[a, h]anthracene	5.369	0.158	11.621	0.542	0.000	0.000	0.000	0.000	0.0	0.0
Benzo[g, h, i]perylene	33.561	1.808	72.642	6.191	0.103	0.052	0.223	0.176	0.3	2.9
Indeno[1, 2, 3-c, d]pyrene	40.976	2.142	88.693	7.334	0.081	0.035	0.176	0.120	0.2	1.6
15 PAH	492.966	29.995	1,098.651	102.715	4.918	0.846	10.657	2.893	1.0	2.8

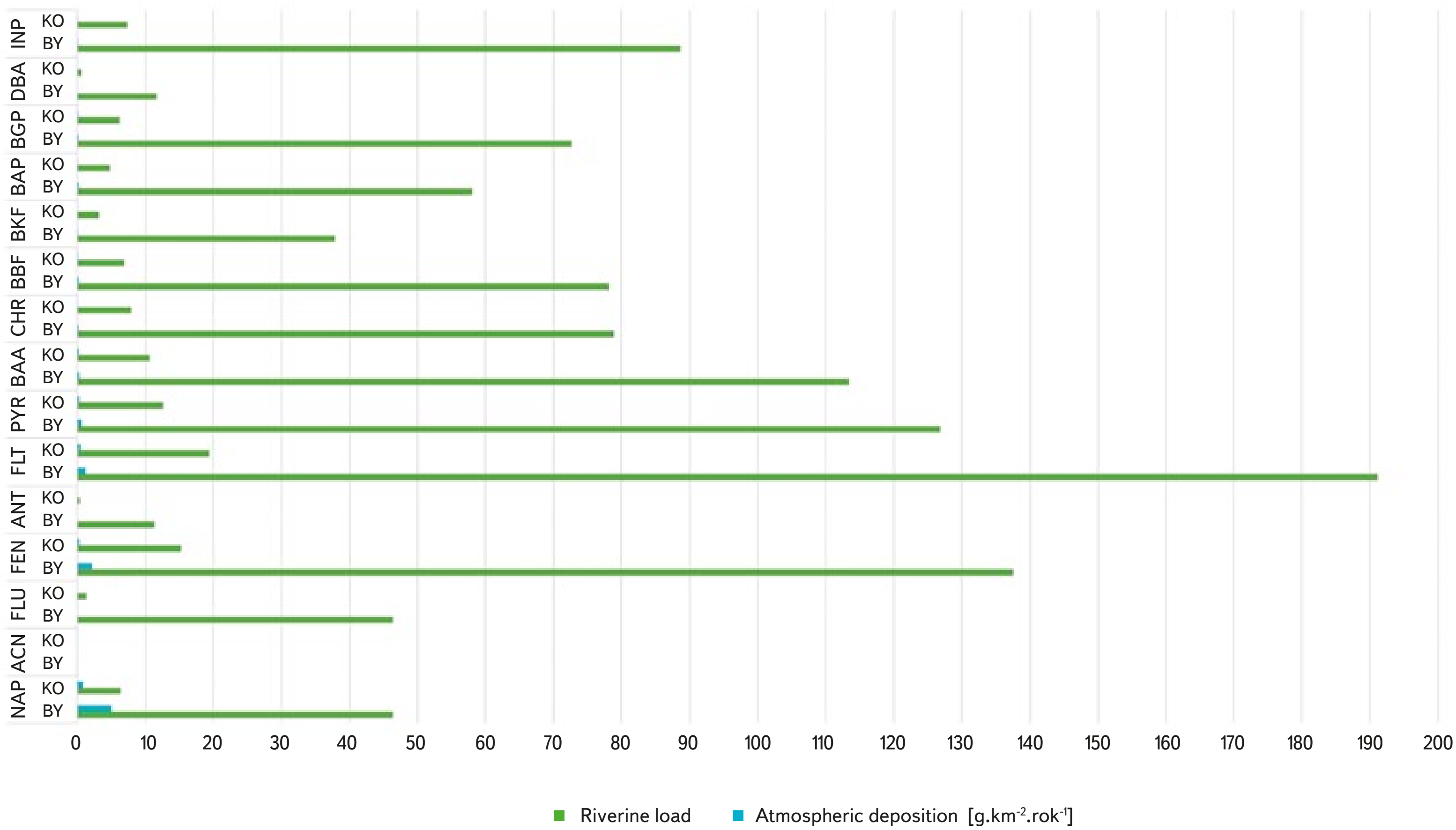

Fig. 13. Calculation of atmospheric deposition and riverine load per area

DISCUSSION AND CONCLUSION

Field measurements carried out in selected forest micro-catchments of Bystřice and Košetice confirm that pollution of precipitation by polycyclic aromatic hydrocarbons is many times higher than surface water pollution. The contribution to PAH by atmospheric precipitation is more significant than by surface water, which is confirmed by, for example, Lipiatou [16]. Significant seasonal variation in PAH concentrations in precipitation with maxima in winter was recorded. PAHs are removed from the atmosphere by dry and wet deposition. The range of concentrations is directly dependent on meteorological conditions. Seasonal changes in PAH concentrations show a maximum in winter and a minimum in summer. Maxima in the cold season of the year in connection with the frequent burning of fossil fuels and atmospheric conditions may not always lead to an increased PAH content in the rivers. In summer, forest fires are also a significant source of PAHs in connection with increasing climate change [17]. Higher temperatures contribute to more effective oxidation by atmospheric trace gases (NO_x, SO_2, O_3), so that their degradation takes place faster in summer than in winter. Their regional distribution is dependent on local sources, with the main sources being fossil fuel combustion processes, domestic heating, and vehicle transport.

The PAH content in precipitation depends on their solubility in water. PAHs with a low molecular weight are soluble within $mg.l^{-1}$, while higher PAHs are soluble within $ng.l^{-1}$. PAHs with a lower molecular weight are found in the atmosphere on solid particles as well as in the gas phase; with increasing molecular weight, PAHs are more sorbed on solid particles and only a small part is in the soluble fraction.

Gas-phase PAHs become part of wet atmospheric deposition through interfacial gas-liquid exchange in the below-cloud washout process, while PAHs associated with solid particles are more effectively washed out by intra-cloud washout processes as a consequence of diffusion, impaction, and entrapment [18].

Particles with bound PAH compounds from combustion processes can be transported long distances in the atmosphere and thus reach areas without obvious sources. This long-range transport mechanism depends on the particle size of the atmospheric aerosol. Aerosol particles of smaller dimensions (< 1 mm), which are not effectively removed from the atmosphere by dry and wet deposition processes, remain in the atmosphere for a longer time and may therefore be the reason for their presence in remote areas. Larger atmospheric aerosols (> 5 µm) are more effectively removed by precipitation and are deposited closer to their sources, which is the case of the Bystřice site in the Suchý stream basin.

The amount of Σ15 PAH atmospheric deposition at the Bystřice site was calculated at 1,098.7 $g.km^{-2}.year^{-1}$; at the Košetice site it is 10 times lower at 102.7 $g.km^{-2}.year^{-1}$. Fluoranthene (18 %), phenanthrene (13 %), and pyrene (12 %) contribute the most to this deposition. For comparison with already published data, the deposition was converted to $ng.m^2.d^{-1}$: 3,010 $ng.m^2.d^{-1}$ (BY) and 102 $ng.m^2.d^{-1}$ (KO). In rural areas, atmospheric deposition (bulk) is reported to be 38–2,000 $ng.m^2.d^{-1}$, in urban areas 36–20,000 $ng.m^2.d^{-1}$ [17]. When normalizing the amount of Σ15 PAH atmospheric deposition at the Bystřice site to the amount of precipitation at the Košetice site, the result is that the load of polycyclic aromatic hydrocarbons in Bystřice is 4.5 times higher than at the reference site of Košetice.

The top soil layer and vegetation cover sorb PAHs. PAHs enter surface waters through erosion. The Σ15 PAH concentration in the Suchý stream in Bystřice was 0.026 ± 0.049 $mg.l^{-1}$, in the Lesní stream in Košetice it was 0.033 ± 0.038 $mg.l^{-1}$. Riverine load from the Suchý stream micro-catchment thus accounted for only 1 % of the atmospheric deposition by wet deposition in Bystřice and 2.8 % from the Lesní stream micro-catchment in Košetice.

Due to their extremely low volatility and low solubility in surface water, high molecular weight PAHs occur in very low concentrations. However, their contribution to surface waters is significant during higher rainfall episodes, when erosion and runoff from paved areas are applied. The accuracy of the balance of PAH riverine load through surface waters is affected by:

— the time of surface water sampling in relation to precipitation in the previous period,
— proportion of fine particles in river sediment,
— flow rates at the time of sampling, when the fine fraction of sediment in the water column rises at higher flow rates.

Given that only some point samplings of surface water in the experimental micro-catchments of the Suchý stream and Lesní stream were carried out immediately after a rainfall-runoff event with possible erosional wash, the actual proportion of PAH riverine load through surface water to the balance of atmospheric deposition through wet deposition will probably be higher than the above values 1 % and 2.8 %. Further clarification of the effect of PAH atmospheric deposition on surface water quality will require more research, also due to the significant proportion of surface water bodies not achieving good chemical status in most PAH indicators.

The origin of PAHs can be inferred from the ratio of fluoranthene to pyrene [e.g., 19]. If this ratio is greater than 1, the origin are combustion processes; if it is lower than 1, the origin are petrochemical products. Both at the Bystřice and Košetice sites, this ratio was greater than 1. Specifically, in the total wet deposition (bulk) it was 1.6 in Bystřice and 1.5 in Košetice. In the case of throughfall deposition, it was almost the same: 1.5 and 1.55 in Košetice. In the colder part of the year, this ratio in Bystřice was slightly higher (bulk 1.7) than in summer. In the Suchý stream, the ratio of fluoranthene to pyrene was 1.4, in the Lesní stream it was 1.3. Similar ratios were confirmed in solid matrices except for humus: in the Suchý stream basin, the ratio was 1.5, but in the Lesní stream basin it was 2.4. In red-stemmed feathermoss, the ratio of both polyaromatic hydrocarbons was 1.5 in Bystřice while in Košetice it was a slightly lower at 1.25.

A more detailed description of the representation of PAHs in the monitored matrices and the links between the pollution of individual components of the environment is available on the project's website [20].

In autumn 2022, the European Commission published a draft amendment to Directive 2008/105/EC, in which the AA-EQS environmental quality standard for fluoranthene is significantly tightened. The issue of environmental and water pollution by polycyclic aromatic hydrocarbons is thus gaining importance.

Acknowledgements

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[2] *Directive 2013/39/EU of the European Parliament and of the Council of 12 August 2013 amending Directives 2000/60/EC and 2008/105/EC as Regards Priority Substances in the Field of Water Policy.*

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Development of pond locations in the Polabí lowland since the mid-19th century – part 2 – Poděbrady region

PAVEL RICHTER

Keywords: ponds – archival maps – landscape changes – water retention in the landscape – GIS

ABSTRACT

This article presents the results of research on landscape changes in the Poděbrady region as part of the Polabí lowland, where there have been significant changes in the location of ponds. The area of all types of ponds (according to stability) makes up 3.17 % of the Poděbrady region. According to their occurrence in the area in 1836/1852–2022, the ponds (or their parts) were divided into disappeared, continuous, and new. Disappeared ponds have the largest representation – about 60 % of the total pond area according to stability. They are followed by continuous ponds, with the minimum area represented by new ponds. The historical or (more precisely) disappeared ponds were more robust than the present ones, i.e., they had a larger average size. Analyses show that almost three-quarters of the disappeared ponds have been replaced by arable land.

INTRODUCTION

The results presented here are part of a wider research concerning the Polabí lowland, where areas were selected with the greatest changes in the occurrence of wetlands, ponds (as one of the wetland types), small-scale protected areas, and well-preserved sections of watercourses.

The Pardubice and Poděbrady regions are designated as sites with the largest representation of historical or current ponds within the Polabská lowland, based on the state of the landscape recorded on the maps of Second Military Mapping and on contemporary documents. In this article, the results for the Poděbrady region are presented, and follow on from the research in the Pardubice region, whose results were presented in an article published in the previous issue of the VTEI journal [1].

Study area

The study area, which is located in the Polabí lowland in the Poděbrady region, was defined by the boundaries of the fourth order hydrological basins [2] in combination with the typology of the current landscape of the Czech Republic [3]. However, only those fourth order hydrological basins belonging to the warm landscape of the lowlands according to the mentioned typology were taken into account.

