VODOHOSPODÁŘSKÉ TECHNICKO-EKONOMICKÉ INFORMACE

(WATER MANAGEMENT TECHNICAL AND ECONOMIC INFORMATION)

VTEI / 2023 / 1

22 March 2023 – World Water Day

In March, the whole world commemorates World Water Day. It has been celebrated since 1993 and its theme changes every year. At the 34th UN Water Meeting, its members and partners agreed that the theme for World Water Day 2023 and World Toilet Day campaign in the same year would be "Accelerating change".

The upcoming UN World Water Development Report will focus on partnership and collaboration, tentatively titled "Accelerating change through partnerships and collaboration."

The theme of this year's World Water Day aims to start a discussion on the aspects and impact of campaigns and content, as well as a focus on bringing "people's voices" to the UN Water Conference 2023. Preparations have also been launched for a World Water Day campaign on the theme "What does accelerating change mean to you?"

There are many ways to celebrate World Water Day, from holding conferences, talks, workshops, and charity events, to making physical efforts such as cleaning our rivers and lakes. It may seem like a small and insignificant step, but the waste we produce is very dangerous for the aquatic environment. Every small stream that we clean in our surroundings is the basis of a larger stream or other water body. Therefore, any litter not picked up could end up in larger watercourses, lakes, and seas and become a major problem for their inhabitants.

UN WATER
22 MARCH
WORLD WATER DAY

Another way is to try to reduce your water footprint. Although we may think that we are not wasting water, water consumption in Europe is 120 litres per day for an adult. An average shower uses around 65 litres of water and one flush of the toilet an incredible 25 litres. However, this consumption does not apply to all continents. In this context, it is necessary to mention that more than a billion inhabitants of our planet suffer from a lack of drinking water or do not have access to it. So we should think about water and its protection more often than just when we are thirsty or when we are having a shower.

VTEI Editorial


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Photo: 123rf.com

Dear readers,

We are entering a new year, so it is time to look back on the past year. In 2022, the VTEI journal went through a number of changes, the most fundamental of which was the decision to also publish it in an English version. Since 2022, all professional and informative articles, including interviews with selected water management personalities, have been translated into English and published on the VTEI website. In addition to the complete online English version of the journal, the website has been equipped with tools for displaying the number of citations and searching for potential plagiarism of articles published in VTEI.

In 2022, we also established cooperation with the National Library of the Czech Republic and ensured regular archiving of VTEI website through the "web archive" service. At the same time, our institution began to cooperate with one of the largest Czech water management portals, *Naše voda*, which published a number of articles published in VTEI on its website.

All these steps have expanded the readership of our journal and the reach of individual articles increased more than fourfold compared to 2021. However, the main goal of these activities is to fulfil the conditions required by Elsevier for the inclusion of VTEI in the Scopus database, which is the largest abstract and citation database of peer-reviewed literature in the world. The successful inclusion of our journal in this renowned citation database would not only confirm its professional level, but also increase the attractiveness of VTEI for domestic and foreign authors, and would thus be a worthy contribution to the celebration of the 65th anniversary of its existence.

In conclusion, we can summarize that in 2022 a total of 48 articles – 29 peer-reviewed and 19 informative – and 6 interviews were published in VTEI.

Based on this promising recapitulation, we wish not only the journal, but also you, its readers, great success in 2023.

VTEI Editorial

Dynamics of micropollutant loads into water supply reservoirs Vír I, Opatovice and Ludkovice

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Keywords: surface water — passive sampling — water supply reservoir — pollution — pesticides

ABSTRACT

Pesticides are still an important group of substances involved in surface water pollution. Their increased occurrence in watercourses in the agricultural landscape is mainly linked to rainfall-runoff conditions, types of cultivated crops, and methods of agricultural management. In order to capture these factors, passive sampling techniques were chosen for the assessment of the load of these substances in selected catchments of water supply reservoirs in the administration of Povodí Moravy State Enterprise. These techniques consist of continuous exposure for several weeks with gradual (integrative) capture of pollution on suitable sorbents. The POCIS (polar organic chemical integrative samplers) were chosen in this work – widely used samplers suitable for capturing polar organic substances. They were applied in eight consecutive sampling campaigns to cover the entire growing season. The aim was to assess the spatio-temporal dynamics (in monthly steps) of selected pesticides and their metabolites into five water supply reservoirs. Due to the scope of the obtained data, this article is focused on the presentation of the results of tributaries into water supply reservoirs Vír I, Opatovice, and Ludkovice, which were monitored in 2021. When the sampling rate Rs was published, it was possible to recalculate the pollution captured by the passive sampler to average concentration during exposure. The results showed which tributaries into the reservoirs were loaded by these hazardous substances in the individual periods of the growing season. The results can be compared with the type of crops grown in a given year.

INTRODUCTION

One of the primary activities of water management is ensuring quality surface water for drinking water treatment. In order to clarify information on anthropogenic influences on selected water reservoirs, work on the project "*Study of the introduction of pesticides and other micropollutants into water reservoirs in the Morava and Dyje basins (PESPOM)*" was started in May 2020 as part of the Programme of applied research, experimental development and environmental innovations – Environment for life (Prostředí pro život), Subprogramme 1 – Operative research in the public interest. Its implementation is planned until 2023. The T. G. Masaryk Water Research Institute (TGM WRI) is the only investigator of this project. The application guarantor of the project is the Department of Water Protection of the Ministry of the Environment of the Czech Republic.

In Europe, more than 150,000 chemicals are used commercially. Annually, their number increases by several thousand. For example, in 2015, this represented the consumption of 350 million tons of chemicals, of which 63 % were classified as hazardous to human health and 36 % as hazardous to the environment [1]. These substances enter the environment not only through wastewater from chemical production and other industries, but also from significant consumption by the population via municipal wastewater [2]. The active ingredients of plant protection products reach surface waters directly through erosion during rainfall-runoff events.

Many water reservoirs in the Czech Republic are located in anthropogenically affected areas. Much attention has long been paid to the basin of the Želivka river basin with the largest water reservoir (hereinafter WR) Švihov supplying drinking water to over one million inhabitants. The dynamics of pesticide leaching into surface waters in Švihov WR basin has been investigated by several authors [e.g. 3–5].

The water reservoirs in the Morava and Dyje river basins are also located in areas with significant agricultural activity and, in the case of Vír I WR, also industrial activity. Vír I WR is the largest of them (*Fig. 1*), coming into operation in 1957. The purpose is to ensure minimum flows, water supply abstraction, operational abstraction, electricity generation, flood protection, and improvement of flows for irrigation downstream from Brno. The total volume of the reservoir is 56.193 million m^3. The most important tributary is the Svratka. The Fryšávka and the Bílý stream are important tributaries of the Svratka. The total area of the catchment upstream from the reservoir is 410.35 km^2. The theoretical water retention time in Vír I WR is 154 days (5.14 months) at the average long-term flow of the Svratka (3.7 m^3) if we consider the reservoir volume of 49.342 million m^3 up to the spillway level and 138 days (4.59 months) in in the case of a reservoir volume of 44.056 mil m^3 (useful water level). The largest human settlement is located in the upper part of the Bílý stream basin, namely the town of Polička (8,700 inhabitants). of the municipalities directly related to the water reservoir, the village of Dalečín (660 inhabitants), and further up the river Svratka, the township of Jimramov (1,200 inhabitants) have a municipal wastewater treatment plant (WWTP). Important industrial enterprises in the area include Poličské strojírny, a. s., Masokombinát Polička, a. s., Polička municipal WWTP, and Jimramov WWTP. The landscape of Svratecká vrchovina is approximately 55 % forested and has a high recreational potential. In 2021, intensive logging took place in the immediate vicinity of the reservoir as a result of a large-scale bark beetle outbreak.

Opatovice WR (*Fig. 2*) was put into operation in 1972. The main purpose is to ensure a source of drinking water for the population. The total volume of the reservoir is 10.634 million m^3. The main tributary is the Malá Haná. The larger part of the catchment upstream from the reservoir is occupied by the forested landscape of Drahanská vrchovina, partially encroaching on the military district of Březina in the south. The upper part of the Malá Haná basin is typical of intensive agricultural activity. The catchment area is 43.87 km^2. The nearest human settlement is the village of Ruprechtov (600 inhabitants) in the upper part of the Ruprechtovský stream. The WR volume up to the spillway level

Fig. 1. Vír I water supply reservoir

Fig. 2. Opatovice water supply reservoir

Fig. 3. Ludkovice water supply reservoir

is 7.84 million m^3. At the average flow of the Malá Haná (0.160 m^3.s^{-1}), the theoretical retention time in the reservoir is 567 days, i.e. 18.9 months.

Ludkovice WR (*Fig. 3*) was put into operation in 1968. It is the smallest reservoir that was chosen for the project. Its total volume is only 0.69 million m^3. Its main purpose is to ensure sufficient water for Luhačovice collective water supply system and a minimum flow in the stream below the dam, which is the Ludkovický stream.

The catchment area is 13.1 km^2. The theoretical retention time of water in the reservoir is the shortest; if we consider the volume of the reservoir up to the overflow level of 0.498 million m^3, the retention time is only 62 days at the long-term mean daily flow of the Ludkovický stream of 0.096 m^3.s^{-1}. Immediately above the reservoir is a part of the village of Ludkovice, called Pradlisko. The village of Provodov (780 inhabitants) is located in the upper part of the Ludkovický stream basin. Treated wastewater from the village is transferred outside the Ludkovický stream catchment area. Its length above Ludkovice WR is about 7 km. 60 % of the catchment area is forested, the remaining area is dominated by meadows; fields make up about 10 % of the catchment area.

METHODOLOGICAL APPROACH

The dynamics of the pollution of selected tributaries to the water supply reservoirs was investigated using passive samplers. It is a continuous capture of pollutants for a specified period of time on a suitable type of sampler according to the type of monitored substances. In contrast to spot sampling, this makes it possible to gather accidental pollution (in the case of pesticides during rainfall-runoff episodes) or very low concentrations of substances that, even at low levels in water, show adverse effects on the aquatic environment and, consequently, on humans. The exposure time is chosen so that it takes place in the linear region of pollution reception by the sampler (*Fig. 4*).

In surface waters, the exposure time is usually three weeks; due to the sampling of cleaner waters an exposure of around four weeks was chosen. Alvarez [7] also confirms that the typical exposure time in the linear region of substance uptake by a POCIS does not exceed 28 days, although for some of the substances tested by him linearity of reception was maintained even after 56 days of exposure. Sampling took place throughout the growing season from April to November, i.e. in a total of eight sampling campaigns. The exact dates of installation and replacement of passive samplers are given in *Tab. 1*.

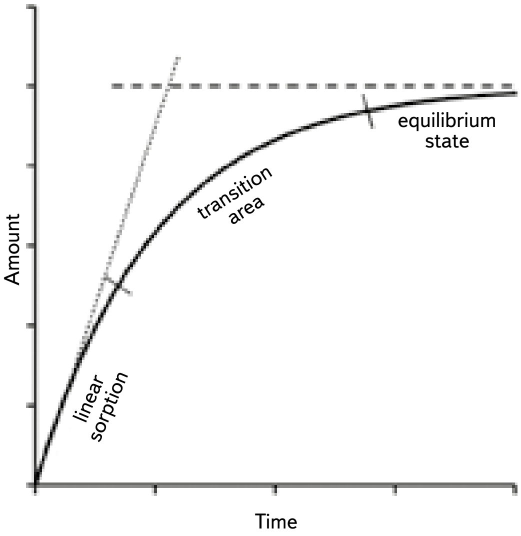

Fig. 4. General curve of the pollution capture by passive sampler depending on the sampling time [6]

Tab. 1. The installation and removal terms of the passive samplers in sampling campaign 2021

Campaign	**Exposure**	**Vír I WR**		**Opatovice & Ludkovice WR**	
		Installed	**Removed**	**Installed**	**Removed**
1	April	30. 3. 2021	30. 4. 2021	31. 3. 2021	3. 5. 2021
2	May	30. 4. 2021	31. 5. 2021	3. 5. 2021	1. 6. 2021
3	June	31. 5. 2021	29. 6. 2021	1. 6. 2021	1. 7. 2021
4	July	29. 6. 2021	2. 8. 2021	1. 7. 2021	3. 8. 2021
5	August	2. 8. 2021	2. 9. 2021	3. 8. 2021	3. 9. 2021
6	September	2. 9. 2021	4. 10. 2021	3. 9. 2021	5. 10. 2021
7	October	4. 10. 2021	3. 11. 2021	5. 10. 2021	4. 11. 2021
8	November	3. 11. 2021	2. 12. 2021	4. 11. 2021	1. 12. 2021

Suitable locations for placing the samplers were selected together with the employees of Povodí Moravy State Enterprise. It is necessary to choose such places where the submersion of the sampler is guaranteed for the entire duration of the exposure and unauthorized handling or theft is minimized. The following types of passive samplers were used to capture a wide range of pollutants:

- POCIS-hlb for the capture of a wide spectrum of polar organic substances, manufacturer: E&H services, a. s., Budějovická 618/53, 140 00 Prague 4 – Krč.
- POCIS-Glyphosate for the capture of highly polar Glyphosate and its metabolite aminomethylphosponic acid (AMPA), Manufacturer: Affinisep, 10 Rue Richard Dufour, 76 770 Le Houlme, France.

The samplers were protected from mechanical damage in a stainless steel canister or casing (*Fig. 5*). The samplers were anchored to the riparian vegetation with a stainless steel cable. The closing profile was the inflow of raw water into the water treatment plant or, if this was not possible, in the water reservoir near the intake facility at the dam. At the main inflow and outflow from the water reservoir, the sampling canisters were equipped with a HOBO Pendant MX 2202 data logger for continuous recording of temperature and light intensity throughout the exposure period.

Before use, the samplers were stored according to the data given by the manufacturer; after exposure they were transported to the laboratory at a temperature of +2 to +4 °C and, before processing, they were stored at a temperature of -18 °C.

Fig. 5. Passive sampler POCIS in big canister (left) and in the casing (right)

The spectrum of verified substances included 36 active substances of plant protection products and 14 metabolites of pesticides (a total of 50 substances). The criterion for the selection of pesticides was the evaluation of the results of surface water monitoring carried out by the basin manager during 2017–2019 and significant consumption of plant protection products recorded by the Central Institute for Supervising and Testing in Agriculture (ÚKZÚZ) in the affected districts [8].

After being removed from the freezer, the exposed samplers (shown in *Fig. 6*) were allowed to reach laboratory temperature before processing. At the same time, they remained closed in their original packaging to prevent secondary contamination from the surrounding environment. Subsequently, they were removed from the transport package and rinsed with deionized water. In the next step, they were disassembled on aluminium foil (releasing the metal surround). The sorbent placed between the PES membranes was quantitatively transferred with deionized water to SPE columns, dried under vacuum and nitrogen, and then eluted with the necessary volume of methanol as recommended by Grabic [9]. The eluate was concentrated to a volume of 1 ml and transferred to LC-MS/MS analysis. Pesticides were measured in positive mode, pesticide metabolites in negative mode. Agilent 1290 Infinity II + Sciex X500R Q-TOF and Exion LC (Shimadzu) + Sciex Triple Quad™ 7500 were used for analysis.

POCIS-Gly was processed according to the procedure published by Claude [10]. After transferring the sorption media with deionized water on the frit, the sorbent was dried under vacuum and nitrogen. Elution was carried out with 8 ml of 0.1 M hydrochloric acid. The obtained extract was concentrated to dryness under a stream of nitrogen and supplemented with a mixture of methanol and water to a ratio of 1 : 1. The determination of glyphosate and its metabolite AMPA was carried out by the LC/MS/MS method in negative mode.

The resulting substance concentrations are based on 1 ml of extract.

Fig. 6. Exposed passive samplers POCIS

Data provided by: CHMI, ČÚZK, TGM WRI
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Fig. 7. Spots of passive sampling on the tributaries into Vír I water supply reservoir in 2021

RESULTS

Vír I water supply reservoir basin

The locations of passive sampling of the tributaries to Vír I WR are shown in *Fig. 7.* They include the left- and right-hand small tributaries to WR, the main tributary of the Svratka, and the outflow from the reservoir. Information on the type of cultivated crops and the area in the catchments of interest was created by the classification of multitemporal remote sensing images (RSI). Their representation in Vír I WR basin is documented in *Tab. 2.* Non-agricultural use prevails. of the crops, cereals are the most common, to a lesser extent oilseed rape and maize. Intensive agricultural activity takes place mainly in the basins of the left-hand tributaries of the Svratka, the Bílý stream, the Černý stream, and their tributaries.

Of the pesticides and pesticide metabolites, 29 substances and DEET (N,N-diethyl-3-methylbenzamide), which is part of mosquito and tick repellents, were confirmed in the passive samplers. The most prominently represented were 2,4-dichlorophenoxyacetic acid (2,4-D), atrazine, metazachlor, terbuthylazine and their metabolites, and glyphosate including its metabolite AMPA (aminomethylphosphonic acid). Summary results indicating the maximum concentration of pesticides found, including their metabolites, from eight sampling campaigns are shown in *Tab. 3.*

Tab. 2. Cultivated crops in the river basin above Vír I water supply in 2021 from the SSE

Land use	**[m^2]**	**[%]**
non-agricultural	257,527,500	63.0
rapeseed	11,126,875	2.7
winter cereals	16,793,125	4.1
spring cereals	26,411,875	6.5
beet	1,237,500	0.3
maize	7,603,750	1.9
sunflower	440,625	0.1
winter crops harvested in spring	822,500	0.2
potatoes	110,000	< 0.1
other crops	1,363,125	0.3
permanent grassland	85,560,625	20.9

Source: Czech Hydrometeorological Institute

Tab. 3. Maximal concentrations of pesticides and metabolites established by passive sampling on the tributaries into Vír I water supply reservoir in 2021 (in ng/POCIS)

	Vír WR												
Profile	**Bílý stream – above the Černý stream influx**	**Černý stream – Bílý stream influx**	**Fryšávka – influx**	**Chlumský stream – influx**	**Janovický stream – influx**	**Karasínský stream – influx**	**Korouhvický stream – influx**	**Nyklovický stream – influx**	**Písečenský stream – influx**	**Stream from the village of Hluboké**	**Svratka above WR (Dalečín)**	**Svratka below the dam – drive**	**Veselský stream – influx**
2,4-D	4.06	1.17	0.52	415.42	1.52	0.42	0.00	0.39	1.97	0.27	0.53	1.92	0.00
Acetochlor and metabolites	1.25	1.45	3.10	2.44	2.22	2.72	0.99	1.21	5.81	0.19	3.04	4.09	1.50
Alachlor and metabolites	4.72	18.58	5.48	0.27	30.70	13.47	0.49	1.84	134.78	2.11	9.18	11.36	15.44
Atrazine and metabolites	8.35	29.39	6.36	32.15	3.15	0.00	1.31	1.40	14.70	1.63	6.21	6.23	0.27
Azoxystrobin	2.70	1.60	1.20	3.00	0.00	0.00	0.00	0.00	1.80	1.20	1.30	4.90	0.00
Bentazone	5.11	3.84	0.00	4.59	0.00	0.00	0.00	0.00	0.14	0.08	1.19	3.31	0.07
DEET	27.00	15.00	24.00	19.00	1.20	14.00	3.10	0.00	70.00	8.10	23.00	3.60	1.20
Dimethachlor and metabolites	1.10	0.29	0.22	0.02	3.04	0.42	0.00	0.26	1.66	0.00	1.24	1.86	0.00
Glyphosate and AMPA	–	–	16.60	57.00	10.66	57.40	3.20	5.33	107.38	28.00	103.90	30.50	28.24
Chlortoluron	67.94	3.91	11.14	3.71	3.19	0.00	7.33	0.00	4.00	0.00	6.13	36.01	0.00
MCPA	2.19	16.37	0.32	3.11	0.21	0.09	0.00	0.00	2.36	0.10	2.21	2.99	0.31
Metazachlor and metabolites	23.67	49.78	37.72	0.50	80.58	32.61	0.80	8.94	105.54	0.60	39.56	82.34	1.34
Metolachlor and metabolites	33.29	15.88	30.28	6.71	9.90	31.81	4.00	33.76	6.60	3.72	23.86	73.51	2.82
Pethoxamid	1.10	22.38	0.82	0.67	48.45	0.00	0.36	0.58	6.94	2.93	576.42	27.49	0.38
Spiroxamine	3.43	4.29	1.24	0.35	1.98	1.27	0.00	0.00	2.33	0.23	1.16	0.15	0.00
Tebukonazole	14.57	2.95	0.00	1.21	0.00	0.00	0.00	0.00	0.00	0.00	0.71	1.46	0.00
Terbuthylazine and metabolites	349.27	109.20	55.94	22.30	144.22	38.78	3.23	63.45	240.45	2.06	66.94	12,913.59	0.98
Terbutryn	0.00	0.00	3.50	1.10	0.00	0.00	0.00	0.00	1.90	1.00	2.50	2.00	0.00

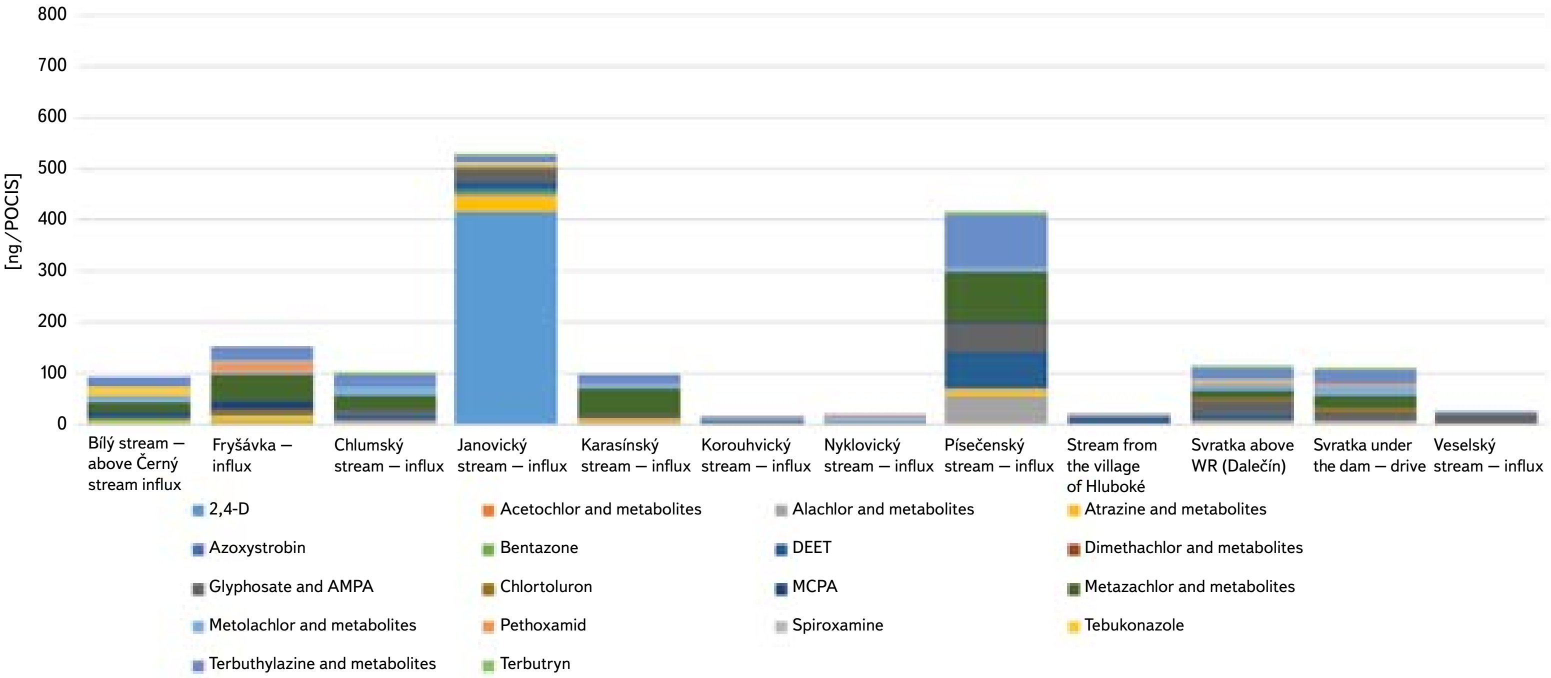


Fig. 8. Concentration of pesticide residues in the basin of Vír I water supply reservoir – 2nd sampling campaign (May 2021)