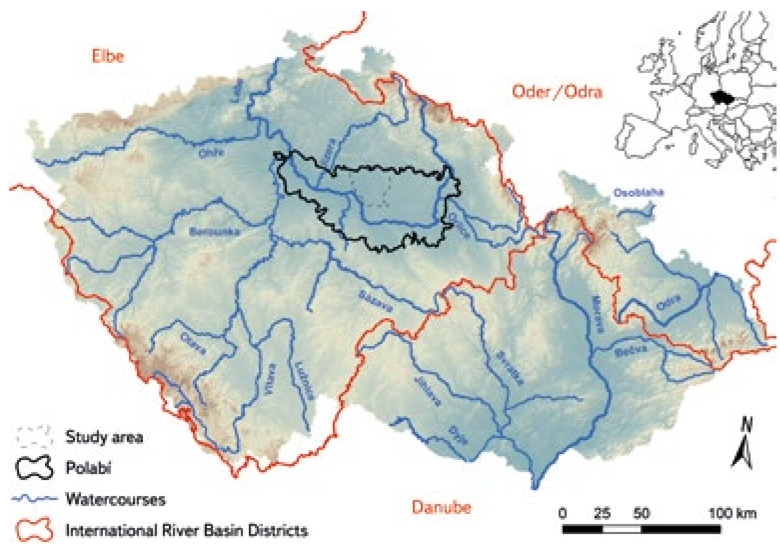

Fig. 1. Location of Poděbrady region study area within Polabí lowland

The study area of Poděbrady region is located on the edge of Poděbrady and includes the surroundings of Městec Králové and Rožďalovice. The defined area of Poděbrady region (*Fig. 1*) consists of 46 fourth order hydrological basins with a total area of 48,969.6 ha and covers almost the same area as the Pardubice region (50,104.5 ha). The following fourth order basins are part of the following third order basins: 1-04-04 Cidlina from Bystřice to the mouth and Elbe from Cidlina to Mrlina, 1-04-05 Mrlina and Elbe from Mrlina to Výrovka, and 1-04-07 Elbe from Výrovka up to Jizera [2].

METHODOLOGY AND MAPS USED

The Poděbrady region is adjacent to Pardubice; both are part of the Polabí lowland. The same methodology was used in both study areas. The first step was the selection and subsequent comparison of the current and historical state of the sites of current and historical ponds based on map data interpretation. This was followed by a field survey of sites with the largest share of historical and current ponds to verify their current condition, or the state of the disappeared pond sites. The methodology for processing and interpreting map data was also identical. For the primary detection of the occurrence of ponds, the map of the Second Military Mapping was selected, available on the CENIA Geoportal as a WMS service [4]. To approximate the state of the landscape before Second Military Mapping, the map of the First Military Mapping was

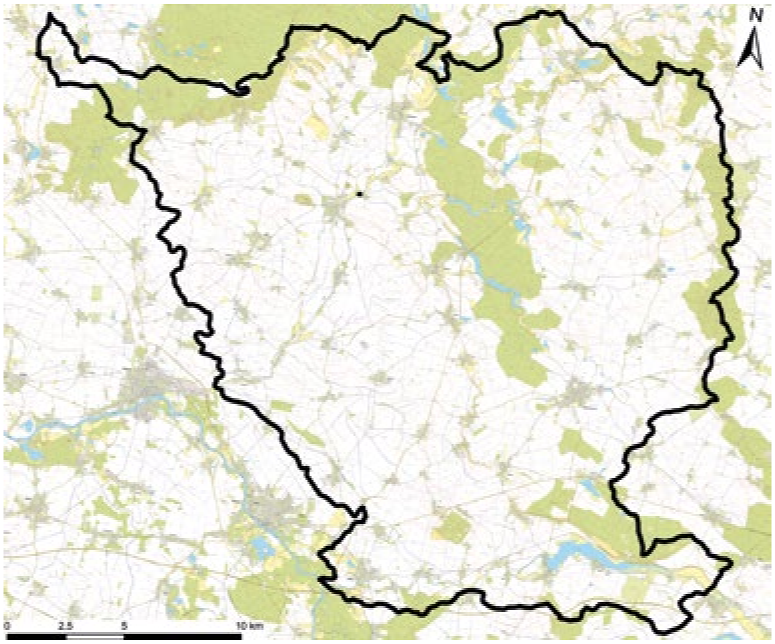

Fig. 2. The study area in the Poděbrady region on current BM 10

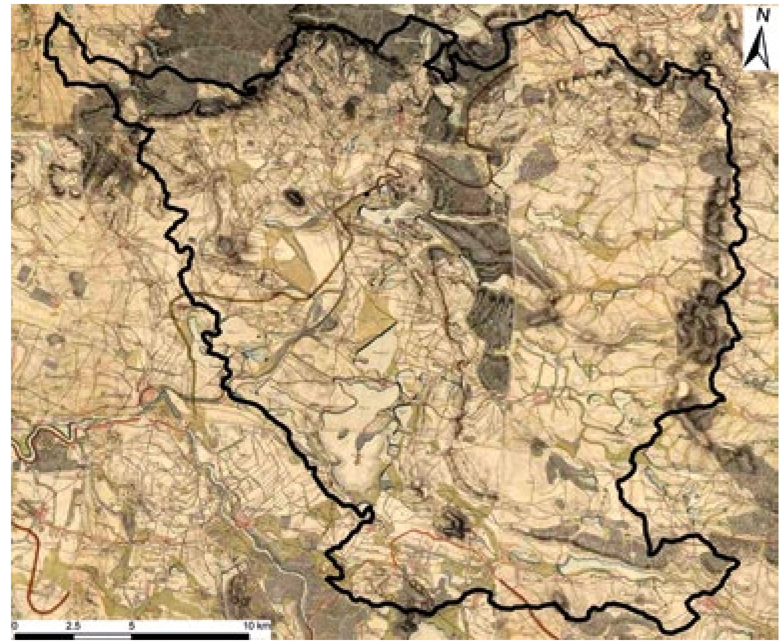

Fig. 4. The study area in the Poděbrady region on a map of the 1st Military Mapping

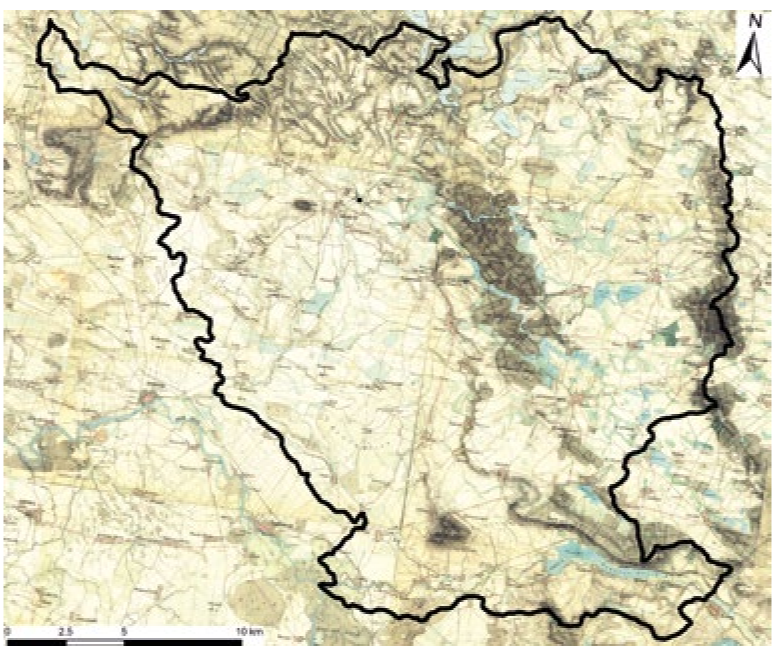

Fig. 3. The study area in the Poděbrady region on a map of the 2nd Military Mapping

Fig. 5. The study area in the Poděbrady region based on Müller's mapping

used, available in the map browser on the Arcanum Maps – The Historical Map Portal website [5], and Müller's map of Bohemia from 1720, available in the map browser of the Land Surveying Office archive [6].

To display the current state of ponds and other water bodies, the current Basic Map of the Czech Republic 1 : 10,000 (BM 10) and the current orthophoto map of the Czech Republic available on the ČÚZK Geoportal [7] as a WMS service were primarily used. More detailed information about the methodology, the maps used, and the definition of the Polabí lowland area can be found in the previous article dealing with ponds in the Pardubice region [1].

RESULTS

During the initial visual detection and subsequent analysis of changes in pond location in the Polabí lowland based on the maps of the Second Military Mapping and current documents, two areas with the largest share of historical and current ponds were selected, namely in the Pardubice and Poděbrady regions.

In the following part of the article, the results for the Poděbrady region, presented in this article, are compared with the results from the Pardubice region. A cursory look at the study area of Poděbrady region on the map of the Second Military Mapping and the current BM 10 shows a clear decrease in pond area, and in particularly larger pond areas have disappeared or been reduced (*Figs. 2* and *3*). When looking at the documents of Müller's mapping and the First Military

Mapping, it is obvious that there was a greater representation of ponds in the course of the 18th century than in the middle of the 19th century in the Poděbrady region. The vast Blato pond near Poděbrady is worth mentioning, which is no longer found on the map of the Second Military Mapping (*Figs. 4* and *5*). Blato pond was one of the largest ponds in Bohemia, together with Čeperka pond in the Pardubice region and Rožmberk pond in the Třeboň region [4, 5, 8].

The area of all types of ponds according to stability makes up 3.17 % of the study area in the Poděbrady region. Disappeared ponds are the most represented – 58.26 % of the area of all ponds according to stability (906.96 ha). Continuous ponds follow with 38.22 % (595 ha), and new ponds occupy the smallest area with 3.52 % (54.81 ha) (*Fig. 6, Tab. 1*). The average area of disappeared ponds is 15.91 ha, continuous ponds 9.15 ha, and new ponds only 0.9 ha. The minimum size of the new ponds area is identical to the minimum size that was considered during the data analysis: 0.03 ha for continuous ponds and 0.41 ha for disappeared ponds. For the maximum size of the area, the largest were historical ponds (disappeared and continuous), while the new ponds are the smallest (*Tab. 1*).

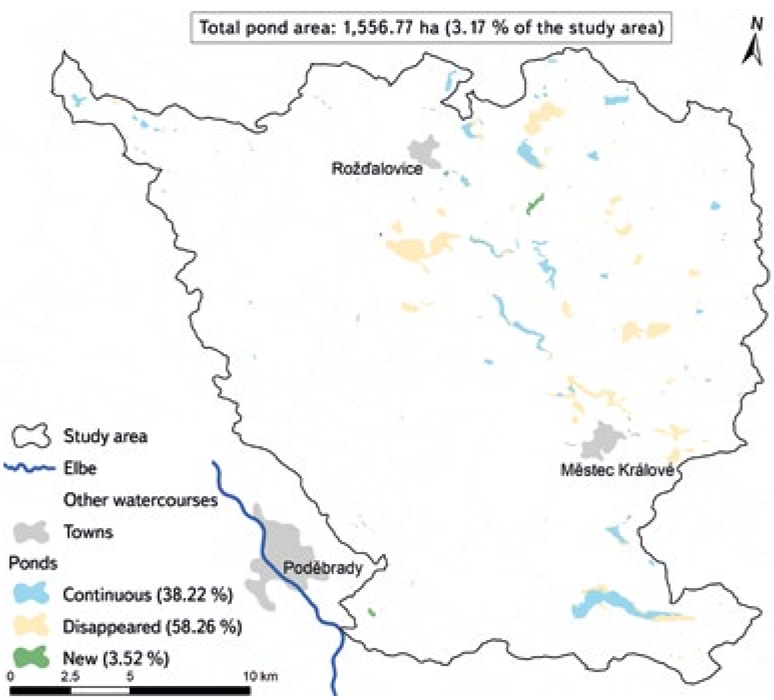

Fig. 6. Pond location development in the Poděbrady region

Tab. 1. Landscape-ecological characteristics of pond development according to stability in the Poděbrady region

Poděbrady region (48,968.9 ha)			
Ponds 1836/52–2022	dissapeared	continuous	new
Area [ha]	906.96	595.00	54.81
Number of plots [pcs]	57	65	61
Minimum plot size [ha]	0.41	0.03	0.01
Maximum plot size [ha]	188.02	185.87	19.73
Average plot size [ha]	15.91	9.15	0.90
Share of the total area of ponds in the study area [%]	58.26	38.22	3.52
Ratio to the total area of the study area [%]	1.85	1.22	0.11

Arable land currently covers 74.45 % of the disappeared pond area; the share of permanent grassland (11.79 %) is also significant. Swamps and marshes replaced 7.77 % of the disappeared pond area, and forest 3.85 % of their area. Other land use types at the site of disappeared ponds do not exceed 1 % of their total area (*Tab. 2*).

Tab. 2. Current land use types in places of disappeared ponds in the Poděbrady region

Land use	**[ha]**	**[%]**
arable land	675.21	74.45
forest	34.96	3.85
permanat grassland	106.94	11.79
swamps, marshes	70.51	7.77
built-up area	2.10	0.23
orchards, parks, and gardens	8.09	0.89
shrubs	6.50	0.72
watercourses	2.55	0.28
quarries, landfills and other areas	0.10	0.01

When comparing the above results with data from the Pardubice region [1], it is clear that during the Second Military Mapping the total area of historical (i.e., disappeared and continuous) ponds in Pardubice was twice as large, and the total area of new ponds was six times larger; correspondingly, also a larger average size of their area. However, from the point of view of the maximum pond size, the larger ponds in the Pardubice region are disappeared and new, while the Poděbrady region these are continuous.

Pardubice and Poděbrady regions together occupy 99,073.4 ha, which is 23.33 % of the defined territory of Polabí. However, in both of these areas there are 77.91 % of the area of disappeared ponds, 72.84 % of continuous ponds, and 30.55 % of new ponds. In Polabí, there are historical and new ponds on 1.71 % of the area, in the Poděbrady region on 3.17 %, and in the Pardubice region on 6.83 % of the area. Pardubice and Poděbrady regions are also home to the largest areas of historical and new ponds.