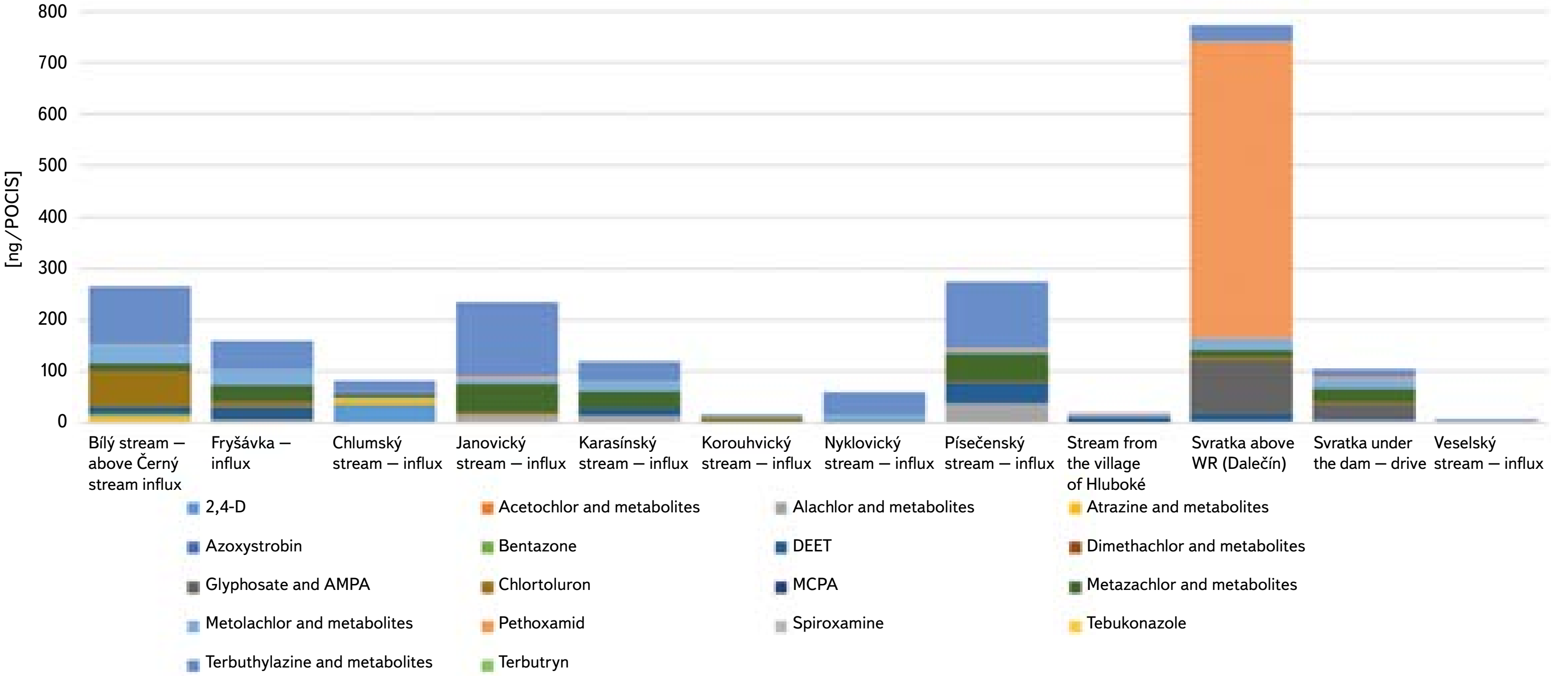


Fig. 9. Concentration of pesticide residues in the basin of Vír I water supply reservoir – 3rd sampling campaign (June 2021)

The highest concentrations of pesticides were found in the tributaries to the reservoir in the second, third, and fourth sampling campaigns (May to July 2021) (*Figs. 8* and *9*). The Chlumský stream was the most polluted left-side tributary, with a high content of 2,4-dichlorophenoxyacetic acid (2,4-D) in the second sampling campaign. This stream is the shortest of the monitored tributaries to Vír I WR (less than 1 km long) and originates from a small pond below the village of Chlum. 2,4-D is an organochlorine selective herbicide used on dicotyledonous weeds and applied mainly to cereals, to a lesser extent to maize and forage crops. Its significant occurrence in this small watercourse may be related to a rainfall-runoff episode that occurred in the area on 14 May 2021, with a total of 26 mm of rainfall (*Fig. 10*). It was the first significant spring rainfall. In 2021, spring cereals were grown in the Chlumský stream basin.

The Písečenský stream (length 3.05 river km), originating at the upper end of the Písečná village, dominated the right-hand tributaries with the variety of captured pesticides. Terbuthylazine and its metabolites, metazachlor and its metabolites and alachlor metabolites were significantly represented.

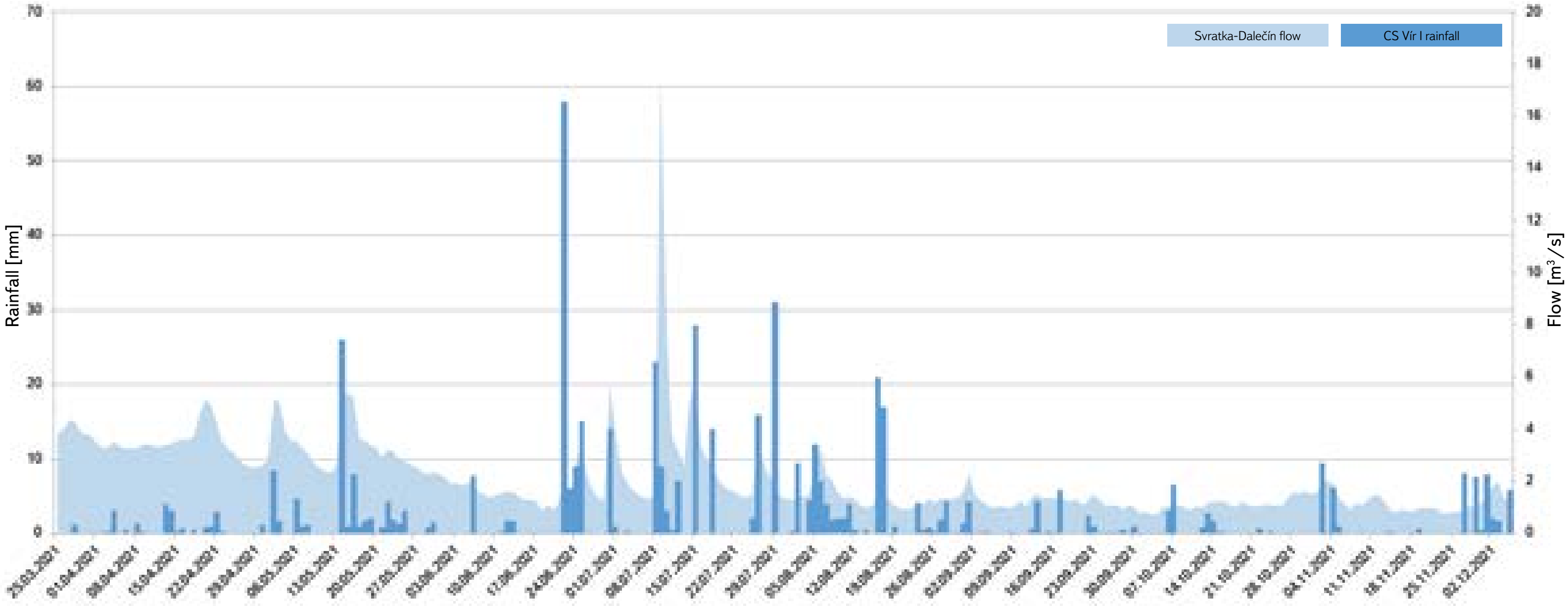


Fig. 10. Rainfall-runoff relationships in the basin of Vír I water supply reservoir in 2021

Terbuthylazine, which is used to treat maize, was predominant in the form of the metabolite Terbuthylazine-2-hydroxy (*Fig. 11*) with a maximum in the fourth sampling campaign (7/2021). The areas sown with maize were very small in the location in 2021, namely in the uppermost part of the catchment. The "parent" substance was thus confirmed only in minimal amounts. It is probably a load from previous years or a transformation of the original active substance during transport to the watercourse through the soil profile from a greater distance.

Metazachlor is used for oil crops that were not grown in the Písečenský stream basin in 2021. Solely the metabolite metazachlor ESA was confirmed by passive sampling in the first sampling campaign in April (*Fig. 12*). This indicates its leaching from applications in previous years; the dynamics of concentrations is different and not so dependent on rainfall-runoff episodes. The dynamics of alachlor was similar, the use of which has been prohibited since 2007 and was represented in surface water exclusively by the ESA metabolite with a maximum in the sixth sampling campaign (9/2021).

In the Svratka above WR (Dalečín) profile, the amount of pesticides captured was mostly lower than in the small left and right tributaries to the reservoir. Agriculture is particularly intensive in the Bílý stream basin in its upper part around the town of Polička, i.e. at the very upper border of the Svratka basin. Higher concentrations of pesticides in the Bílý stream are gradually diluted further downstream. The exception was the third sampling campaign with a confirmed high content of pethoxamid in the Svratka above WR (*Fig. 9*). This pesticide is used to treat maize and oil crops alone or in combination with terbuthylazine (e.g., BALATON). Its high capture in this sampling campaign is probably related to the heaviest precipitation event on 22 June 2022 (58 mm) (*Fig. 10*) and flushes from locations between the township of Jimramov and the village of Strachujov, just a few kilometres above the sampling profile.

Intensive agricultural activity around Polička with a significant proportion of cereals, maize and oilseed rape (*Fig. 13*) was manifested in the Bílý stream profile – above the Černý stream influx, mainly by the capture of terbuthylazine with the predominance of its metabolites with a gradual concentration increase until July 2021 in the fourth sampling campaign (*Fig. 14*) and chlorotoluron with a maximum in the third sampling campaign (*Fig. 15*).

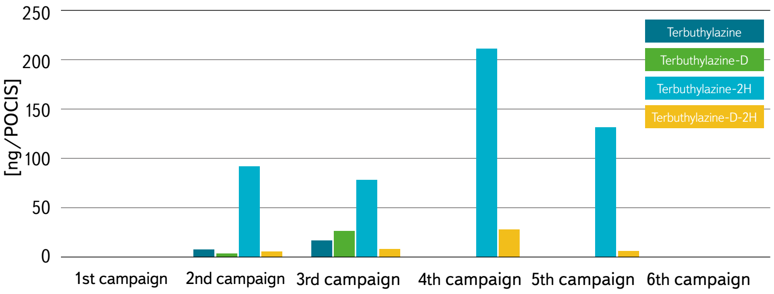


Fig. 11. Terbuthylazine and metabolites concentration dynamics in the outfall of Písečenský stream in 2021

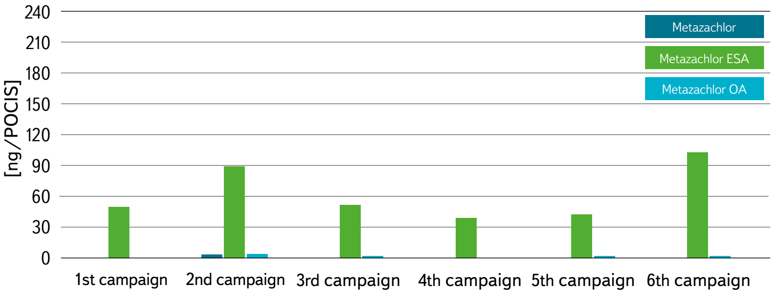
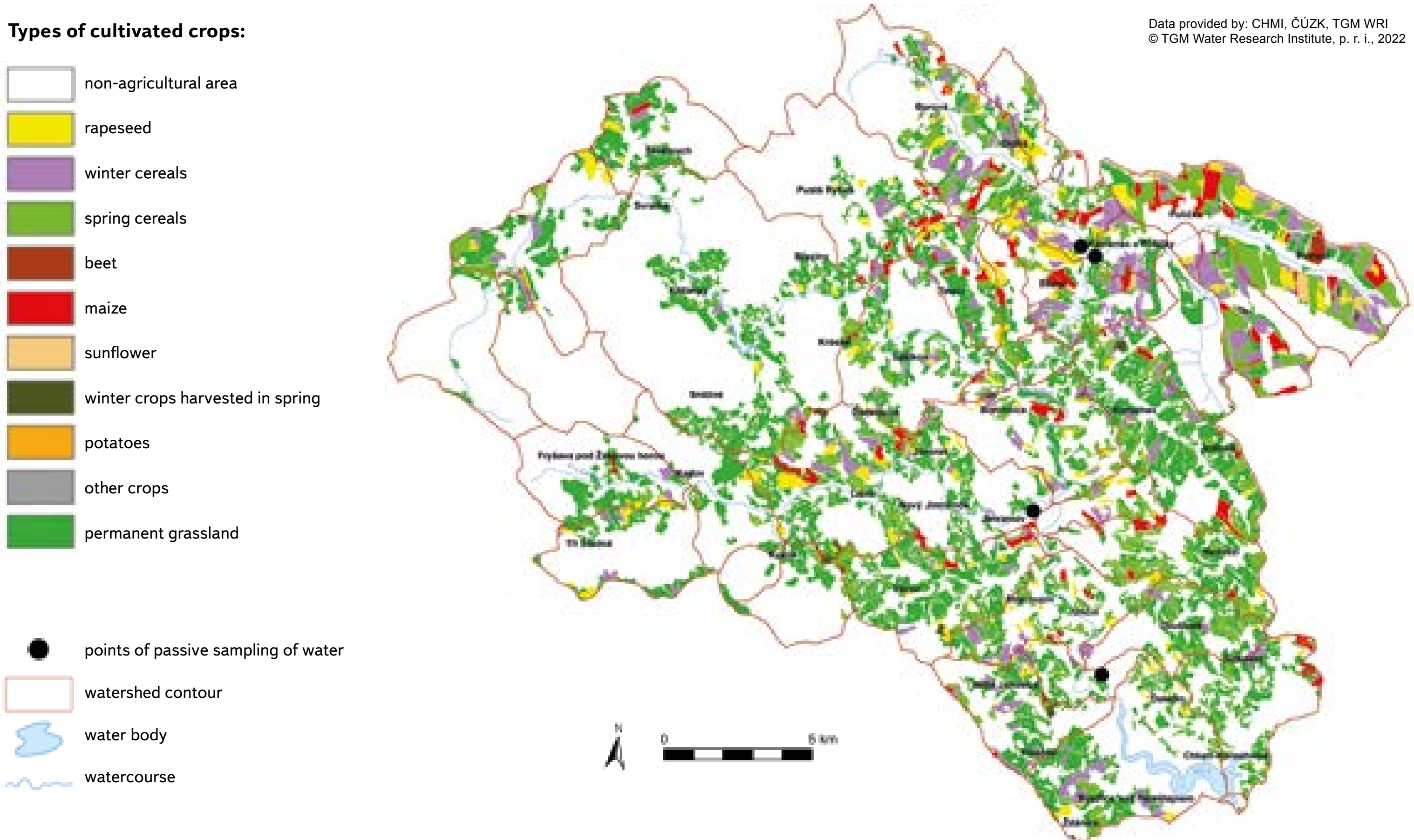