Tab. 3. Landscape-ecological characteristics of pond development according to stability in the Polabí lowland

Polabí (424,615.7 ha)			
Ponds 1836/52–2022	dissapeared	continuous	new
Area [ha]	4,068.03	1,970.76	1,224.48
Number of plots [pcs]	310	304	594
Minimum plot size [ha]	0.10	0.01	0.01
Maximum plot size [ha]	520.45	185.87	63.84
Average plot size [ha]	13.12	6.48	2.06
Share of the total area of ponds in the study area [%]	56.01	27.13	16.86
Ratio to the total area of the study area [%]	0.96	0.46	0.29

Tab. 4. Current land use types in places of disappeared ponds in the Polabí lowland

Land use	[ha]	[%]
arable land	2,210.15	54.33
forest	791.46	19.46
permanat grassland	630.15	15.49
swamps, marshes	169.12	4.16
built-up area	158.64	3.90
orchards, parks, and gardens	56.15	1.38
shrubs	38.53	0.95
watercourses	8.48	0.21
quarries, landfills and other areas	5.35	0.13

Based on a field survey in May 2023, the sites of the disappeared Nepokoj, Krčský, Štítarský, Záhorský, and Kněžický ponds are presented below.

The current state at the site of the disappeared Nepokoj pond near Svídnice is shown in *Figs. 7–9*. At this site, arable land shows signs of seasonal waterlogging at the site of the disappeared pond. There is also a straightened and deepened watercourse of the Štítarský stream.

The current state at the sites of disappeared or current Krčský and Štítarský ponds between Městec Králové and Vinice is shown in *Figs. 10–14*. At the site of both historical ponds there are currently much smaller bodies of water of the same name; this is especially true of Štítarský pond. Between the two current ponds lies Dymokursko natural monument (NM) [7]. There are reed beds at this site and the watercourse of Štítarský stream has been also straightened and deepened at the site of the disappeared pond. At Vinice, there is a grassy strip of several metres along the modified watercourse, and the area beyond it is used as arable land. On the left-bank tributary of the Štítarský stream, arable land extends to the watercourse, and signs of both seasonal waterlogging and flooding of arable land are visible.

Fig. 7. Site of the disappeared Nepokoj pond based on the current orthophoto map of the Czech Republic

Fig. 8. Current state of the landscape at the site of the disappeared Nepokoj pond near Svídnice village (May 2023)

Fig. 9. Waterlogged arable land at the site of the disappeared Nepokoj pond near Svídnice village (May 2023)

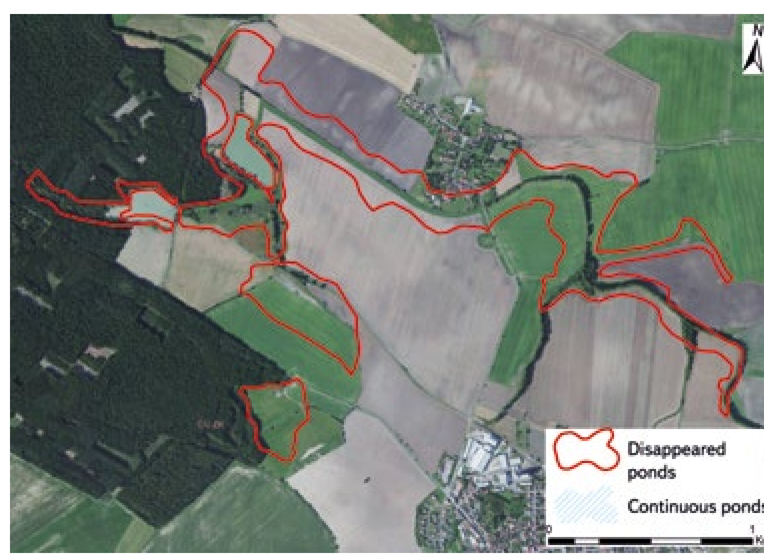

Fig. 10. Site of the disappeared Krčský and Štítarský ponds based on the current orthophoto map of the Czech Republic

Fig. 11. Current state of the landscape at the site of the disappeared Štítarský pond near Městec Králové in Dymokursko NM (May 2023)

Fig. 12. Krčský pond (May 2022)

Fig. 13. Arable land, including waterlogged sites along the sites near Štítarský stream in the area of the disappeared Štítarský pond near Městec Králové (May 2023)

Fig. 14. Grassy strip along Štítarský stream in the area of thedisappeared Štítarský pond near the Vinice village (May 2023)

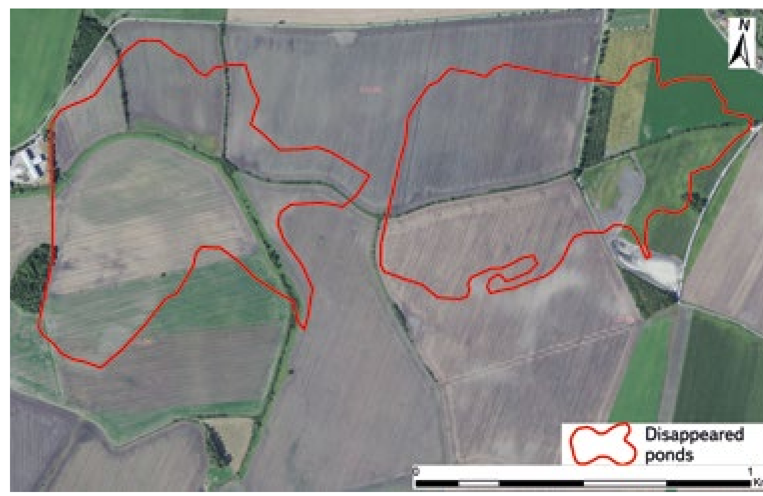

Fig. 15. Site of the disappeared Záhorský and Kněžický ponds based on the current orthophoto map of the Czech Republic

Fig. 16. Current state of the landscape at the site of the disappeared Kněžický pond, view towards the disappeared Záhorský pond (May 2023)

Fig. 17. Waterlogged site used as arable land at the site of the disappeared Kněžický pond (May 2023)

The current state at the site of the disappeared Záhorský and Kněžický ponds between Záhornice and Kněžice is presented in *Figs. 15–17*. At this site of disappeared ponds, there is a straightened and deepened watercourse of the Záhornický stream – here, however, with woody bank vegetation. It is one of the sites where ponds have mainly been replaced by arable land. There are signs of both seasonal waterlogging and flooding of arable land of such a nature that it practically makes use for growing crops impossible.

DISCUSSION

The results from the Poděbrady region regarding pond area according to stability do not correspond to the data for the entire Czech Republic, similarly to the Pardubice region [1]. In the Poděbrady region, from the mid-19th century to the present, disappeared ponds have the largest share – 58.26 % of the area of all ponds according to stability (906.96 ha), followed by continuous ponds with 38.22 % (595 ha), and the smallest area is occupied by new ponds at 3.52 % (54.81 ha). In the Pardubice region, from the mid-19th century to the present, disappeared ponds also have the largest share – 66.11 % of the area of all ponds according to stability (2,262.57 ha), followed by continuous ponds with 36.56 % (840.51 ha), and the smallest area is represent by new ponds at 13.4 % (319.29 ha). In contrast, data for the entire Czech Republic indicate the smallest area of ponds in the mid-19th century; since then it has been slightly increasing. This difference is probably due to the fact that in the lowlands there was generally pressure for another wave of pond desiccation only in the second half of the 19th century, although a large part of them had already disappeared from there earlier [1, 4–6, 9–11]. This is particularly evident from the documents of the First Military Mapping and Müller's mapping. In *Figs. 3, 4*, and *5*, this trend is also confirmed for the Poděbrady region, as it was previously for the Pardubice region [1].

However, compared to Poděbrady region, there is a noticeable change. While the largest ponds in Pardubice region, i.e. Velká Čeperka, Oplatil, Rozkoš, etc. (with the exception of the Rutvas pond) were still recorded on the maps of the Second Military Mapping, the largest Blato pond in the Poděbrady region is no longer recorded in these maps. This also applies to the other ponds of the historical Poděbrady and Nymburk pond system (Šumburk, Bobnický, Chlebský, Vestec, etc.) [4–6, 9, 10, 12]. This fact is also visible in *Fig. 6* because, in the western part of the study area (near Poděbrady and Nymburk), there are no larger areas of historical ponds analysed according to the methodology presented here (i.e., from the Second Military Mapping). In *Figs. 4* and *5*, the areas of large ponds are shown both in the study area and just beyond its borders. Therefore, if only the area between Rožďalovice and Městec Králové (*Fig. 6*) was evaluated, the area of historical ponds would be similar to that of the Pardubice region [1].

As part of the evaluation of historical pond representation in Polabí, the part between Pardubice and Poděbrady was chosen as the one where their representation was the highest. Subsequently, this area was divided into two approximately equal parts, which were evaluated separately. From a hydrological point of view, however, this division was not the most ideal; part of the fourth order basin in Cidlina belongs to the Poděbrady region and part to the Pardubice region. However, if the location of the Cidlina river were taken into account, the area with the largest number of ponds in Polabí would have to be divided into three parts: the Pardubice region (Opatovický canal), Chlumec region (Cidlina), and Poděbrady/Nymburk region (Mrlina). However, this division is complicated by the Sánský canal, which connects Cidlina with Mrlina. Due to the size of both study areas and the locations of the respective fourth order basins, this division would not offer approximately the same areas, which would make it difficult to compare the results. In the sites of disappeared ponds, there is mainly arable land, permanent grasslands, and in Pardubice region also forests. Simultaneously, in places of historical ponds, in addition to waterlogged sites, there are small-scale protected areas on current arable land, which show the path that could be taken in the effort to transform the current landscape into a landscape that is more ecologically stable, reflecting its current state. In addition to Dymokursko NM, in the Poděbrady region there are, for example, Žehuňský rybník, Dlouhopolsko, and Kopičácký rybník national natural monuments (NNM), and Louky u Choťánek and Rybník Kojetín NM; in the Pardubice region, Bohdanečský rybník National Nature Reserve (NNR), and U Podhránovského rybníka NM [2, 7].

CONCLUSION

Given the current state of the landscape and ongoing climate change, it would be appropriate to use data on the location of disappeared ponds for landscape planning. This study can be used for the restoration of ponds in the places of their historical occurrence because it can be reasonably assumed that such locations are optimal in terms of landscape functional parameters and pond management. This could be justified especially where there is periodic waterlogging or flooding of locations currently used as arable land, and therefore it is not sensible – and in some places not even possible – to harvest the planted crop. Of course, it would not be a matter of restoring the original extensive ponds. It would be possible to build systems of small water bodies meeting the definition of a pond as one of the wetland types, including the occurrence of a littoral zone and with a corresponding maximum depth [13–15]. Another option is to at least plant hygrophilous trees in waterlogged areas, or leave these locations for succession.

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Wastewater based epidemiology, determination of selected illicit drugs and Covid-19 pandemic

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Keywords: Wastewater Based Epidemiology (WBE) — illicit drugs — THC — methamphetamine — amphetamine — MDMA — cocaine — Covid-19 pandemic

ABSTRACT

The World Health Organization (WHO) declared an outbreak of a global health emergency on 30th January 2020 and a pandemic caused by Covid-19 in March of the same year. In our paper, we tried to find out if and how this situation affected drug consumption from the perspective of wastewater analysis. We compared the results of weekly sampling events from 2019, 2020, 2021 and 2022, which took place at approximately the same period of the year, but in 2020, 2021, and 2022 were affected by the state of emergency and other pandemic-related measures. We monitored the concentration of selected drugs – THC, methamphetamine, MDMA, cocaine, and some of their metabolites (amphetamine and benzoylecgonine) in wastewater samples taken at the inflow to wastewater treatment plants. According to our measurements, virtually all monitored drugs experienced changes in their consumption.

INTRODUCTION

Almost 25 years have passed since the hypothesis that wastewater can be treated as a highly diluted urine sample [1, 2]. Gradually, a new interdisciplinary field of science emerged – Wastewater Based Epidemiology (WBE), which was initially focused primarily on licit and illicit drugs [3] and gradually expanded to include other groups of substances and markers excreted by the population into wastewater. Municipal wastewater therefore contains a complex mixture of chemical substances, including human metabolites – biomarkers. Quantitative measurement of these specific substances will provide information, for example, about the way of eating, health status of the population, occurrence of diseases, alcohol and drug consumption, and the population's exposure to environmental contaminants [4].

Given that SARS-CoV-2 viral particles were excreted by the infected population in urine and feces into municipal wastewater even before the onset of disease symptoms, the Covid-19 pandemic contributed significantly to increasing the importance of the epidemiological approach to wastewater [5, 6], which can also be used as an early warning tool before the onset of the disease.

The determination of selected drugs in municipal wastewater has long been used at the European and global level for monitoring drug consumption in monitored urban agglomerations; monitoring results are regularly published on the website of the European Monitoring Centre for Drugs and Drug Addiction (EMCDDA) [7, 8].

METHODOLOGY

The TGM WRI hydrochemical laboratory has been dealing with the determination of illegal substances in wastewater for more than ten years. The range of determined licit and illicit drugs is gradually expanding, and new substances are included in the analyses according to the current situation on the drug scene. The analytical method was developed according to the procedure published by Postigo et al. [9]. It is a fully automated on-line SPE and LC-MS/MS (ESI) drug determination method. The analytical methods in ESI+ or ESI-mode are accredited, and the laboratory annually participates in an international interlaboratory comparison of tests. This interlaboratory comparison takes place as part of global monitoring of the drug situation organized by the SCORE-network [14]. A weekly monitoring sampling campaign is implemented every year in spring, usually from April to May, and was not interrupted even during the Covid-19 pandemic. We used the results obtained as part of these sampling campaigns to monitor the impact of the pandemic on drug use from the point of view of the epidemiological approach to wastewater, as we had the measurement results available for both "normal" situation before the pandemic and during the period affected by Covid-19 and related measures. These measures also affected WWTP operation, which operated in a special regime.

History of emergency measures in the Czech Republic

From the beginning of March 2020 up to and including 2022, various regulations and measures affected by the current pandemic situation were gradually announced, expanded and cancelled, mainly in connection with the number of infected and hospitalized persons. The following overview briefly shows the announcement dates of selected measures, especially those that were in force at the time of the weekly monitoring campaigns for determination of illicit substances. An overall detailed overview of government resolutions related to the fight against coronavirus is available on the Government of the Czech Republic website [10].

Brief overview of selected measures related to Covid-19 pandemic:

- 2019 – in December, Covid-19 was first identified in Wuhan, China
- 2020
  - 1st March – first case in the Czech Republic
  - 12th March – state of emergency, closure of schools, restaurants, state borders, etc.
  - 18th May – end of state of emergency, extraordinary measures still apply, gradual relaxation
  - autumn – state of emergency again

— 2021
  - state of emergency is gradually extended
  - 11th April – end of state of emergency, followed by measures according to pandemic law
  - 23rd April – additional measures were taken to enable partial relaxation

— 2022
  - various emergency measures related to Covid-19 epidemic are still in place
  - declaring state of emergency for 30 days from 4th March to 2nd April 2022
  - extending state of emergency until 31st April 2022
  - 11th April – due to a fundamental improvement in the epidemic situation, most of the nationwide emergency measures of the Ministry of Health were cancelled. Partial measures for healthcare and social care facilities remain in force.

Wastewater sampling and analysis

For comparison, sampling and analyses of wastewater from the Prague Central Wastewater Treatment Plant (CWWTP), at the inflow to the old (OWL) and new (NWL) water line were chosen. At OWL, water is treated from main sewers B, D, E and F, at NWL from sewers A, C and K. The sewer network of the capital city of Prague is shown in *Fig. 1*. The sampling campaign always started on Tuesday or Wednesday and ended a week later. 24-hour composite samples were collected, and sampling was carried out every 15 minutes at the inflow to the WWTP, behind the screens (after rough pre-treatment). Samples were cooled to 4–8 °C; if they could not be processed within 48 hours or, in the most urgent cases, within 72 hours, they were kept frozen at -20 °C until analysis. The sampling dates in individual years are not exactly the same, but they were always carried out in April and May. In the years affected by the pandemic, the sampling was also related to the capacity of the CWWTP, which worked in a special regime. Sampling took place from 2nd to 8th April 2019, from 20th to 26th May 2020, from 20th to 26th April 2021, and from 6th to 12th April 2022.

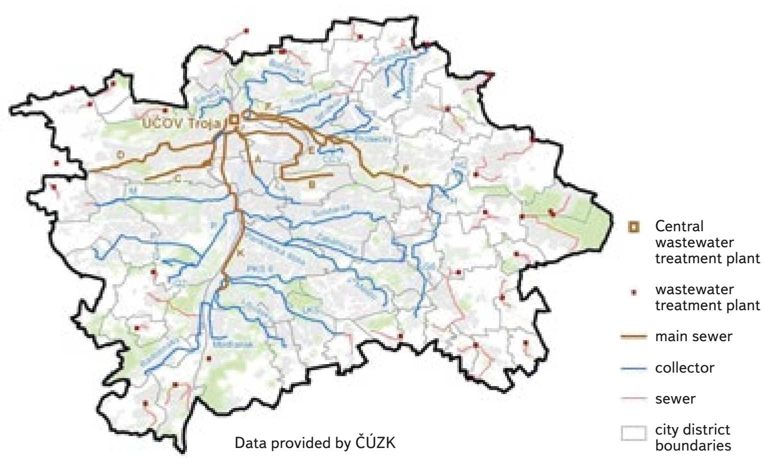

Fig. 1. Sewer network of the capital city of Prague

Results were compared for MDMA (ecstasy, 3,4-methylenedioxy-N-methamphetamine), methamphetamine and its metabolite amphetamine, cocaine and its main metabolite benzoylecgonine, and the tetrahydrocannabinol (THC) metabolite 11-nor-9-carboxy-delta- 9-THC (nor-THC), i.e., for the most common drugs. Amphetamine is used as a drug in many countries rather than methamphetamine; in the Czech Republic, it is considered a metabolite of methamphetamine in wastewater. Ecstasy and cocaine are common "party" drugs, i.e., drugs often used at parties and dancing events.

Methods for determining the above-mentioned analytes are described in detail in Pospíchalová et al. [11]. Before the actual analysis, the samples were conditioned to laboratory temperature, filtered through membrane filters to remove solid impurities, and a mixed solution of internal standards, including isotopically labelled ones, was added to the filtrate. This was followed by online SPE-LC-MS/MS determination, according to the analyte in ESI+ (MDMA, methamphetamine, amphetamine, cocaine, benzoylecgonine) or ESI- mode (nor-THC), and evaluation of the measured results.

RESULTS AND DISCUSSION

After the borders were closed due to the Covid-19 pandemic, precursors for the production of meth became more difficult to find in the Czech Republic because these substances are largely smuggled from abroad, where their sale is not strictly limited by legislation. Closing of borders also affected the availability of cocaine and heroin, which also led to an increase in the prices of individual drugs. The situation on the drug scene gradually "normalized" during 2020 and most probably adapted well to the existing state in 2021 and 2022. More detailed information about the situation on the drug scene during the state of emergency is available on the National Monitoring Centre for Drugs and Addiction website [12].

In this paper, we tried to evaluate the drug situation in the Czech Republic from the point of view of municipal wastewater analysis, i.e., use wastewater based epidemiology which, based on our experience, has a great informative value in terms of behaviour of the population connected to the sewage system in the monitored area.

Fig. 2 compares the average concentration values of individual drugs in the compared years. All values for a given analyte obtained from analyses of samples taken at both water lines are averaged.

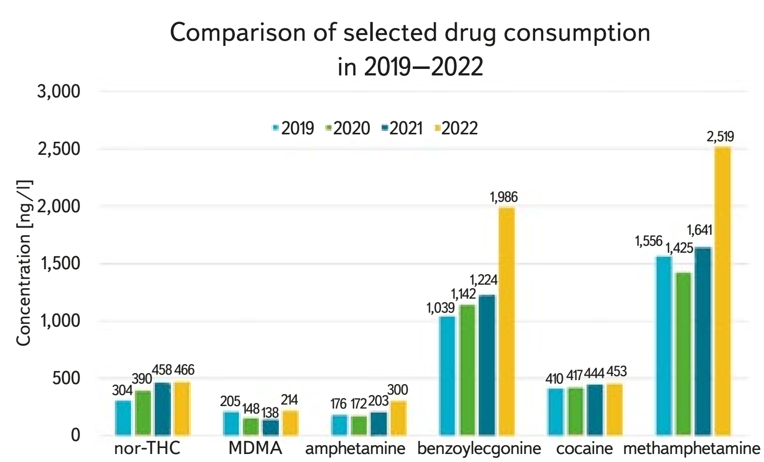

Fig. 2. Average concentration values of individual drugs and their metabolites in the compared years

It is obvious that in the first pandemic year (i.e., 2020), there was a partial reduction in the consumption of methamphetamine and ecstasy (MDMA) from the point of view of wastewater analysis. In the case of methamphetamine, this reduction was probably caused by the poorer availability of precursors for its production; in 2021, the situation on the methamphetamine drug market apparently normalized, and in the last pandemic year, at least during the sampling campaign, consumption even increased. For ecstasy, a typical "party" drug, this was most probably the impact of the ban on organizing various events where ecstasy is used, and this trend continued in 2021. In 2022, during the sampling period, most of the nationwide measures were cancelled, and the drug scene reacted very quickly to this fact.

Marijuana, or its metabolite nor-THC, which is determined in wastewater, and cocaine's main metabolite benzoylecgonine, which is crucial for monitoring cocaine consumption, saw an increase in incidence over the years compared. Very high values for benzoylecgonine in 2022 are probably again related to the lifting of restrictive measures and the possibility to organize dance and other parties again. In the following figures, the measured results for individual drugs and their metabolites in the compared years are presented in the form of graphs. They always show the analyte concentration, date of sampling, and the water line where the sampling for the given substance was carried out. Weekends are marked with red or yellow columns.

The changes during the weekly monitoring are clearly visible here. It should be emphasized that the concentrations of monitored substances in wastewater are compared. Daily wastewater flows through a treatment plant do not vary much from day to day. Higher flows are mainly caused by rainfall, when the wastewater is diluted, and thus the concentrations of the monitored substances can be reduced.

Methamphetamine

Fig. 3 to *6* show the determined concentrations of methamphetamine and amphetamine which, as mentioned above, is mainly a metabolite of methamphetamine in the Czech Republic.

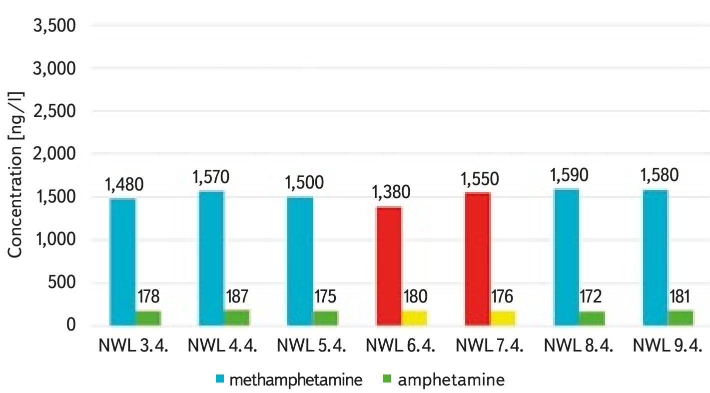

Fig. 3. Concentration of methamphetamine and amphetamine in wastewater sampled at the inflow to NWL in 2019 from April 3 to 9

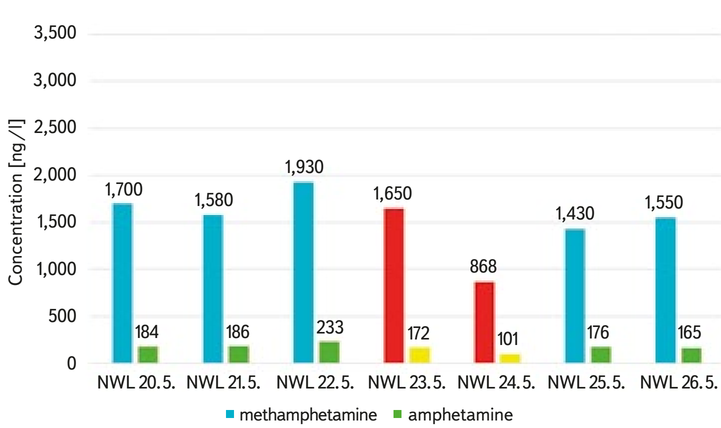

Fig. 4. Concentration of methamphetamine and amphetamine in wastewater sampled at the inflow to NWL in 2020 from May 20 to 26

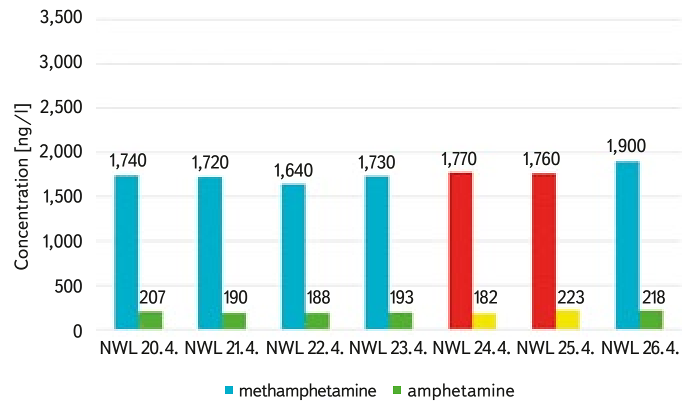

Fig. 5. Concentration of methamphetamine and amphetamine in wastewater sampled at the inflow to NWL in 2021 from April 20 to 26

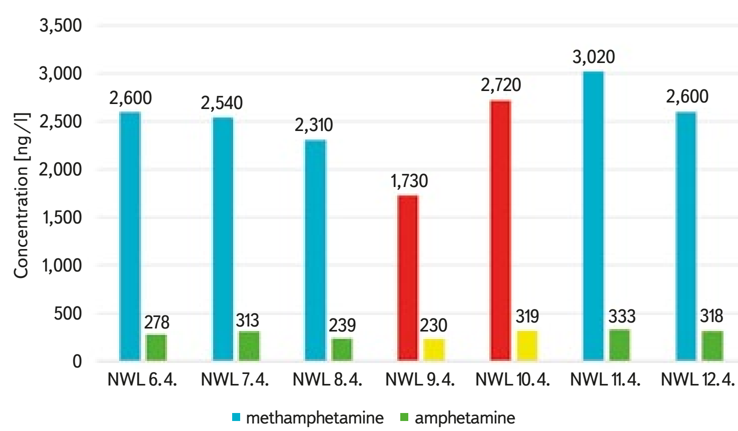

Fig. 6. Concentration of methamphetamine and amphetamine in wastewater sampled at the inflow to NWL in 2022 from April 6 to 12

Methamphetamine consumption does not vary much between the days of the week, as can be seen in *Figs. 3* and *5*. In *Fig. 6*, the lower concentration on 9th April was probably caused by heavy rainfall and thus dilution of a water sample. In the following days, there was also a higher consumption of this drug, which could have been caused by the cancellation of emergency measures on 11th April. This increase is also clearly visible in *Fig. 2*.