Fig. 12. Metazachlor and metabolites concentration dynamics in the outfall of Písečenský stream in 2021



Data provided by: CHMI, ČÚZK, TGM WRI
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Fig. 13. Cultivated crops in the river basin above Vír I water supply in 2021 from the multitemporal shots of satellite survey of the Earth

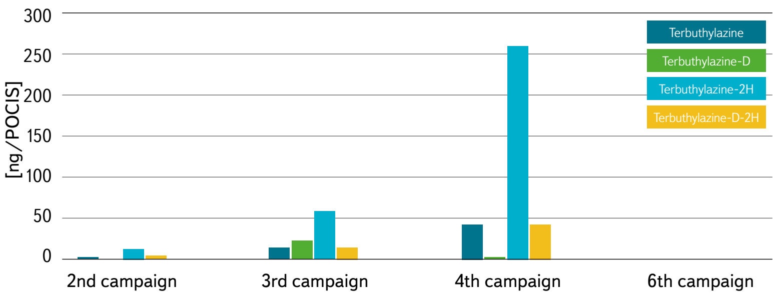

Fig. 14. Terbuthylazine and metabolites concentration dynamics in Bílý stream above the outfall of Černý stream in 2021

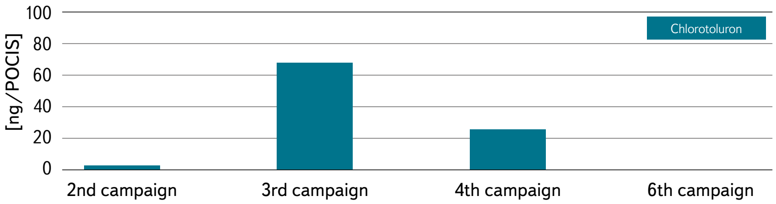

Fig. 15. Chlorotoluron concentration dynamics in Bílý stream above the outfall of Černý stream in 2021

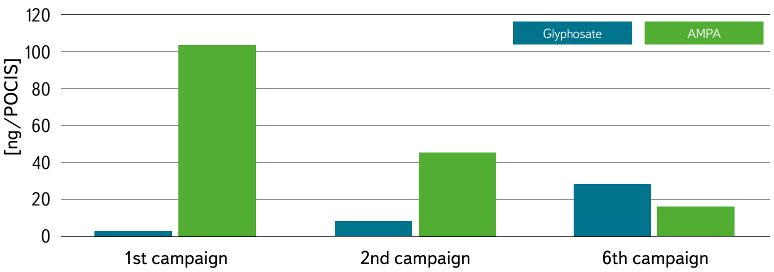

Fig. 16. Glyphosate and AMPA concentration dynamics in the outfall of Písečenský stream in 2021

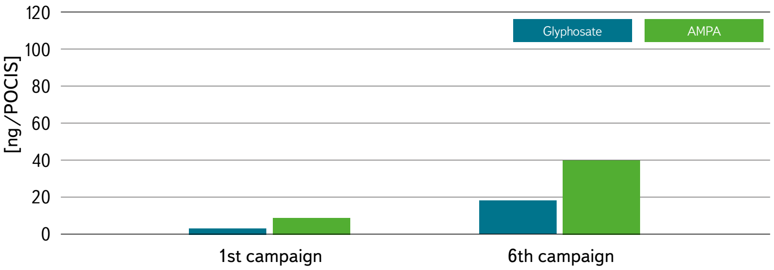

Fig. 17. Glyphosate and AMPA concentration dynamics in the outfall of Karasínský stream in 2021

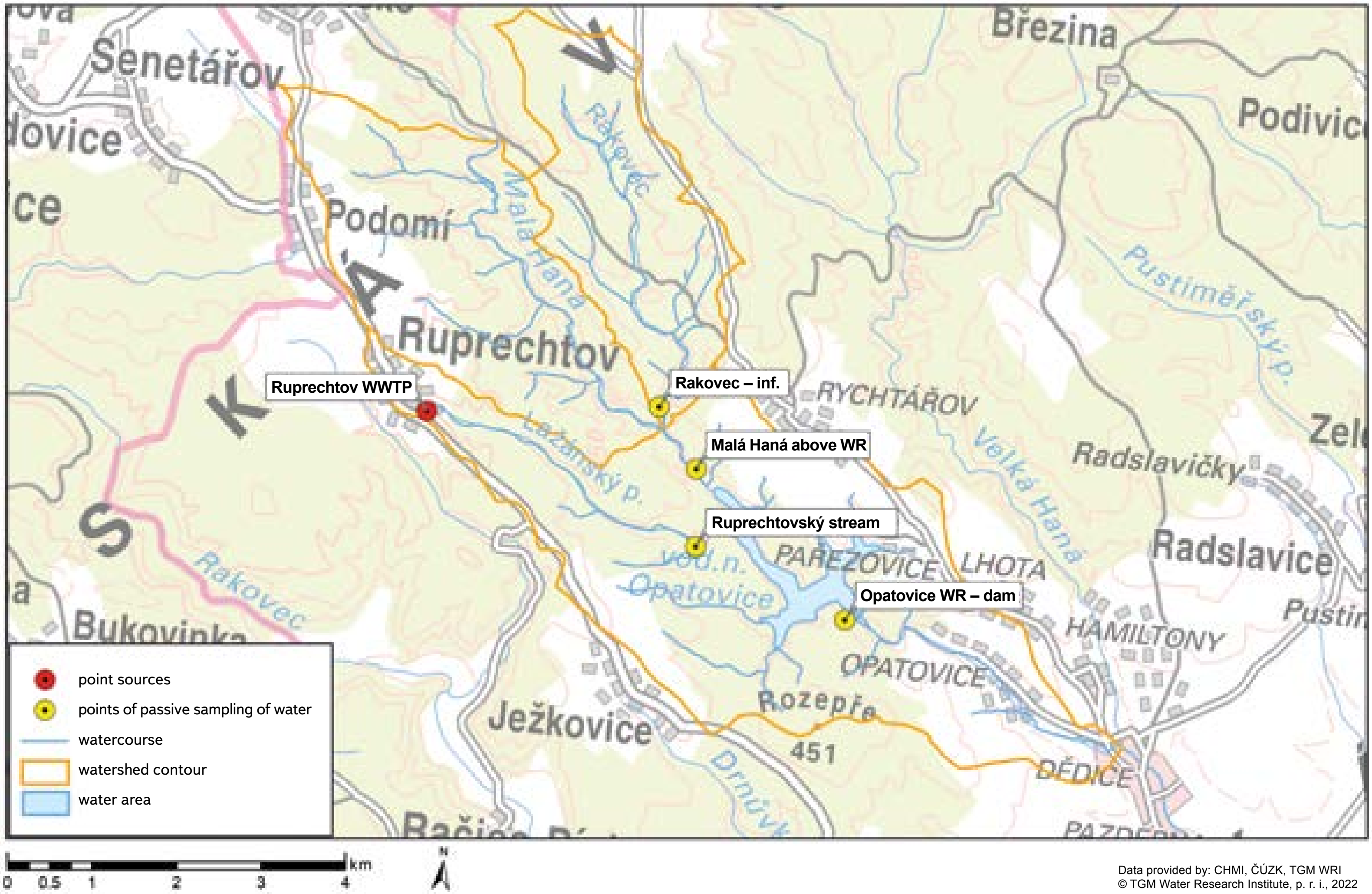

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Fig. 18. Spots of passive sampling on the tributaries into Opatovice water supply reservoir in 2021

The dynamics of concentrations of glyphosate and its metabolite AMPA is interesting. It is normally used at the beginning of spring, before sowing, and at the end of summer, before sowing winter cereals. Since 1 January 2019, glyphosate has been prohibited from being used for desiccation of crops that are used for food purposes [11]. Glyphosate is relatively rapidly transformed into the AMPA metabolite depending on temperature, moisture, and soil microbial activity. The kinetics of the transformation under different conditions defines its decrease in the interval of 1.5 to 53.5 days for DT50 and 8 to 280 days for DT90. The AMPA metabolite is more stable, its persistence is 11 to 21 times greater [12]. It always depends on specific conditions, and even the type of cultivated crops [13]. At low temperatures (+5 °C), the transformation of glyphosate is 8.3 times slower than at +30 °C.

Two different cases of the dynamics of the concentrations of these two compounds can be seen in *Fig. 16* and *17*. In the Písečenský stream basin, the maximum concentration of the AMPA metabolite was demonstrated in the first sampling campaign in April, and in the sixth campaign in September, where mainly the parent substance was captured. In the Karasínský stream basin, glyphosate was only applied before autumn sowing.

In the Svratka, at the tributary to WR, glyphosate slightly prevailed over the AMPA metabolite, with a maximum in the third sampling campaign. It is interesting that glyphosate was not completely transformed in Vír I WR and was also confirmed in outflow from the water reservoir.

Opatovice water reservoir catchment area

The locations of passive sampling on tributaries to Opatovice WR are shown in *Fig. 18*. The water reservoir only has two significant tributaries: the Malá Haná and the Ruprechtovský stream. The left-hand tributary of the Malá Haná is the Rakovec stream, which partly extends into the military district of Březina. Small left-hand tributaries to the WR, with a length of 300–400 m in the cadastres of Rychtářov and Pařezovice, were not included in the project due to their minimum water bearing. Information on the type of cultivated crops and the area in the basins of interest was created by classification of multitemporal remote sensing images (RSI). Their representation in the Opatovice WR basin is shown in *Fig. 19* and documented in *Tab. 4*. Non-agricultural use makes up 81 % of the catchment area. Nevertheless, the pesticide load on the water reservoir is considerable. Cereals and oilseed rape are the most represented crops. Intensive agricultural activity takes place in the upper parts of the Ruprechtovský stream, the Malá Haná around the village of Krásensko, and on the left side of the reservoir around the villages of Rychtářov and Pařezovice.

Of the verified pesticides and metabolites, 27 substances and DEET (N,N-diethyl-3-methylbenzamide) were confirmed in the passive samplers. Summary results indicating the maximum concentration of pesticides found, including their metabolites, from eight sampling campaigns are shown in *Tab. 5*. The dynamics of pesticide concentrations compared to the previous water reservoir was different.

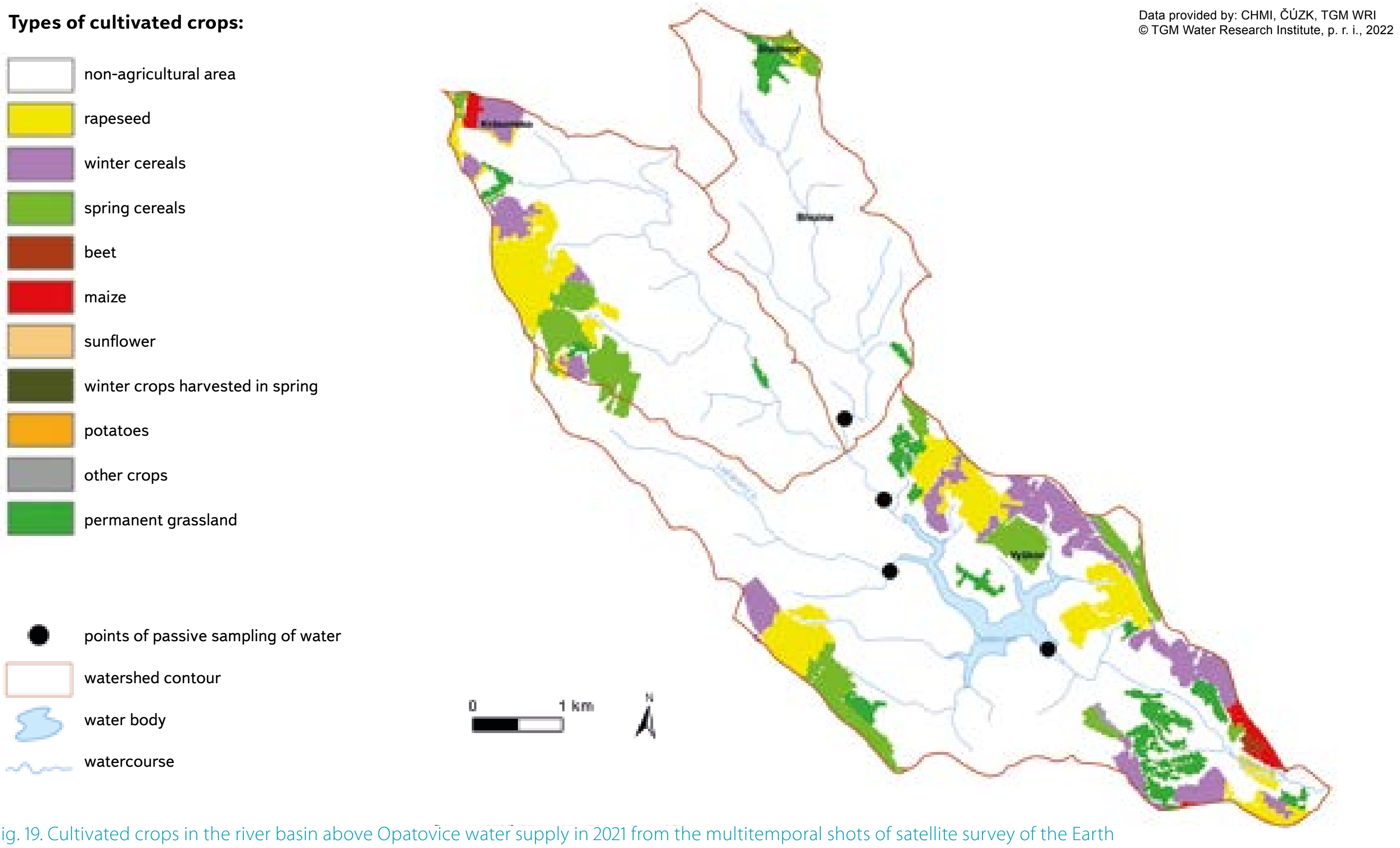

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Fig. 19. Cultivated crops in the river basin above Opatovice water supply in 2021 from the multitemporal shots of satellite survey of the Earth

Metazachlor, metolachlor, terbuthylazine and their metabolites, glyphosate including its AMPA metabolite, and alachlor metabolites were most significantly represented (*Fig. 20–23*). In the Rakovec basin, agricultural activity is developed only in the upper part around the village of Studnice; passive sampling confirmed that the presence of pesticides in this watercourse is very low. The main pesticide load of the reservoir comes from the Malá Haná and the Ruprechtovský stream.

Tab. 4. Cultivated crops in the river basin above Opatovice water supply in 2021 from the SSE

Land use	[m²]	[%]
Non-agricultural	27,038,125	77.5
Oilseed rape	2,543,125	7.3
Winter cereals	1,986,250	5.7
Spring cereals	1,829,375	5.2
Beet	39,375	0.1
Maize	204,375	0.6
Other crops	31,250	0.1
Permanent grassland	1,225,625	3.5

Source: Czech Hydrometeorological Institute

In the April first sampling campaign, glyphosate and especially the metabolite AMPA prevailed in both of the above-mentioned tributaries; the load of other pesticides was minimal. In the second sampling campaign, increased and almost equivalent concentrations of metolachlor, metazachlor, and terbuthylazine, including their metabolites, were confirmed in the main tributary to the reservoir.

S-metolachlor applied to maize was represented almost exclusively in the form of its metabolite ESA on its way from the upper parts of the Malá Haná basin to the reservoir. It repeatedly occurred in significant concentrations in other sampling campaigns. The half-life of S-metolachlor in soil ranges from 23.6 to 40.1 days, depending on soil temperature and moisture [14]. The rate of its representation in surface water was high, although the area planted with maize was small in the Haná basin in 2021.

Metazachlor, also exclusively represented by the ESA metabolite, showed the same concentration dynamics with a gradual increase up to the eighth sampling campaign in the Malá Haná. It is used to treat oil crops, which were an important cultivated crop in this basin in 2021. According to [15], the half-life of the parent compound in the aquatic environment is 19.3 days, with only microbial processes participating in its degradation. Metazachlor is stable against hydrolysis and photolysis. Terbuthylazine, which is used to treat maize, was detected in the Malá Haná only in the second sampling campaign and to a lesser extent in the seventh sampling campaign, both times as terbuthylazine-2 hydroxy.

Terbuthylazine-2 hydroxy was only detected in the Ruprechtovský stream in the fourth and fifth sampling campaigns (July to August). In 2021, maize was not cultivated in its catchment; this late increase in its concentration in the watercourse was most probably caused by erosion due to use in previous years by intense flushes during precipitation episodes during summer occurring in late June (*Fig. 24*). The rainfall-runoff event beginning on 22 June 2021 was so enormous that the passive samplers of the third sampling campaign were torn off and lost, even though they were fixed to a tree trunk with steel cable.

Tab. 5. Maximal concentrations of pesticides and metabolites established by passive sampling on the tributaries into Opatovice and Ludkovice water supply reservoirs in 2021 (in ng/POCIS)

	Opatovice WR				**Ludkovice WR**	
Profile	**Malá Haná above WR**	**Rakovec**	**Ruprechtovský stream**	**Opatovice WR – dam**	**Ludkovický stream above WR**	**Ludkovice WR – dam**
2,4-D	1.42	0.46	1.28	1.61	3.39	4.00
Acetochlor and its metabolites	11.74	0.59	0.63	9.93	1.24	50.61
Alachlor and its metabolites	123.60	2.30	12.68	37.80	0.86	15.92
Atrazine and its metabolites	4.26	0.00	37.91	7.63	16.64	10.93
Azoxystrobin	1.70	0.00	1.40	0.00	1.00	0.00
Bentazone	0.18	0.00	0.00	1.03	0.13	0.07
DEET	0.00	0.00	3.60	0.00	19.00	20.00
Dimethachlor and its metabolites	4.74	0.00	0.93	18.76	0.12	3.44
Glyphosate and AMPA	71.61	4.60	145.90	10.47	155.10	14.62
Chlortoluron	0.61	0.00	0.00	1.99	–	–
MCPA	0.22	0.32	0.00	1.07	0.38	0.87
Metazachlor and its metabolites	138.02	0.76	18.46	426.70	1.46	27.72
Metolachlor and its metabolites	200.32	16.32	2.92	270.56	6.12	94.32
Pethoxamid	1.44	0.00	12.85	5.21	0.00	2.36
Spiroxamine	0.31	0.27	0.00	0.00	0.29	0.00
Terbuthylazine and its metabolites	77.28	4.31	456.36	123.23	21.12	15.61
Terbutryn	0.00	0.00	1.00	0.00	2.30	0.00

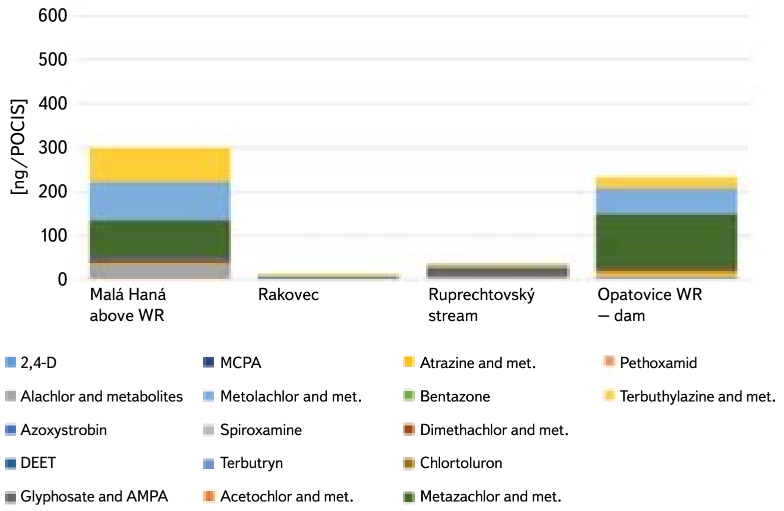

Fig. 20. Concentration of pesticide residues in the basin of Opatovice water supply reservoir – 2nd sampling campaign (May 2021)

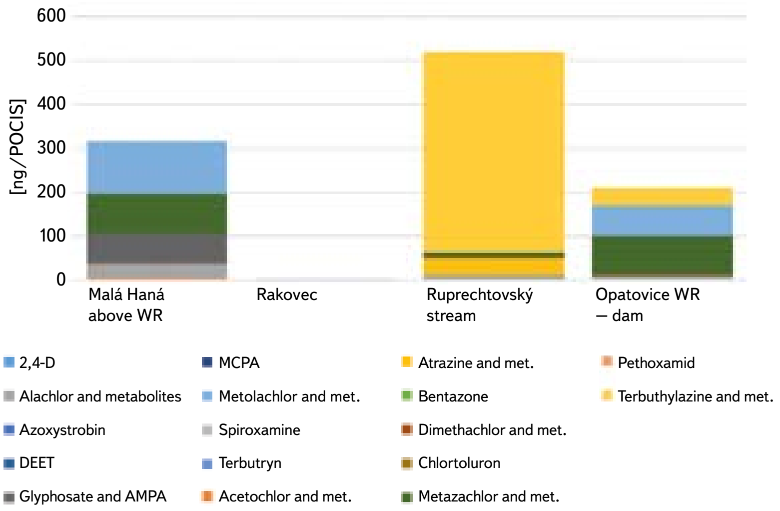

Fig. 21. Concentration of pesticide residues in the basin of Opatovice water supply reservoir – 4th sampling campaign (July 2021)

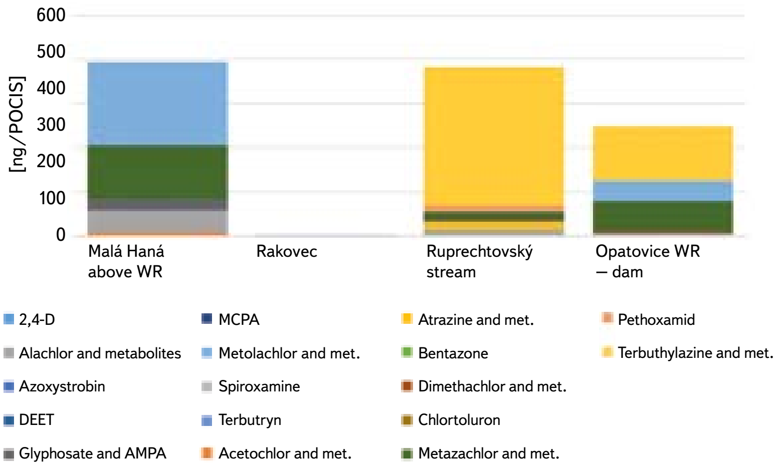

Fig. 22. Concentration of pesticide residues in the basin of Opatovice water supply reservoir – 5th sampling campaign (August 2021)

For technical reasons, it was not possible to place passive samplers in the stream of raw water at the treatment plant in the village of Lhotka. Therefore, they were placed in a water reservoir near the outlet tower with the samplers submerging to a depth of 3–4 m below the surface. The concentration of pesticides in this location has gradually increased since the sixth sampling campaign (from 9/2021). *Fig. 25* and *26* show the dynamics of concentrations of the two most significantly represented metabolites, metazachlor and metolachlor. Concentrations increased significantly in autumn sampling campaigns.