Marijuana

Marijuana consumption is monitored by the rate of occurrence of its stable metabolite nor-THC (11-nor-9-carboxy-delta-9-THC). With this drug, as with methamphetamine, consumption does not depend on specific days of the week. *Figs. 7* to *10* document its consumption.

According to the wastewater analysis, marijuana consumption gradually increased between 2019 and 2022; practically the same applies to this drug as in the case of methamphetamine.

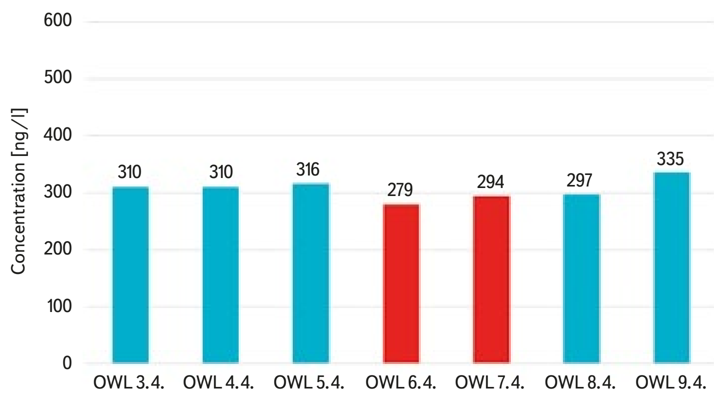

Fig. 7. Concentration of nor-THC (11-nor-9-carboxy-delta-9-THC) in wastewater sampled at the inflow to the OWL in 2019 from April 3 to 9

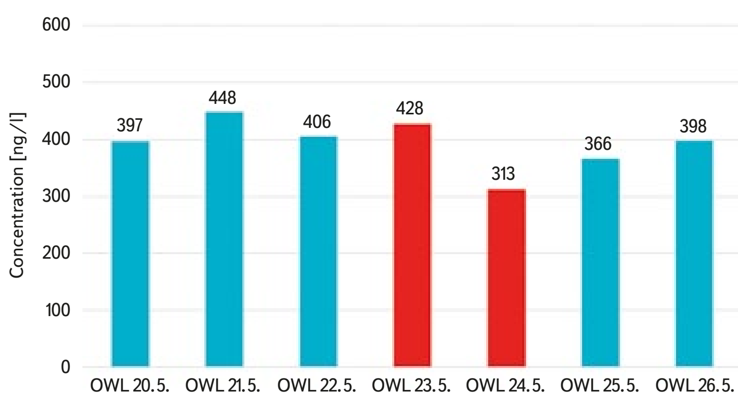

Fig. 8. Concentration of nor-THC (11-nor-9-carboxy-delta-9-THC) in wastewater sampled at the inflow to the OWL in 2020 from May 20 to 26

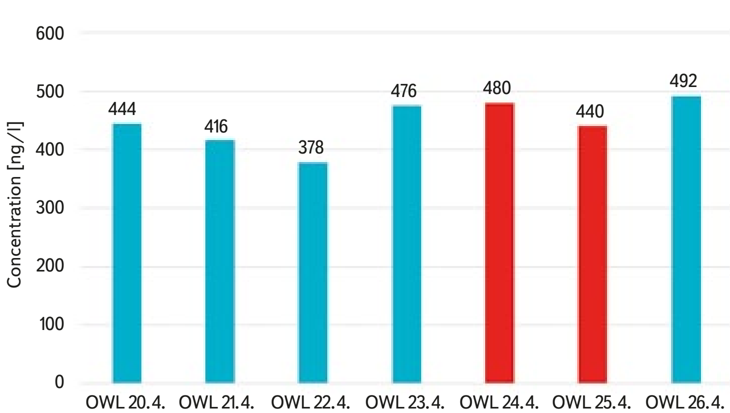

Fig. 9. Concentration of nor-THC (11-nor-9-carboxy-delta-9-THC) in wastewater sampled at the inflow to the OWL in 2021 from April 20 to 26

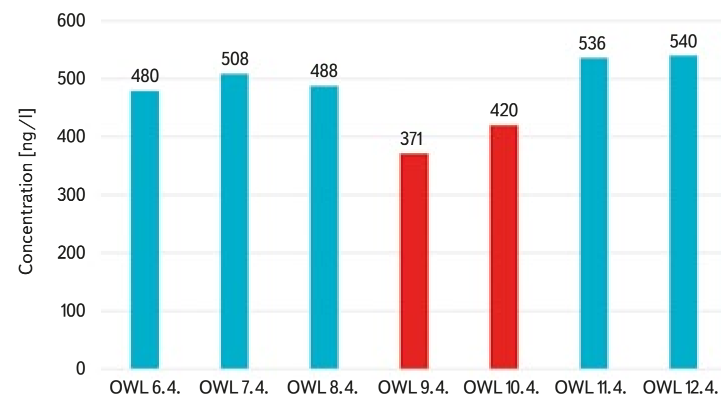

Fig. 10. Concentration of nor-THC (11-nor-9-carboxy-delta-9-THC) in wastewater sampled at the inflow to the OWL in 2022 from April 6 to 12

Ecstasy (MDMA, 3,4-methylenedioxy-N-methamphetamine)

The determined concentration of ecstasy in municipal wastewater is presented in *Figs. 11* to *14*. Due to its nature, consumption of this drug was reduced during Covid-19 pandemic.

The graphical representations above in particular confirm the weekend consumption of ecstasy. *Fig. 11*, where the results are from a year unaffected by the pandemic situation, shows an up to fourfold increase in consumption at the weekend compared to a normal working day. In 2020, during the monitoring event, restrictive measures were still in force, including a state of emergency. However, there was already a reduction in the number of infected persons, and thus also less tension in the population. The state of emergency was lifted in mid-May 2020. The situation was similar in 2021: the state of emergency ended on 11th April, and measures according to the pandemic law remained in force. On 23rd April, there was another relaxation, to which the drug scene immediately reacted, as it was again possible to organize social events. *Fig. 14* shows the situation most clearly for 2022. The reaction to the information that most of the emergency measures will be lifted from 11th April was immediate; the consumption of ecstasy increased more than three times.

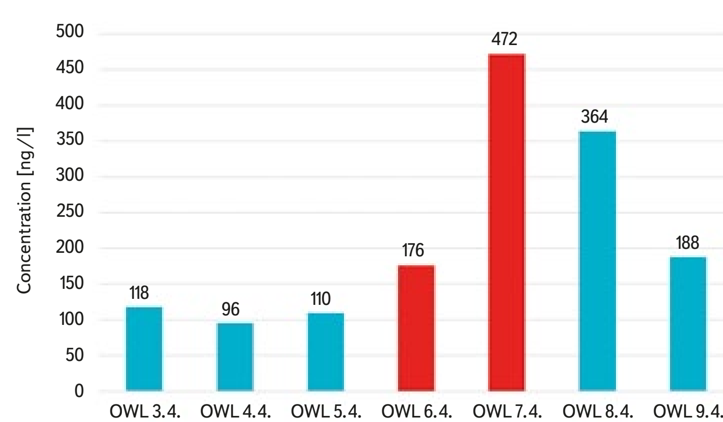

Fig. 11. Concentration of ecstasy (MDMA, 3,4-methylendioxy-N-methamphetamine) in wastewater sampled at the inflow to OWL in 2019 from April 3 to 9

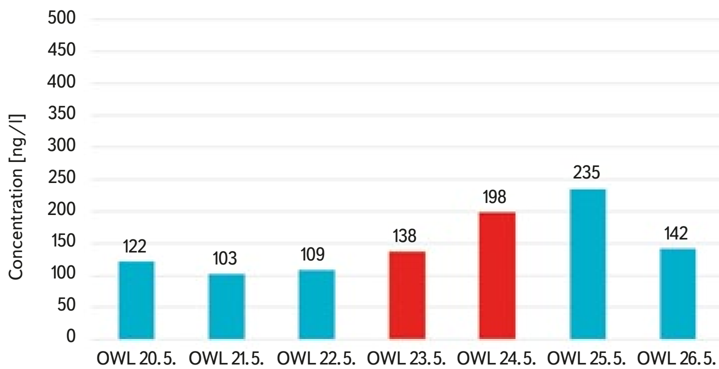

Fig. 12. Concentration of ecstasy (MDMA, 3,4-methylene-dioxy-methamphetamine) in wastewater sampled at the inflow to OWL in 2020 from May 20 to 26

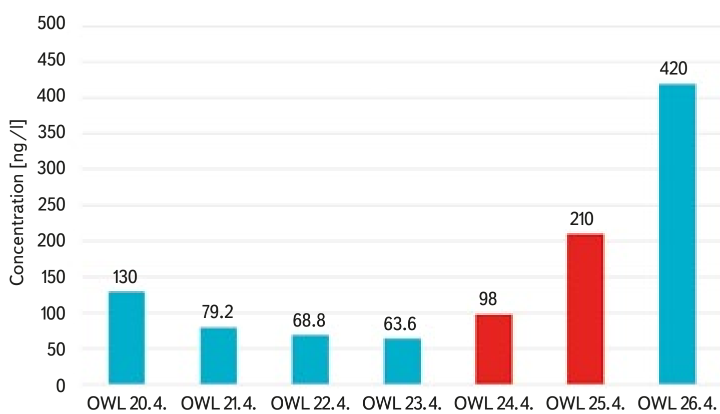

Fig. 13. Concentration of ecstasy (MDMA, 3,4-methylendioxy-N-methamphetamine) in wastewater sampled at the inflow to OWL in 2021 from April 20 to 26

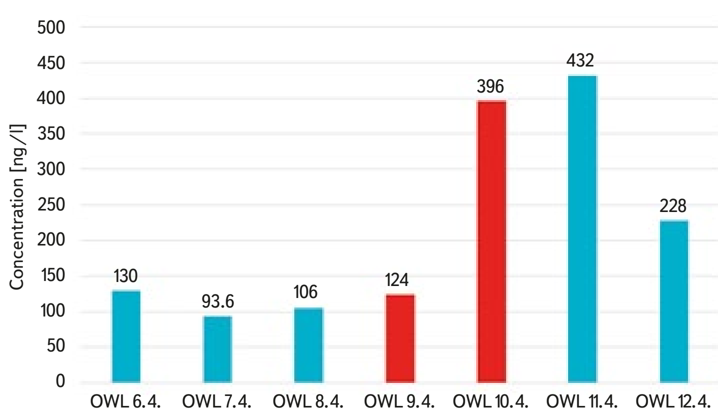

Fig. 14. Concentration of ecstasy (MDMA, 3,4-methylene-dioxy-methamphetamine) in wastewater sampled at the inflow to OWL in 2022 from April 6 to 12

Cocaine

Cocaine is monitored through the determination of its most important metabolite, benzoylecgonine. It is an expensive drug used mainly at parties of the population group with higher incomes. In this case, we specifically selected the inflow to the old water line (OWL) for monitoring, where the water from main sewer B is also discharged. Here, the cocaine concentration, or its metabolite benzoylecgonine, is the highest in the whole of Prague and prevails over methamphetamine, which is a typical dominant drug in the Czech Republic [13].

The results obtained for cocaine can be seen in *Figs. 15* to *18*.

Basically, the same applies to cocaine as it does to ecstasy. In the graph in *Fig. 15* (2019), there is again a typical increase at the weekend in the concentration of the monitored drug, especially its metabolite. In 2020 (*Fig. 16*), the concentration is approximately the same throughout the week. As a result of the restrictions imposed by the state of emergency, it was forbidden to organize social events; the expectation of a certain relaxation did not show in the case of cocaine. In 2021 (*Fig. 17*), the impact of the relaxation of emergency measures has already partially manifested itself. However, the most significant change is in *Fig. 18* (2022), where the rapid reaction to the mere announcement that the emergency measures will be lifted on 11th April is evident.

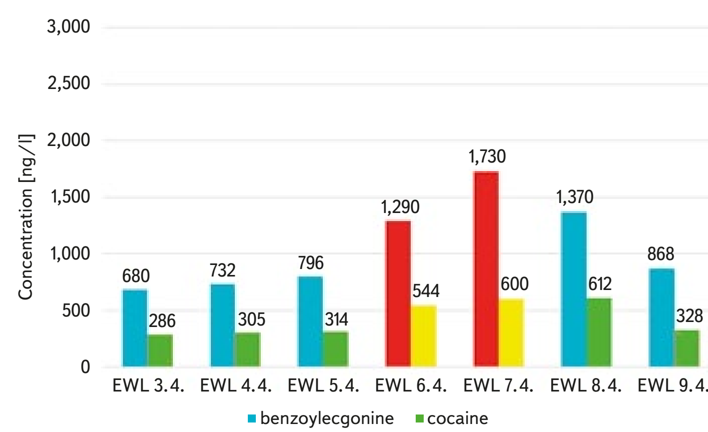

Fig. 15. Concentration of cocaine and benzoylecgonine in wastewater sampled at the inflow to OWL in 2019 from April 3 to 9

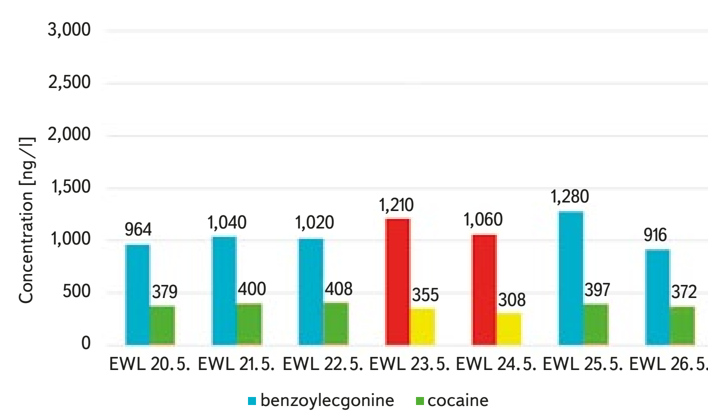

Fig. 16. Concentration of cocaine and benzoylecgonine in wastewater sampled at the inflow to OWL in 2020 from May 20 to 26

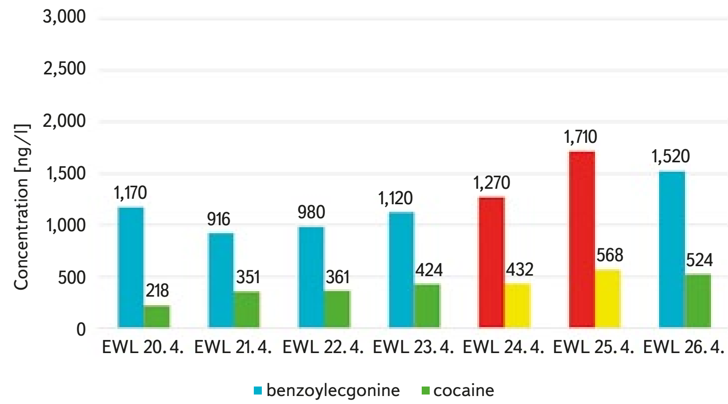

Fig. 17. Concentration of cocaine and benzoylecgonine in wastewater sampled at the inflow to OWL in 2021 from April 20 to 26

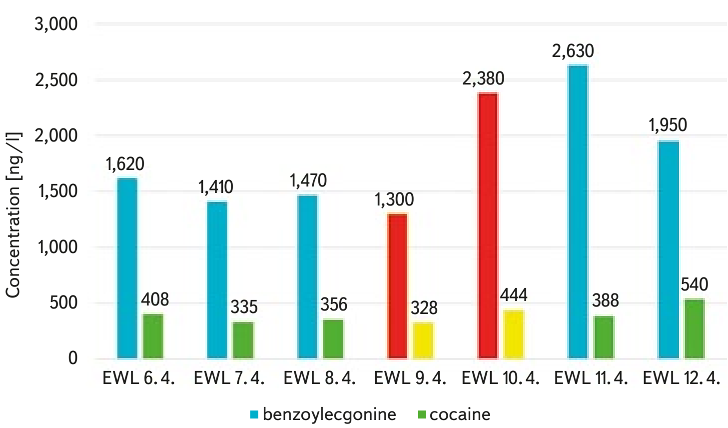

Fig. 18. Concentration of cocaine and benzoylecgonine in wastewater sampled at the inflow to OWL in 2022 from April 6 to 12

CONCLUSION

We tried to find out if and how the pandemic situation affected drug consumption from the point of view of wastewater analysis. We compared the results of weekly sampling events from 2019, 2020, 2021 and 2022, which took place around the same time of year; however, in 2020, 2021 and 2022, they were affected by the state of emergency and other measures related to the pandemic. We monitored the concentration of selected drugs (THC, methamphetamine, MDMA, cocaine and their metabolites amphetamine and benzoylecgonine). According to our measurements, there were changes in consumption for practically all monitored drugs, and it can be seen how quickly the drug scene reacted to the announcement of mainly positive changes related to the state of emergency and various measures, such as the re-introduction of dance parties and other mass events. In our opinion, the high informative value of the wastewater analysis results and the ever-increasing importance of the epidemiological approach to these waters, which was significantly influenced and highlighted by the Covid-19 pandemic, was thus confirmed. Precisely due to the very high informative value and predictive ability of municipal wastewater, it would be very appropriate to continue research using the Wastewater Based Epidemiology and, if possible, to further include other groups of substances and biomarkers that may occur in municipal wastewater [15].

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Interview with Dr. rer. nat. Slavomír Vosika, Head of the Secretariat of the International Commission for the Protection of the Elbe River in Magdeburg

Mr. Vosika, why did you choose the topic of water and what were your beginnings in the field of water management? What was the impulse to apply for a position of the Head of the Secretariat of the ICPER?

I got into water and water management through working in the Secretariat of the International Commission for the Protection of the Elbe River – ICPER. At the end of 1990, they were looking for employees for their Secretariat in Magdeburg. It was an opportunity for me to use both my professional and language knowledge. I studied chemistry with a focus on analytical chemistry at the Technical University of Merseburg, about 30 km west of Leipzig. In August 1991, I joined the Secretariat as a clerk, in October 1995 I took over the position of researcher, and on 1st January 2004, the position of Head of the ICPER Secretariat.

If I am not mistaken, the ICPER Agreement was the first negotiated international agreement for the Federal Republic of Germany after reunification. In addition to the water sector, the agreement thus has special significance for Germany itself.

Yes, that's right. The ICPER Agreement, signed on 8th October 1990 in Magdeburg, was the first international treaty concluded by Germany after its reunification on 3rd October 1990.

Do you remember the first task you worked on at the Secretariat?

One of my first tasks was to support the activities of the "Accidental water pollution" (H) ICPER working group and to prepare the relocation of the Secretariat from the building of the former Water Management Directorate of the Middle Elbe, in which the State Assembly of Saxony-Anhalt had shown interest, to the premises of the Water and Navigation Authority Magdeburg, where the Secretariat is still located today.

During more than thirty years of ICPER's existence, many projects have passed through the Secretariat. Which one has stuck in your mind the most?

There were a lot of projects related to the Elbe, especially in the 1990s. Both the European Union and Germany significantly supported financing of these projects. Projects were always managed by relevant ministries or research institutions. The effort of the working groups and the ICPER Secretariat was to implement the outputs of these projects into the ICPER recommendations. If I had to mention one activity in particular, then it would be the improvement of water quality in the Elbe. At the end of the 1980s, the Elbe was one of the most polluted rivers in Europe. In order to improve this situation, an agreement was negotiated in the early 1990s to monitor water quality in the Elbe basin based on an agreed international measurement programme. The cornerstone of monitoring the development of water quality in the Elbe and its tributaries was the network of water quality measuring stations, and their comparability was an important prerequisite for the common interpretation of the measured values.

On the ICPER website it is possible to read about the functioning of individual ICPER working groups and their presidents. An important part of the ICPER is its Secretariat, but we cannot read anything about it anywhere, or about you, which is a pity.

The ICPER Secretariat supports the Commission's activities from a professional, language, and organizational-technical point of view. The eight-member team consists of three researchers, two translators-interpreters, two administrative workers, and the Head of the Secretariat.

What are the current topics that the ICPER and its Secretariat are currently dealing with?

The analysis of the low water period 2014–2020 in the Elbe basin has been completed. In cooperation with the flood forecasting centres in Prague, Dresden and Magdeburg, information channels with cross-border significance are being checked and updated between the flood forecasting centres on the Elbe. The International Elbe Monitoring Programme for 2024 and the International Elbe Monitoring Programme for Monitoring Water Quality in Extreme Hydrological Situations are being prepared, as well as an update of the International Elbe Warning and Alarm Plan. Work continues on the extension of the Elbe Alarm Model (ALAMO, a model for forecasting the spread of harmful substances in the Elbe) by the Bílina tributary. We are supporting the main organizer, Povodí Ohře state enterprise, in the preparation of the 20th Magdeburg Seminar on Water Protection, which will take place on 11–12th October 2023 in Karlovy Vary.

The ICPER Secretariat has been involved in the preparation of the Magdeburg Seminar for a long time. Do you remember the first of them, and can you briefly describe the development of this important water management event?

The tradition of Magdeburg Seminars on Water Protection was established in 1988 in Magdeburg. The first Czech-German Magdeburg Seminar on Water Protection, in which ICPER participated for the first time, took place in September 1992 in Špindlerův Mlýn. Since 1992, the seminar has been held alternately in the Czech Republic and in Germany, and over the years it has gained a reputation as one of the most important professional and scientific events in the field of water protection in the Elbe basin. It became a platform for representatives from the field of science, practice, and state administration to exchange the latest knowledge and experience. Due to its connection to the Elbe basin, the seminar is unique and has no parallels in the context of large European river basins.

This year's Magdeburg Seminar will take place under the title "Extreme hydrological phenomena and their impacts in the Elbe basin". What can we look forward to?

As part of the 20th Magdeburg Seminar on Water Protection, on 11–12th October 2023 in Karlovy Vary, a total of 26 lectures will be given in five specialist blocks. The seminar also includes presentations of about 30 posters and three excursions.

What do you think is the future of ICPER, or rather what will ICPER look like in 2050?

The principle of a coordinated cross-border procedure in dealing with water protection issues in river basins has been the basis of Czech-German cooperation within the framework of the ICPER since its inception. This principle is an integral part of European legislation, for example the Water Framework Directive and the Flood Directive. In view of the future challenges facing river basins, this approach will not change fundamentally. As proven instruments of international cooperation, commissions for protection of water in river basins will certainly be an important part of its future implementation.

Dr. Vosika, thank you for taking the time to talk to us.

Ing. Josef Nistler

Dr. rer. nat. Slavomír Vosika

Dr. rer. nat. Slavomír Vosika, the Head of the Secretariat of the International Commission for the Protection of the Elbe River (ICPER) in Magdeburg, studied chemistry with a focus on analytical chemistry at the University of Technology in Merseburg. In August 1991, he took up the position of clerk in the Secretariat of the International Commission for the Protection of the Elbe River (ICPER) based in Magdeburg; in October 1995 he took over the position of researcher, and in January 2004 the position of Head of the ICPER Secretariat.

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Fundamental revision of the Urban Waste Water Treatment Directive provokes conflicting reactions from European Union member states

Council Directive 91/271/EEC of 21st May 1991, the Urban Waste Water Treatment Directive (UWWTD), entered into force 32 years ago, which is a respectable age for a legal regulation. Since then, through the consistent implementation of its requirements, good results in water protection have been achieved in practice. Between 1990 and 2014, there was a reduction in the amount of pollutants in treated and discharged urban waste water for organic pollution expressed as BOD_5 by 61 %, for total nitrogen by 32 %, and for total phosphorus by 44 %. The extensive support provided to cities and municipalities from EU financial instruments as well as from national sources and the relatively strict application of sanctions have led, according to data published by the European Commission (EC), to the fact that currently 98 % of waste water in the EU is effectively collected and removed of and 92 % properly treated. Until now, the Directive's requirements have primarily focused on centralized systems for the collection, removal, and treatment of waste water in agglomerations producing loads at the level of 2,000 population equivalent (PE) and more.

Since, after 32 years, a certain obsolescence of this legal regulation was evident, the EU came to a decision on its extensive amendment, for which it cited five main reasons:

- The decisive reason given by the EC was the significant residual pollution in waste water discharged from agglomerations below 2,000 PE, in storm water runoff from urbanized areas, in water runoff from storm water overflow during torrential and long-lasting heavy rains, and contamination produced by individual waste water treatment systems.
- The second reason cited by the EC was insufficient alignment of the Directive with EU policy goals set by the European Green Deal, especially in the area of reducing the production of greenhouse gas emissions, reducing the high energy demand of waste water treatment processes, reusing treated waste water, and using the raw material and energy potential of sewage sludge.
- The third reason cited by the EC was the persistently insufficient and very different level of management in individual member states in the operation of sewage networks and WWTPs, in enforcing the "polluter pays" principle, and in managing the level and effectiveness of monitoring and reporting results with the use of modern digitized systems.
- The fourth reason cited by the EC was the need to deal with new problems, such as the high content of micropollutants in waste water (mainly products of the pharmaceutical industry and personal care products), the introduction of effective monitoring of the presence and quantity of epidemic and pandemic factors in waste water, and the implementation of an extended responsibility scheme of producers and importers (Extended Producer Responsibility – EPR).
- The fifth reason cited by the EC was insufficient alignment of the Directive with current scientific knowledge and technological development.