On the other hand, increased concentrations of glyphosate and the metabolite AMPA at the tributary to Opatovice WR were not manifested in the reservoir near the dam during the entire sampling season. However, it should be borne in mind that the theoretical retention time of water in the reservoir is over 1.5 years.

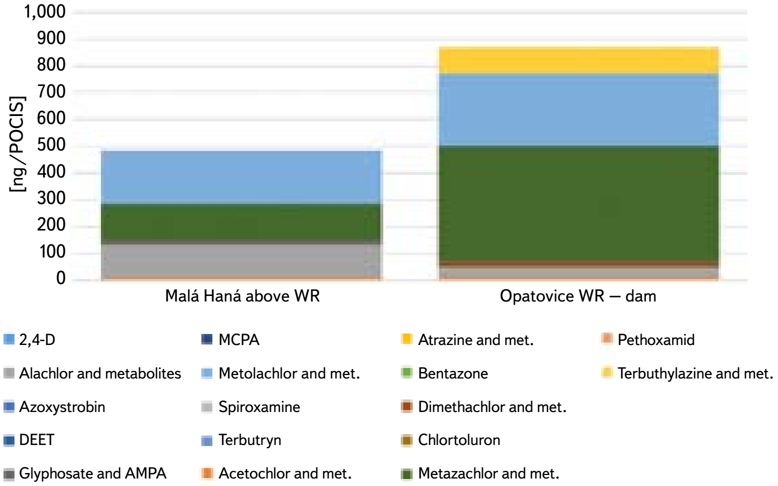

Fig. 23. Concentration of pesticide residues in the basin of Opatovice water supply reservoir – 8th sampling campaign (November 2021)

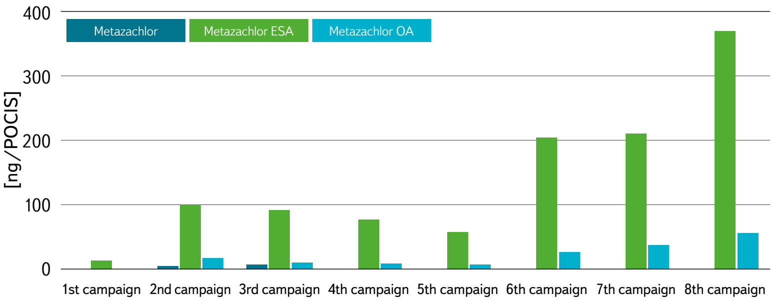

Fig. 25. Metazachlor and metabolites concentration dynamics at the dam of Opatovice water supply reservoir in 2021

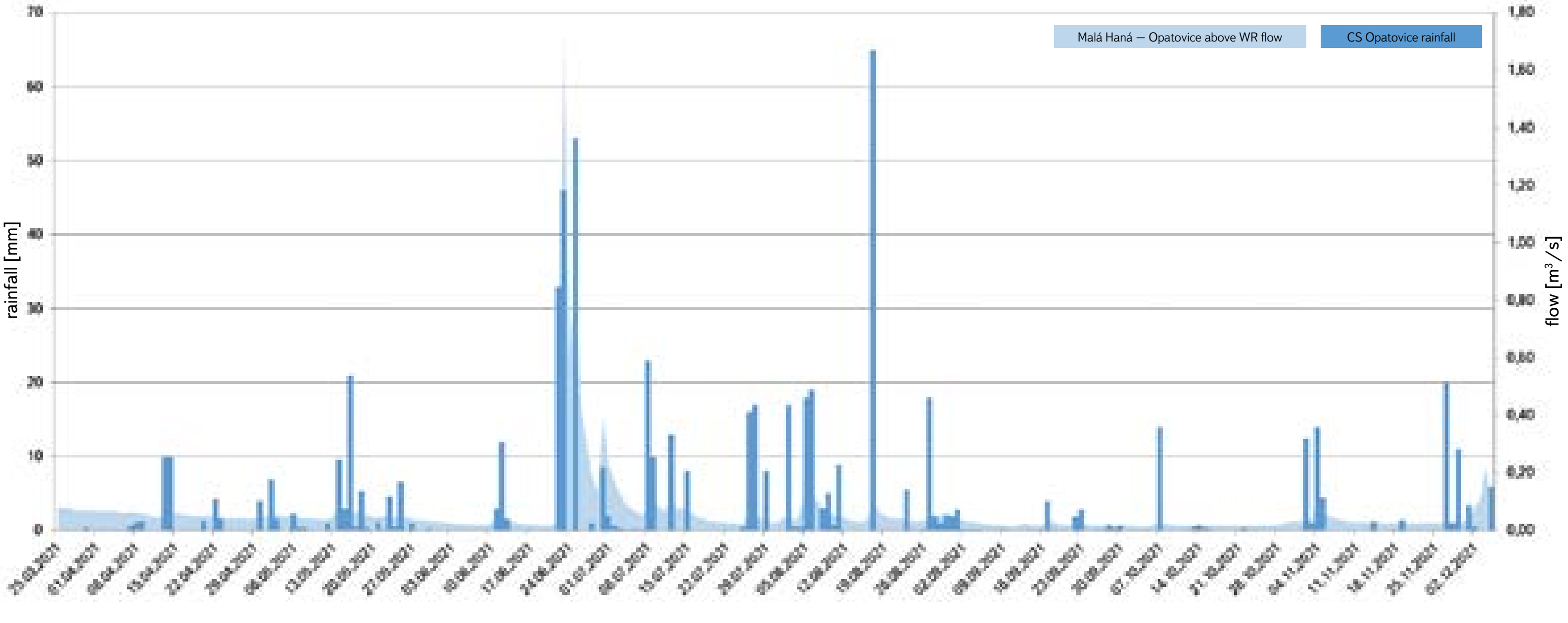

Fig. 24. Rainfall-runoff relationships in the basin of Opatovice water supply reservoir in 2021

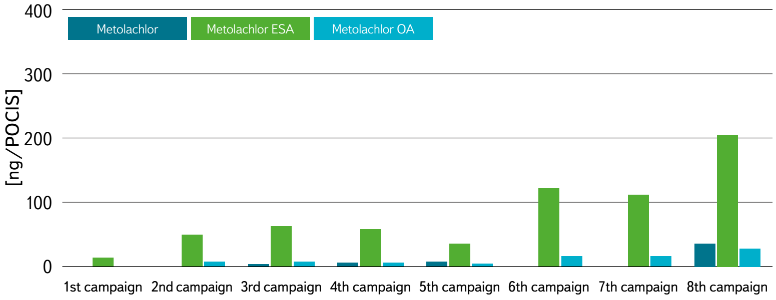

Fig. 26. Metolachlor and metabolites concentration dynamics at the dam of Opatovice water supply reservoir in 2021

Ludkovice water reservoir catchment area

Ludkovice WR has only one tributary – the Ludkovický stream. The second sampling profile was the reservoir in close proximity to the outlet tower at the dam (*Fig. 27*). Information on the type of cultivated crops and the area in the catchments of interest was created by the classification of multitemporal remote sensing images (RSI). Their representation in the WR basin is shown in *Fig. 28* and documented in *Tab. 6*. Non-agricultural use makes up 91.7 % of the catchment area. of the crops, winter cereals were the most represented in 2021.

Tab. 6. Cultivated crops in the river basin above Ludkovice water supply in 2021 from the SSE

Land use	**[m²]**	**[%]**
Non-agricultural	9,164,375	68.8
Oilseed rape	87,500	0.7
Winter cereals	578,750	4.3
Spring cereals	193,750	1.5
winter crops harvested in spring	246,875	1.9
Permanent grassland	3,043,750	22.9

Source: Czech Hydrometeorological Institute

Of the verified pesticides and their metabolites, 24 substances and DEET (N,N-diethyl-3-methylbenzamide) were confirmed in the passive samplers. The vast majority of them (with the exception of glyphosate) were detected only in low concentrations, both at the inflow and at the outflow of the reservoir, even though this basin also experienced several significant rainfall-runoff events in the summer. Summary results indicating the maximum concentration of pesticides detected, including their metabolites, from eight sampling campaigns are shown in *Tab. 5*. The supply of pesticides to the reservoir by the Ludkovický stream remained unchanged from the second to fourth sampling campaigns (*Fig. 29*). Glyphosate or its metabolite AMPA dominated in the initial sampling campaigns. Glyphosate as the parent compound was confirmed in the Ludkovický stream before the sowing of winter cereals in the sixth sampling campaign and, surprisingly, also in the eighth sampling campaign in November (*Fig. 30*).

In the reservoir near the dam, increased concentrations of pesticides were detected only in the sixth sampling campaign in September (*Fig. 31*). Metolachlor metabolites ESA and OA were most abundantly represented, without the presence of the parent substance. Metolachlor is used to treat maize. However, it was not cultivated in the catchment area that year. Simultaneously, significant concentrations of acetochlor metabolites, the use of which has been banned for ten years, were identified in this campaign. Metabolites of original substances from applications in previous years were captured by the passive sampler, probably due to the autumn circulation in the reservoir between the epilimnion and the hypolimnion.

The third important herbicide identified in the reservoir by the sixth sampling campaign was metazachlor, or again only its metabolites ESA and OA. This herbicide is used to treat oil crops. Given that neither metazachlor nor its metabolites were confirmed by passive sampling in 2021 at the tributary in the Ludkovický stream, it is also a matter of capturing pollution from previous years originating from deeper layers of the water column during their circulation in the reservoir.

Fig. 27. Spots of passive sampling on the tributaries into Ludkovice water supply reservoir in 2021

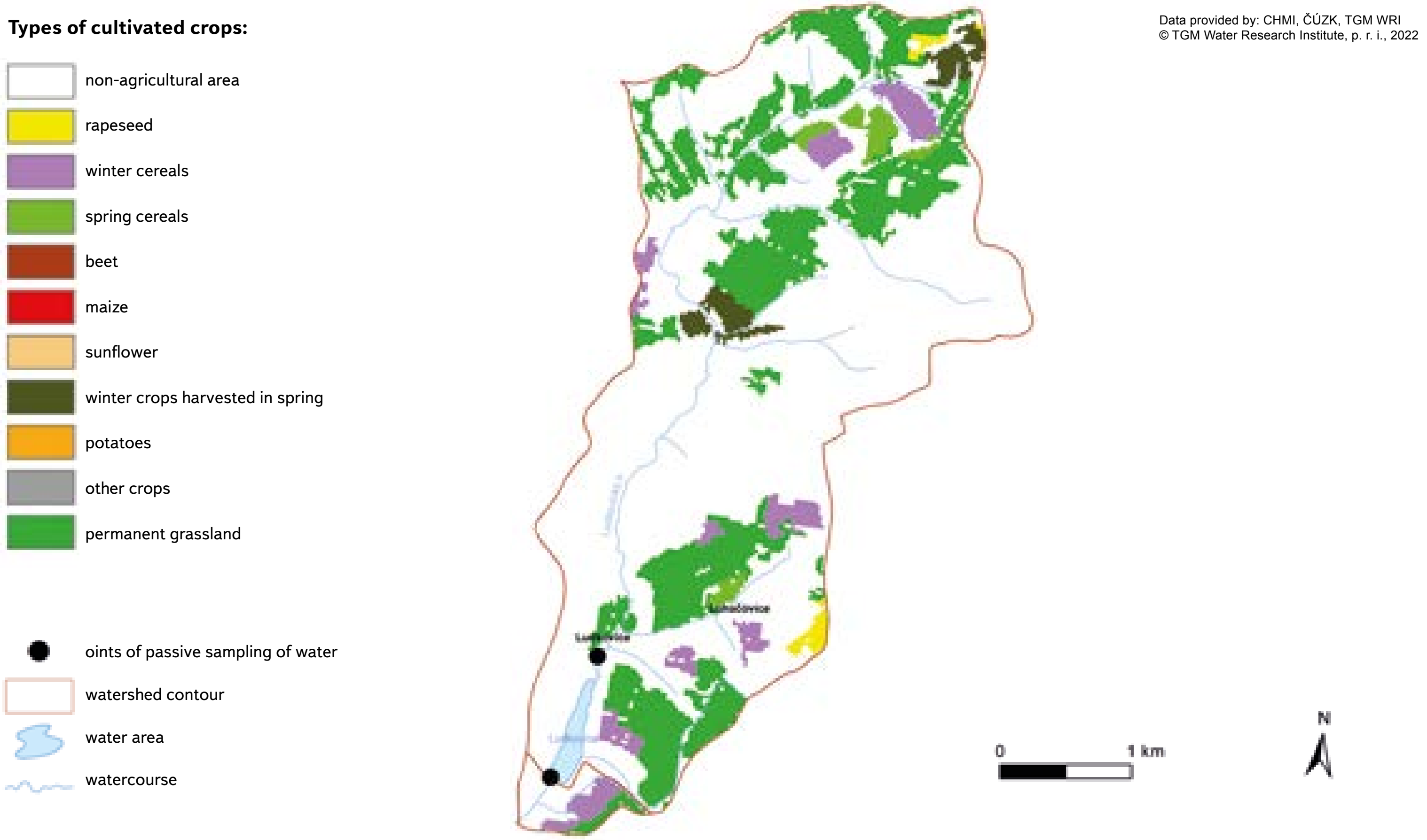

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Fig. 28. Cultivated crops in the river basin above Ludkovice water supply in 2021 from the multitemporal shots of satellite survey of the Earth