The legislative process of the Urban Waste Water Treatment Directive revision is quite lengthy and complicated. In 2019, a detailed evaluation of this legislation was completed as part of the REFIT [1] programme and published by the EC. On 26th October 2022, the first draft revision of Council Directive 91/271/EEC of 21st May 1991 on Urban Waste Water Treatment was published. Its text was expanded from the original 20 articles and 3 appendices to 35 articles and 8 appendices. In addition to the goals in the original primary area

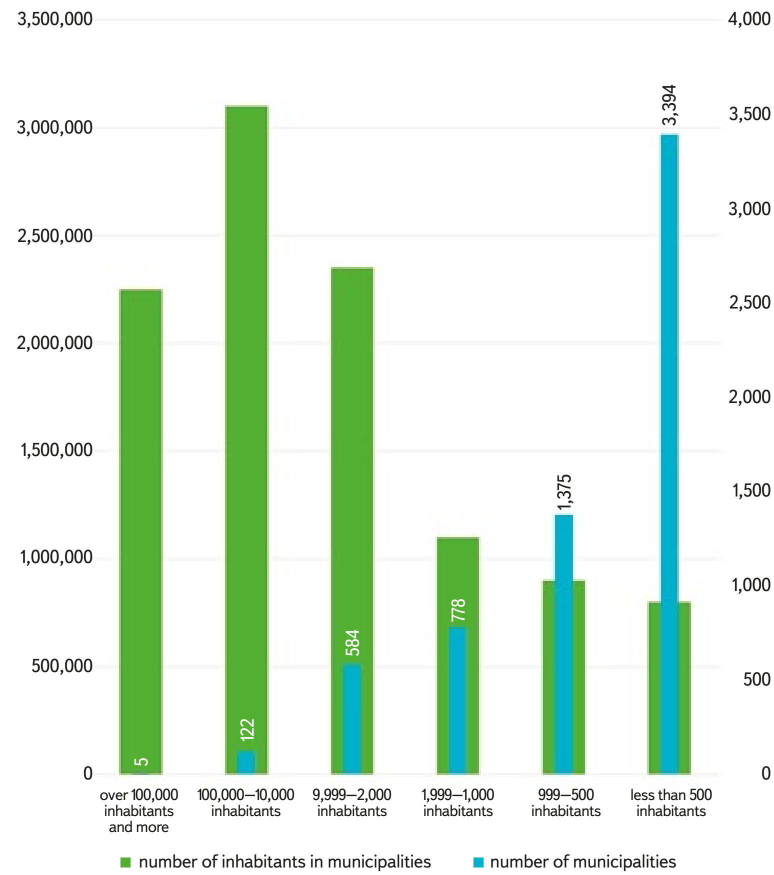

Fig. 1. Number of inhabitants in municipalities and number of municipalities in the Czech Republic (Source: Czech Statistical Office)

of environmental protection, new goals were introduced in the areas of public health protection, reduction of greenhouse gas emissions, management and transparency of the water management sector, access of citizens of EU member states to hygiene and sanitation facilities, and monitoring of the collection, removal and treatment of waste water. In the proposal, the EC requested the authority to issue a total of 16 delegated acts.

The draft revision of the Directive was subsequently discussed in Brussels by EU Council Working Party on the Environment J.1, composed of representatives of the EC and individual member states, during the Czech presidency at the EU Council (4th November 2022 and 2nd December 2022) and subsequently during the Swedish presidency (13th January 2023, 27th January 2023, 6th February 2023, and 21st March 2023). The proposal was also one of the items on the agenda of the informal meeting of the water directors of the EU member states, EC representatives, the states of the European Free Trade Association (EFTA), and candidate countries, which took place from 20th to 22nd November 2022 in Prague. The topic of the revision and its political context and consequences were also addressed by the ministers of environment at the meeting of the Committee

Fig. 2. Ledce municipality – WWTP 1,000 PE with sewerage (Photo: T. Homola)

Fig. 3. The capital city of Prague – TGM WRI in the foreground, Central WWTP 1,400,000 PE on the left (Photo: I. Ibrahimovič)

on the Environment, Public Health and Food Safety of the European Parliament (ENVI) Council held on 16th March 2023 in Brussels. On 26th April 2023, the proposal was discussed by ENVI. According to the preliminary programme of the legislative process, the European Parliament should discuss the draft report on 24th October 2023, and a vote in plenary should take place on 20th November 2023.

However, it is still not entirely certain whether the legislative process will be completed within the above-mentioned deadline, as a number of problems and controversial topics emerged during the negotiations, which were reflected on by individual member states and subsequently commented on by the EC. For some of them, it is very problematic to extend the scope of the Directive to all agglomerations over 1,000 PE within the requirement to ensure centralized collection, removal, and secondary treatment of waste water by 31st December 2030. Regarding this goal, the situation may be significantly complicated by the discussion of the revised Directive in the European Parliament, where an amendment to include all agglomerations over 500 PE has already appeared. For the Czech Republic, the adoption of this amendment would mean an extension of the scope of the Directive to an additional 1,375 municipalities (*Fig. 1*).

Equally controversial are the proposed limits on the content of total phosphorus and nitrogen in treated municipal waste water discharged into watercourses. For total phosphorus, the proposed reduction of produced pollution by 90 % by 31st December 2035 and by 95 % by 31st December 2040 is unrealistic. It will not be possible for member states with a small area of land and a small number of large WWTPs to implement the energy neutrality of urban waste water treatment plants. Even for medium-sized and large member states, it will be essentially unattainable in the case of the proposed condition of energy production only from renewable sources of individual WWTPs. The re-use of purified waste water for irrigation in agriculture is welcomed by countries from the Mediterranean region with a long-term water shortage, which have been practicing this measure for several years. In contrast, states in middle and higher latitudes reject this measure because of the real risk of soil and groundwater contamination. The use of nutrients from sewage sludge in agriculture poses a risk to water and soil for some member states. A controversial topic is the introduction of quaternary treatment at WWTPs from 10,000 to 100,000 PE by 31st December 2040 in areas where the concentration or accumulation of micropollutants poses a risk to human health or the environment. The EC has a basic requirement that manufacturers and importers of pharmaceutical and personal care products cover 100 % of the costs of quaternary treatment, which will concern products placed on the EU market (producers, importers, distributors) and will include residues of substances in waste water (micropollutants from the pharmaceutical and cosmetic industry). All EU member states are concerned about the extremely high costs associated with the implementation of all measures to meet the requirements of the proposed revision of the Directive and, according to them, most of the set deadlines are unrealistic. An example of time-consuming and financially demanding investments in both small-scale and large-scale waste water treatment in the Czech Republic can be the construction of sewerage and WWTP in Ledce municipality in the Pilsen Region, as well as the modernization and intensification of the Central WWTP in the capital city of Prague (*Figs. 2* and *3*).

Considering the importance of the Urban Waste Water Treatment Directive for the water management sector, as well as the need to adapt it to the knowledge and needs of the third decade of the 21st century through a fundamental revision, as demonstrated by expert arguments, it is necessary that further negotiations of the legislative process are constructive and that the amended Directive is approved in an optimal form both for owners and operators, as well as for the protection of water and aquatic ecosystems.

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Ministry of Agriculture of the Czech Republic

Graphical use of AI

In the June VTEI issue, we got familiar with the AI tool ChatGPT in the form of an "interview". We continue with the topic of artificial intelligence and this time we present experiences with a more "visual" tool. Our intention was to create different visualizations of the situation using text input, the so-called "prompt", or from a master photo, for example a watercourse restoration or the idea of building a water tower in the countryside. But before we get to the visualizations themselves, let us say a few words about this topic.

There are several AI tools that allow users to generate desired images based on text inputs, called prompts. These tools use advanced machine learning technologies and generative models and can create realistic images based on the description provided by the user. Such tools include, for example, DALL-E from the OpenAI company and MidJourney from David Holz's American company of the same name. These tools have the potential to be used for various applications, including the creation of visual content, visual design, or even the design of new products.

For our purposes, we chose MidJourney, a service for generating graphics using artificial intelligence. The tool launched in the middle of 2022, and users create graphics using commands given to a chatbot in the Discord app.

MidJourney's function is to recognize the relationship between images and text, where a machine learning algorithm is trained on a large number of images with text descriptions. If the user enters a request/prompt in the chat window, artificial intelligence will allow the creation of an image that matches the description.

We tested the functioning/usage of the MidJourney AI tool on four examples.

Design for the Jezerka stream restoration

In this case, the basis was the image of the visualization of the restoration of the inflow into a reservoir with a bridge and wetland vegetation published in this year's April VTEI issue [1]. The entire process of generating the result took place in the following order – uploading a real photo of the park before the restoration (*Fig. 1a*), generating a bridge over the stream (only about 20th prompt with a satisfactory result, *Fig. 1b*), connecting both outputs (*Fig. 1c*), and fine-tuning the resulting image (*Fig. 1d*). The time required for this process was approximately three hours.

Water tower

In another case, our intention was to depict the construction of a water tower. Here, too, the source was a picture from an article on water towers published in VTEI 6/2022 (*Fig. 2a*) [2]. The following written prompt was used: *"a tall concrete tower with a metal dome of the tower, featured on cg society, danube school, arial shot, watertank, germany, low pressure system, awe – inspiring award – winning, waterdrops, manufactured in the 1920s, aquiline features, parks and monuments, brenizer method --v 5"* which then drew a preview image of the four variants (*Fig. 2b*). Individual variants can then be created separately at a higher resolution. The time required for the process was about ten minutes.

Fig. 2a, b. Tower reservoir in Kolín designed by architect František Janda in the functionalist style (Photo: O. Civín, subsequent editing with the MidJourney tool)

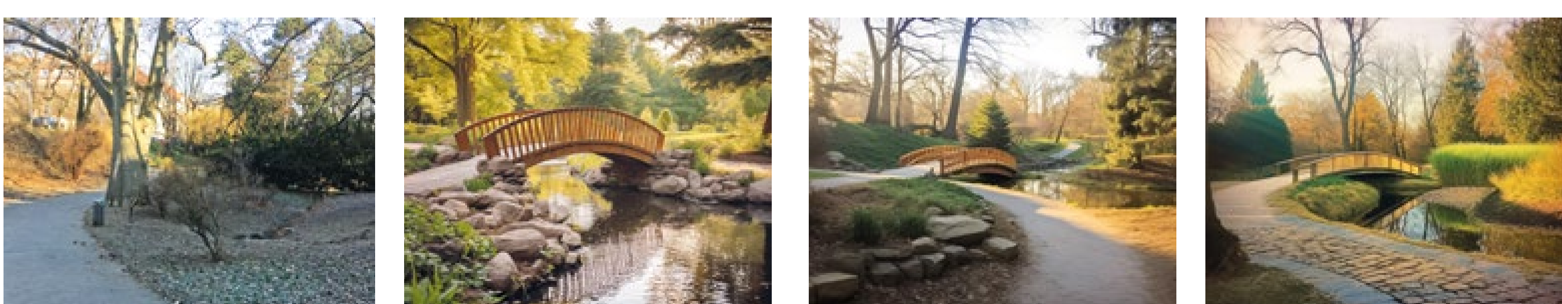

Fig. 1a, b, c, d. The Jezerka stream, the situation of the groundwater drainage outlet as an occasional inflow into the water reservoir (Photo: T. Hrdinka, subsequent editing with the MidJourney tool)

Fig. 3a. The result of the “crayfish” entry – the first MidJourney attempts

Figs. 3b, c. The final result of entering “crayfish” with the MidJourney tool

Aquatic animal

We tested the creativity and capabilities of the MidJourney AI tool on the creation of depictions of living organisms. Using text input, we let the tool draw a crayfish (*Fig. 3a*). It turns out that the Midjourney tool generates crayfish with difficulty – adding the wrong anatomy to them. Compiling the prompt required about 10 attempts. Example of a failed prompt:

„A captivating, hyper-realistic underwater photograph of a crayfish with two antennae, gracefully navigating the crystal-clear waters of a mountain creek, showcasing the intricate details and beauty of this fascinating aquatic creature. This stunning image is skillfully captured using a Nikon D850 DSLR camera, equipped with a NIKKOR AF-S 105mm f/2.8G IF-ED VR Micro lens, renowned for its exceptional sharpness and ability to render vivid, lifelike colors, even in challenging underwater environments. The camera settings are meticulously chosen to highlight the delicate features of the crayfish and the serene ambiance of its habitat, with an aperture of f/11, ISO 800, and a shutter speed of 1/125 sec. The composition is taken from a close perspective, immersing the viewer in the aquatic world of the crayfish as it scuttles among the rocks and submerged plants that line the creek bed. The scene is softly illuminated by natural sunlight filtering through the water's surface, casting shimmering patterns that dance across the crayfish's intricate exoskeleton and the surrounding environment. This awe-inspiring, high-resolution photograph transports viewers beneath the surface of the mountain creek, offering a rare and privileged glimpse into the secret underwater realm of the crayfish. --ar 4:3 --q 2 --v 5.“

After this “failure”, a simple prompt was eventually used: “*A crayfish, captivating, hyper-realistic photograph --ar 4:3 --q 2 --v 5*”. By comparing the first, extensive assignment and the final form, it clearly demonstrates the saying that sometimes less means more :-) (*Figs. 3b, c*). The time required for the process was approximately one hour.

TGM WRI building

The last example on which we tested the AI capabilities was the task of visualizing the building of TGM WRI Prague headquarters, not only in real form (*Figs. 4a, b*), but also in “Lego” form (*Figs. 4c, d*). The template was a photo of the TGM WRI building, which was uploaded to the AI tool with the “image to text” command. Some of the elements from the “image to text” description were used and supplemented with a description of lighting, photographic and artistic styles, and colours. The resulting prompt *“a large red and white brick building, in the style of agfa vista, dark bronze and blue, vray, school of london, computer-aided manufacturing, dark brown and navy, lively and energetic -- ar 31:22 -- v 5”* then produced the following result.