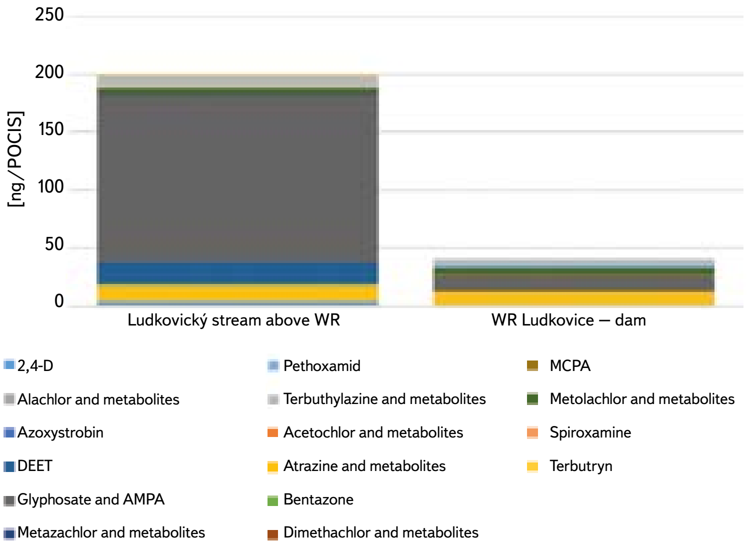

Fig. 29. Concentration of pesticide residues in the basin of Ludkovice water supply reservoir – 2nd sampling campaign (May 2021)

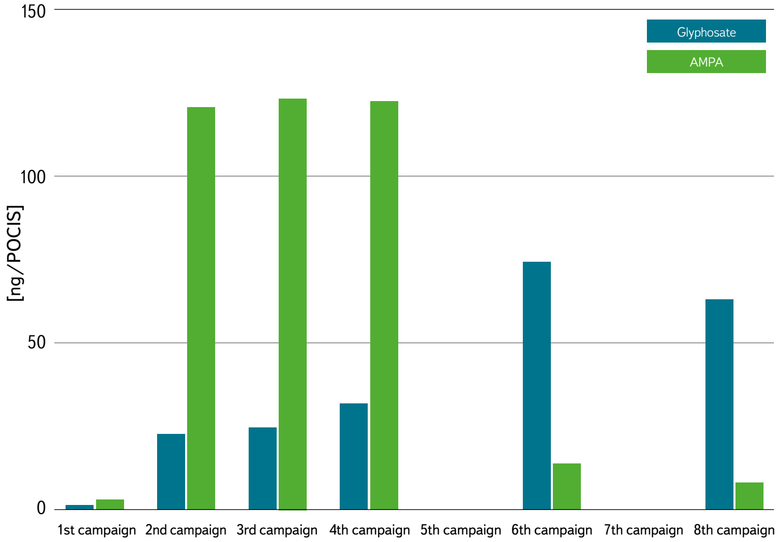

Fig. 30. Glyphosate and AMPA concentration dynamics in the outfall of Ludkovický stream above Ludkovice water supply reservoir in 2021

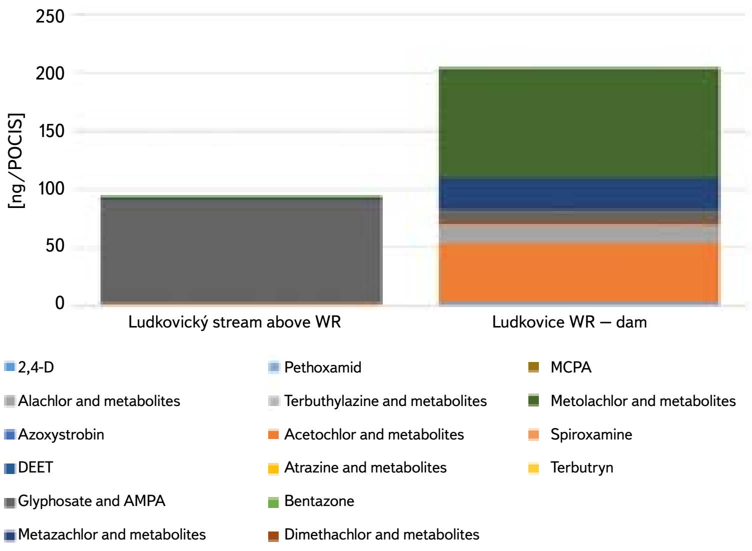

Fig. 31. Concentration of pesticide residues in the basin of Ludkovice water supply reservoir – 6th sampling campaign (September 2021)

Conversion to average concentration in a watercourse

The amount of pesticides captured by a POCIS can be converted to an average concentration during the exposure time (C_{TWA}) if the sampling rate Rs is known for the substance and the type of passive sampler. In the case of POCIS for polar organic substances, the following equation applies to the conversion [16]:

$$C_{TWA} = \frac{N_t}{(R_s \, . \, t)} \qquad (1)$$

where: N_t is: the amount of substance captured by the sampler in ng
R_s sampling rate in $l.day^{-1}$
t sampler exposure time in days

The resulting C_{TWA} concentration is expressed in $ng.l^{-1}$.

The sampling rate is determined by calibration tests, most often in laboratory conditions. For our C_{TWA} calculations, we used the methodological work of Grabic et al. [16]. Its great advantage is that the calibrations of the POCIS were carried out in field conditions on Czech rivers in the spring and autumn seasons. Using equation (1), it was possible to calculate the time weight average concentration C_{TWA} and, knowing the hourly flows at the main inflow to the water reservoir, the substance balance of pollution for selected pesticides for the entire period of passive sampling by the sum of partial balances from each sampling campaign. The results are shown in *Tab. 7*.

The average C_{TWA} concentration for the sum of pesticides was calculated from the total balance of pesticides and the total volume of water that flowed through the given profile during the application of the passive samplers. The accuracy of calculating the average concentration in the watercourse is given by the accuracy of deriving the sampling rate Rs per passive sampler. Therefore, in this case, C_{TWA} ∑ PES cannot be viewed as the actual total concentration of pesticides in the watercourse because some values of Rs are usable according to the work of Grabic [16] only with a lower degree of reliability, as shown in *Tab. 7* and the notes below it. This applies especially to metazachlor ESA, bentazone, DEET and alachlor ESA, which were the most significant from the balance point of view. However, it allows us to compare the level of pesticide load between water reservoirs. The results show that Opatovice WR is the most loaded with pesticides.

DISCUSSION AND CONCLUSION

At nine tributaries to Vír I WR, three tributaries to Opatovice WR, and the tributary to Ludkovice WR, the dynamics of concentrations of 36 active substances of plant protection products and 14 metabolites of pesticides were monitored in monthly steps during the entire growing season. In Vír I WR basin, significant tributaries of the Svratka were also included in the passive sampling: the Fryšávka, the Bílý stream, and the Černý stream. At all three water supply reservoirs, the outflow from the reservoir was also monitored in this way. It was possible to interpret the results in connection with the hydrological and climatic conditions as well as the composition of the cultivated crops in the given locations.

A total of 29 substances were confirmed in passive samplers in Vír I WR basin. The concentration of pesticides had an increasing trend from the second to fourth sampling campaigns. The application of plant protection products is most relevant in this period. In addition, from the end of June to the second half of July, heavy torrential rains were fully manifested in the area. The representation of parent substances of plant protection products was rather minor, with ESA metabolites predominating; in the case of terbuthylazine as an active substance, it was the terbuthylazine-2-hydroxy metabolite. From the left-hand tributaries of Vír I WR, the unnamed stream from the village of Chlum (called the Chlumský stream in this article) was significantly polluted by 2,4-dichlorophenoxyacetic acid, used to treat cereals. The largest erosional flush occurred in the nearby Nyklovický stream, but with a smaller negative response to water quality than in the Chlumský stream.

On the other hand, the Korouhvický stream, the stream from the village of Hluboké, and the Veselský stream were minimally loaded with pesticides. Of the right-hand tributaries, pesticides were significantly represented in the Janovický stream and, in particular, the Písečenský stream, in which concentrations above 100 ng/POCIS were confirmed for three substances. They also included alachlor ESA metabolite. Alachlor was in long-term use from 1975, but since 2006 its use has been banned. In the Písečenský stream, its occurrence was the largest of all verified locations. So the load caused by its former use is still visible.

Intensive agricultural management with a diverse composition of cultivated crops also had a negative effect on the water quality of the Bílý stream below Polička. In the main tributary to WR, in the Svratka, concentrations of pesticides were mostly lower than in other small tributaries, probably due to the dilution of the load from the upper parts of the catchment. The exception was the third sampling campaign with a confirmed high content of pethoxamid, which is used to treat maize. The dynamics of concentrations in the outflow from Vír I WR was different. The concentration of individual pesticides was gradually slightly increasing. A significant increase in concentration was only manifested in the sixth and seventh sampling campaigns. Terbuthylazine-2-hydroxy was most prominently represented. Based on the dynamics of concentrations of glyphosate and the AMPA metabolite, it was possible to estimate where glyphosate was used before spring sowing and where before autumn sowing (or, in both periods).

The results of the load of small left- and right-hand tributaries to Vír I WR are valuable because their monitoring is not implemented in these watercourses by the basin manager.

Opatovice WR differs from the other monitored reservoirs by the long theoretical retention time of water in the reservoir (almost 19 months). Rakovec, a left-hand tributary of the Malá Haná, is minimally loaded with pesticides because agricultural land is used only in the very upper part of its catchment. The opposite is true of the other two most important tributaries to the reservoir: the Malá Haná and the Ruprechtovský stream. The level of their pesticide

Tab. 7. Results of the recalculation of the concentrations from passive samplers on the pesticide load by the main tributary into the water supply reservoir

Profile	**Rs**	**Reliability of determination of sampling rate Rs**		**Svratka – Dalečín above Vír I WR**	**Malá Haná above Opatovice WR**	**Ludkovický stream above Ludkovice WR**
Unit	**[l.day^{-1}]**	**Spring**	**Autumn**	**[kg]**	**[kg]**	**[kg]**
2,4-D	0.0196	🟩	🟨	16.389	0.791	3.173
Acetochlor ESA	0.032	🟩	🟩	41.240	4.170	0.648
Alachlor ESA	0.032	🟩	🟩	136.983	34.797	0.358
Alachlor OA	0.031	🟦	🟦	0.348	0.062	0.020
Atrazine-desethyl	0.090	⬛	⬛	6.021	0.000	0.000
Azoxystrobin	0.060	⬛	⬛	9.650	0.267	0.335
Bentazone	0.003	🟦	🟦	192.140	0.648	0.518
DEET	0.046	x	🟩	240.012	0.000	8.126
Dimethachlor ESA	0.017	🟩	🟩	25.627	3.965	0.014
Chlortoluron	0.169	🟩	⬛	14.082	0.015	0.000
MCPA	0.015	🟩	🟩	43.650	0.135	0.554
Metazachlor ESA	0.016	🟩	🟩	966.795	136.646	0.955
Metazachlor OA	0.023	⬛	⬛	35.662	2.936	0.218
Metolachlor	0.159	⬛	⬛	34.198	0.095	1.372
Metolachlor OA	0.036	⬛	⬛	24.948	2.155	0.162
Tebukonazole	0.067	⬛	🟩	3.029	0.000	0.000
Terbuthylazine	0.149	⬛	⬛	62.006	0.089	0.572
Terbuthylazine-2-hydroxy	0.184	⬛	⬛	87.368	1.834	1.518
Terbuthylazine-desethyl	0.185	🟩	⬛	7.750	0.000	0.272
Terbuthylazine-desethyl-2-hydroxy	0.165	⬛	🟩	27.911	0.065	0.742
Total balance				1,975.81	188.67	19.56
Water volume of the main tributary	**[m^3] for 8 campaigns**			44,186,938	1,273,724	1,529,699
Average concentration of C_{TWA} ∑ pesticide	**[µg.l^{-1}]**			44.7	148.1	12.8

⬛ Rs applicable for robust estimation of substance concentrations in water

🟩 Rs usable but with a lower level of reliability

🟦 Rs cannot be used for quantitative evaluation

🟨 Concentration in water, data from spot samples below the detection limit, Rs could not be verified load was approximately the same, but they differed in both the dynamics and the composition of the pollution. The Malá Haná was a more significant source, due to its water bearing and the constant presence of a wider range of pesticides. Only metabolites of parent substances were represented. The concentration of metazachlor ESA and metolachlor ESA in the samplers was gradually increasing from the first to sixth sampling campaigns and was also significant in the eighth campaign in November. This is very surprising because in 2021 maize was grown on a very small area in the basin. Since it was a gradual rise in concentrations (in contrast to Vír I WR basin, where the onset of concentrations was faster with a maximum in the fourth sampling campaign), it can be concluded that the metabolizing parent substances coming from applications in previous years were gradually leached out. Pesticide concentrations in the reservoir near the sampling facility at the dam showed a similar concentration level until the fifth sampling campaign, then a significant increase from the sixth to eighth sampling campaigns (higher than at the Malá Haná tributary). Pesticides predominantly in metabolized form are probably accumulated in the reservoir.