Fig. 4a. TGM WRI building (Photo: TGM WRI archive)

Fig. 4b. TGM WRI (visualization using the MidJourney tool)

Figs. 4c, d. TGM WRI building in Lego style – preview image of variants and visualization using the MidJourney tool

Creating the TGM WRI building from Lego bricks required modifying the prompt to the following form: *"a large red and white brick building, in the style of agfa vista, dark bronze and blue, vray, school of london, computer-aided manufacturing, dark brown and navy, lively and energetic, as lego. --ar 31:22 --v 5"*. The result was the generation of a preview image (*Fig. 4c*). Individual variants can then be created separately at a higher resolution (*Fig. 4d*). The time required for the process was about 15 minutes.

Conclusion

The MidJourney tool can generate some really nice images, even a bit kitschy in some cases. However, the problem turned out to be that the artificial intelligence does not know what exactly is in the photo. Although it recognizes objects (you tell it to), it cannot assess whether the created image is in accordance with our perceived reality. An example can be the visualization of the font (in our case, the name of our institution on the facade of the building generated by the tool), when the AI tool is not yet able to take the font/signs as parameters from queries. However, Stable Diffusion can already deal with texts.

Due to the relatively dynamic development in the field of artificial intelligence, the functionality and quality of the output in AI applications are constantly changing. For example, the current version of MidJourney already generates very realistic high-resolution images with many details compared to previous versions. On the other hand, there is no detailed documentation of the model on which MidJourney runs, so the resulting graphical outputs vary depending on the form of the prompt that users "fine-tune" based on their experience with the tool, and thus, by "reverse engineering", they discover possibilities and hidden model settings. To create such a prompt, other AIs are widely used in the form of web applications, which allow the creation of a prompt "tailored" to the desired idea of the output. For this purpose, e.g. ChatGPT will also serve very well.

In particular, MidJourney now has not only the function of creating images, but can also describe others in text after inserting them into the tool and offer its own version. Several image inputs can also be mixed in it and the result is then a composite. It also has numerous choices of styles in which it generates graphics (from imitations of the styles of various artists to animated and anime outputs to photorealistic graphics, e.g. in a fantasy environment). It also allows you to vary the outputs offered almost arbitrarily.

It should be noted that the use of this tool is currently charged and requires registration and login via the Discord service.

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Generated by artificial intelligence (Midjourney)

Native versus invasive crayfish in the Czech Republic

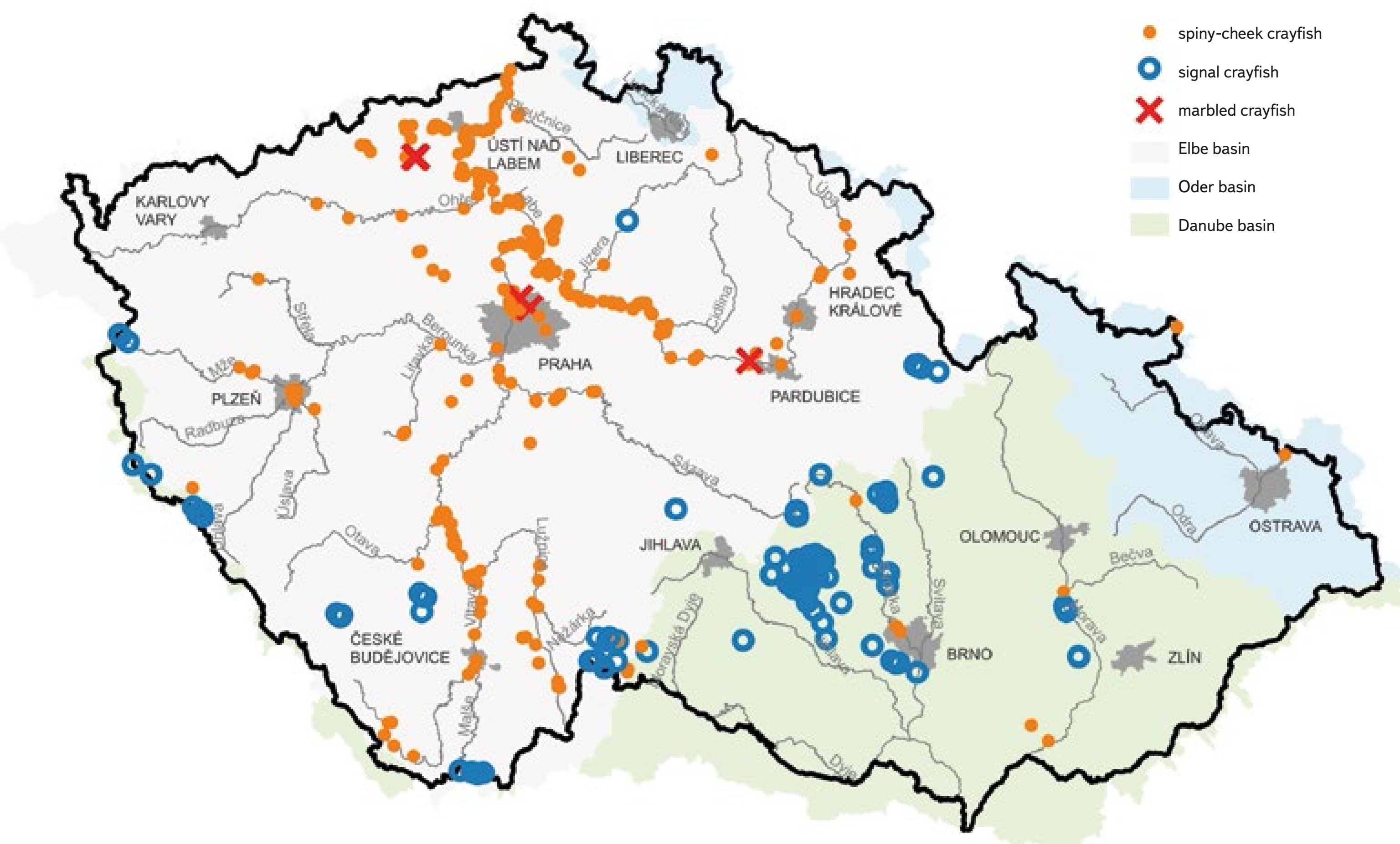
A decrease in species diversity is a negative consequence of many human activities. The number of native animal and plant species is decreasing, their populations are shrinking or completely disappearing, the number of endangered species is increasing, and non-native species are spreading. Global problems are perhaps most evident in the example of freshwater ecosystems.

Invasions of non-native species, associated with high cultural-sociological and economic losses, are currently considered one of the most significant factors in the decline of species diversity. For these reasons, the issue of non-native species is receiving considerable attention worldwide.

There are currently six species of crayfish living in the wild in the Czech Republic, of which only two are native: noble crayfish (*Astacus astacus*) and stone crayfish (*Austropotamobius torrentium*). Narrow-clawed crayfish (*Astacus leptodactylus*) is a European species but not native to the Czech Republic. Other species – signal crayfish (*Pacifastacus leniusculus*), spiny-cheek crayfish (*Orconectes limosus*), and marbled crayfish (*Procambarus fallax*) come from North America and are invasive species [1, 3].

Our crayfish have been around since forever, so to speak. Their current distribution dates back to the period after the last ice age, and man also played a significant role in it; noble and narrow-clawed crayfish are large enough to be used as food, so it was worthwhile for people to move them to new sites. The spread of invasive crayfish is probably due to shipping, with which they were accidentally introduced to Europe in the 19th century. In the second half of the 20th century, American crayfish had already been deliberately released in Europe – as a replacement for native crayfish decimated by crayfish plague, but mainly as a popular culinary delicacy. A problem that continues to this day are aquarists, who brought a number of other crayfish species from all over the world into Europe.

While stone crayfish is mainly found in small and medium-sized streams, the more abundant noble crayfish is also found in large watercourses, in ponds and reservoirs. Narrow-clawed crayfish also prefers different types of stagnant water where it was released in the past. Invasive crayfish are very adaptable and, at the same time, have much lower requirements for water purity, so they basically spread to all the places where native crayfish are or can be found. We can find them in small streams and ponds (signal crayfish), in large watercourses



Map of invasive crayfish species occurrence in the Czech Republic. Jiří Picek, Jitka Svobodová and Silvie Semerádová, TGM WRI, p. r. i., May 2023.
Documentation: Locations of sightings and occurrence of crayfish: NCA CR, TGM WRI, p. r. i., data provided by university students and users of "Crayfish in the Czech Republic" mobile and internet application.

(spiny-cheek crayfish), as well as in reservoirs and ponds (marbled and spiny-cheek crayfish). Their occurrence is shown on the map.

Unlike invasive crayfish, which carry crayfish plague while being resistant to it themselves, native crayfish are killed by the disease. Fortunately, crayfish plague does not usually kill all crayfish in affected streams, but each time a large part of the population disappears. The causative agent of the disease is the fungus-like microscopic pathogen *Aphanomyces astaci*, which lives in the crayfish carapace.

Another advantage that invasive crayfish have is in their reproduction. While our native crayfish usually have tens to hundreds of eggs (stone crayfish up to 100 eggs, noble and narrow-clawed crayfish up to 250 eggs), invasive crayfish can have over 800 eggs at a time. Some can breed twice a season. In addition, marbled crayfish is able to reproduce parthenogenetically, i.e., a single female can lay eggs, produce young, and establish a large population even without the presence of a male (without the need for fertilization). Similarly to other invasive species, non-native crayfish are able to disrupt the balance of the freshwater ecosystem and, simultaneously, eliminate other (especially native) species of basically all animals and plants.

How can we control invasive crayfish?

The basic and cheapest method of preventing the spread of invasive crayfish is to inform the public about the harmful effects of invasive species in order to limit the transmission of invasive crayfish to new locations as much as possible. If invasive crayfish appear somewhere, their complete eradication is no longer possible. The only way to control them is to regularly and repeatedly reduce their number. The most widely used method of controlling invasive crayfish species is manual collection and trapping in bait traps. However, this method carries one significant risk. It may happen that we select large individuals from the population, thereby reducing the pressure on younger developmental stages, which subsequently leads to a greater success rate for their survival. Then, paradoxically, the effort to reduce the population will have the opposite effect. The method of trapping crayfish must therefore be combined with other procedures, such as release of their predators. The best predators are fish that like to feast on invasive crayfish, such as eel, burbot, pike perch, catfish, chub, as well as dragonfly larvae, which successfully destroy juvenile crayfish. Another method of controlling invasive crayfish is the sterilization of the males, who after subsequent release compete for females with other males, which can significantly reduce the number of successfully fertilized females while maintaining predation pressure on younger developmental stages. It is also possible to drain a reservoir, collect the crayfish and then let the site freeze for the winter or dry it in the summer. In combination with the application of, for example, chlorine lime, this method is quite effective. After re-filling the reservoir, it is advisable to release the crayfish predators again. Using poison at a site is considered an extreme method. It can only be used to a limited extent in locations with no run-off and little biological significance, as the poison will kill all other living organisms. Another possibility is to simply separate an invasive crayfish population from its surroundings by creating sufficiently high barriers that crayfish are not able to cross [2].

A crayfish is a crayfish, someone might say. Why does it matter if foreign crayfish replace ours? At first glance, it seems like nothing. However, it is actually a serious problem. The native crayfish species have been living in harmony with the other inhabitants of our watercourses for a long time; other components of aquatic ecosystems suffer from the presence of invasive crayfish because these crayfish destroy both aquatic macrozoobenthos and our native fish species (especially eggs and fingerling). They can also destroy aquatic plants, including critically endangered species, and they attack other animal species, for example, the critically endangered freshwater pearl mussel or the thick shelled river mussel.

Use our Crayfish in the Czech Republic application to record and send your crayfish sightings. By doing so, you will help us protect our native crayfish species.

Noble crayfish

Stone crayfish

Narrow-clawed crayfish

Signal crayfish

Spiny-cheek crayfish

Marbled crayfish

The text was adapted from the leaflet Vlach, P. *Naši vs. invazní raci v Česku* (2023) that serves to inform the public about crayfish species and their effect on the aquatic ecosystem.

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SPÁLOV SMALL HYDRO-ELECTRIC POWER PLANT

Spálov hydro-electric power plant is located between the towns of Železný Brod and Semily, on the Jizera river, above its confluence with the Kamenice. It is an example of a derivation power plant.

It was built between 1921 and 1926 as part of the electrification system of Eastern Bohemia. The project of the entire facility was entrusted to Dr. Ing. Antonín Jílek, provincial senior building councillor, and Emil Králíček, an important architect of his time, and a representative of geometric art nouveau and later cubism. The appropriate local natural conditions were used for the construction of the power plant, namely the Jizera gorge, 3.2 km long with a gradient of 25 m. A 1,323 m tunnel dug in the rock massif leads from the backwater of the fixed weir on the Jizera and continues through a 437 m covered reinforced concrete lateral channel that opens into the surge chamber above the power plant engine room. From the surge chamber, water is fed through pressure pipes to the turbines in the engine room. It was originally fitted with two sets with a Francis horizontal spiral turbine. After the reconstruction in 1998–1999, the original equipment was replaced by Kaplan vertical turbines. One of the original Francis turbines is located in front of the power plant. In the interior of the engine room, in the gable above the gallery, there is a painting by Ferdinand Rubeš symbolizing the production of electricity on the Jizera in Spálov and in Les Království HS. The facade of the engine room, switch room, and surge chamber are equipped with distinctive geometric elements.

The set of buildings of the power plant and its hydraulic structure is an important landscape element and a local landmark. The power plant is not listed, but since 2013 it has been part of the Jizera Valley nature reserve.

Text: Ing. Miriam Dzuráková and Mgr. Michaela Ryšková, photo: Mgr. Michaela Ryšková.

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