Pesticide pollution of the Ruprechtovský stream was of a different nature. Pollution with metabolites of atrazine and terbuthylazine was manifested in increased concentrations only in the fourth and fifth sampling campaigns. Glyphosate "jumped" in concentration in the first and sixth sampling campaigns (applications before spring and autumn sowing). The passive samplers of the third campaign were broken due to enormous rainfall and flow on 22–25 June 2021, which made it impossible to evaluate this campaign.

The level of pesticide load, based on the unit of inflow, is the highest in the case of Opatovice WR. Therefore, if it is decided to implement measures for improvement, this reservoir has the highest priority.

Ludkovice WR is the smallest of the assessed reservoirs with a single tributary. The total pesticide load is the lowest. The inflow to the reservoir was dominated by concentrations of glyphosate and the metabolite AMPA, with a maximum in the second and fourth sampling campaigns (above 100 ng/POCIS). At the outflow from the reservoir, this dynamic did not manifest itself significantly. However, a significant concentration load with metabolites of several types of pesticides (acetochlor ESA, alachlor ESA, metazachlor ESA+OA, metolachlor ESA+OA) at the outflow was recorded in the sixth sampling campaign, which may be related to the circulation in the reservoir between the epilimnion and the hypolimnion at the beginning of autumn.

The amount of obtained results and data did not make it possible to provide complete information within the scope of this article; the most significant ones are presented in the text. In the next phase, the obtained results will be discussed with the basin manager and compared with information on the application of plant protection products in the given locations, if available. The outputs of the project (mainly of the N_{map} type) will help the basin manager to identify and evaluate the risks of water pollution and subsequently specify and check the measures to increase the protection of water resources in terms of water quality.

Acknowledgements

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Impact of weir construction at locality Abovce (Slovakia) on groundwater levels – a case study from Slaná river basin

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Keywords: weir – groundwater table – GIS – weir construction

ABSTRACT

The construction of weirs on rivers affects the dynamics of groundwater levels. The weir built on the river Slaná in the year 2010 between the village of Abovce and Chanava brought the opportunity to study such impact due to preexisting groundwater monitoring wells of the Slovak Hydrometeorological Institute. to verify the impact of the constructed weir on groundwater dynamics in the area, records of weekly data were used ranging from 1986 to 2018. In addition, the spatial range of influenced areas was carried out using geographical information systems, and spatial interpolation techniques were used. The results showed that immediately after the construction of the weir, the groundwater level rose significantly.

INTRODUCTION

The construction of weirs and other works damming watercourses are common practice in the world due to the effectivity of the water hydroenergetic potential. In the 2000s have been built several small hydro powerplants practically in all main Slovak river catchments (Váh, Slaná, Orava, Poprad, Nitra, Hron, Hornád) [1]. The motivation was to change the energetic mix of the Slovak republic from mostly carbon-based to renewable sources [2]. However other environmental, as well as hydrological aspects of the proposed energetic solution, has not been sufficiently taken into account in the landscape planning phase [3]. This has been proved in the actualized strategic document of the Ministry of the environment of the Slovak republic by a decreased number of the river profiles that could be potentially used for future river weirs [4].

However, if the planning process of the future river weirs should be environmentally acceptable, it is necessary to base an authorization process on the scientific datasets and information that are publicly presented.

The paper deals with groundwater dynamics in the Slaná river basin influenced by a river weir constructed in 2010 near Abovce (Southeast Slovakia). Since the Slovak hydrometeorological institute has continuously recorded groundwater levels before and after the weir construction by nine monitoring wells in the area, is the paper an exciting contribution allowing insights into groundwater dynamics influenced by weir construction.

The general objective of this study was to describe and quantify the impact of the constructed weir, on the groundwater table by using directly measured data by groundwater monitoring wells. Specific sub-objectives are:

1) to estimate impact of weir construction on groundwater levels of nearest monitoring wells,

2) spatial influence of the weir construction on groundwater levels in the quaternary groundwater body (GWB) of the Slaná river (SK1001100P).

MATERIALS AND METHODOLOGICAL APPROACH

This study was conducted in the river Slaná watershed in Slovakia. The Slaná river is located in the southern part of central Slovakia, its spring is in Stolické vrchy. Slaná river is a mid-altitude river with a rain-snow outflow regime. The weir constructed in 2010 on the river Slaná is located between the villages of Abovce and Chanava and 10 km south from the city of Tornaľa (*Fig. 1*) in the river kilometer 4.7. The created weir has a maximum usable gradient of 3.2 m. The weir captures a watershed of an area of 1,821 km^2. The purpose of the weir is hydroenergetic with an installed power of 0.5 MW.

The groundwater underlying the weir belongs to the SK1001100P groundwater body (*Fig. 2*). It is characterized as formation of intergranular aquifer of the alluvial sediments of the Slaná river and its tributaries. The water body SK1001100P has an area of 140.24 km^2. The water collector is formed mainly from alluvial and terrace gravel, sand gravel, sand, proluvial sediments, which are characterized by high flow rates [5]. The geological composition of the groundwater body (GWB) mainly consists of fluvial sediments with some other sediments far more upstream [6]. In the affected groundwater body, the Slovak hydrometeorological institute operates a state observation network from which we selected 9 monitoring wells for this study (*Fig. 2*). These monitoring wells are listed in *Tab. 1.*

Dataset of groundwater level altitude with weekly measurement were used and 5 time periods were evaluated. The whole time period used in the study was from 1986 to 2018 and contains 1,670 weekly records. Long term period before the construction of weir (1986–2009, 1,200 weekly records) in the study is named as "Before 2", the shorter time period before weir construction (2002–2009, 417 weekly records) in the study is named as "Before 1", the same time period after the construction of weir (2011–2018, 418 weekly records) in the study is named as "After 1", and a combination of the periods is named "Before 1 + After 1" (2002–2018, 887 weekly records).

The data were organized into hydrological years (November to October), not into calendar years. The dataset was first tested on normal distribution by Shapiro–Wilk test [7], then the time periods were compared. The annual median data were tested on presence and direction of trends by Mann-Kendall test [8]. Data homogeneity was tested by Pettitt´s test [9], Standard normal homogeneity test (SNHT) [10] and Buishand´s test [11], with significance level of 0.05 and confidence level of 95 %.

GIS spatial interpolation method SPLINE was used to interpolate the difference of median values of groundwater levels for the time period for (1986–2009) and for (2011–2018) (*Fig. 5*).

Tab. 1. Localization of the monitoring wells (objects) used in the study

Name of the object	**Abovce**	**Lenartovce**	**Chanava**	**Rumince**	**Včelince**	**Včelince**	**Čoltovo**	**Tornaľa**	**Žiar**
Object number	2918	2921	917	2915	914	927	910	925	972
Terrain elevation of the object in m a.s.l.	155.94	154.36	160.35	166.2	167.5	178.1	194.65	182.97	178.78
Depth of the well in meters	9.98	6.8	13.05	13.02	7.8	7.5	9.57	13.56	7
Longitude (λ) °E	20.32403	20.33134	20.30224	20.29197	20.30062	20.31809	20.36965	20.32683	20.27446
Latitude (φ) °N	48.31633	48.3015	48.34055	48.37002	48.38105	48.38992	48.49428	48.41999	48.43534

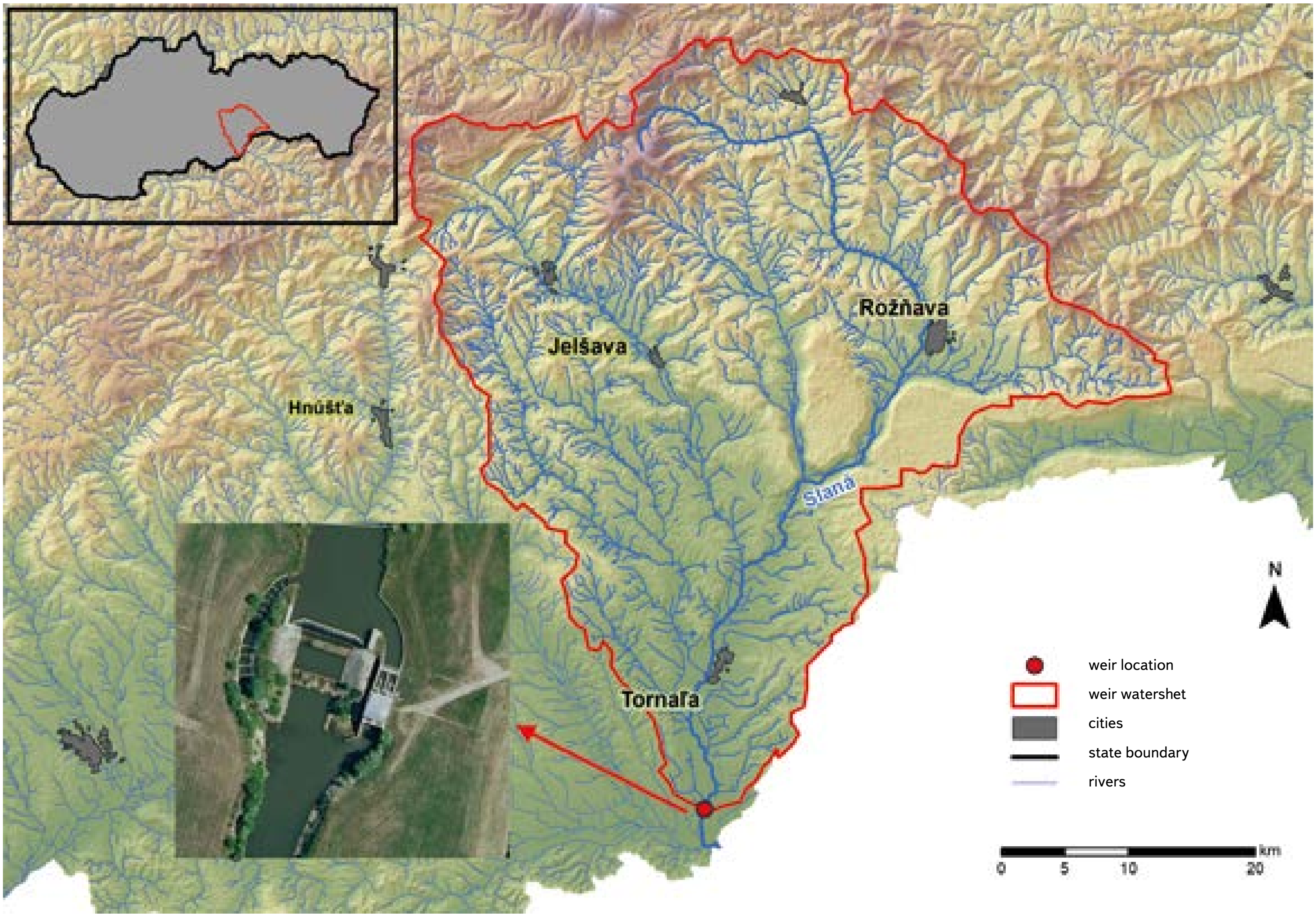

Fig. 1. Localization of the studied watershed and weir near Abovce village; the Upper left figure depicts watershed localization within the Slovak Republic

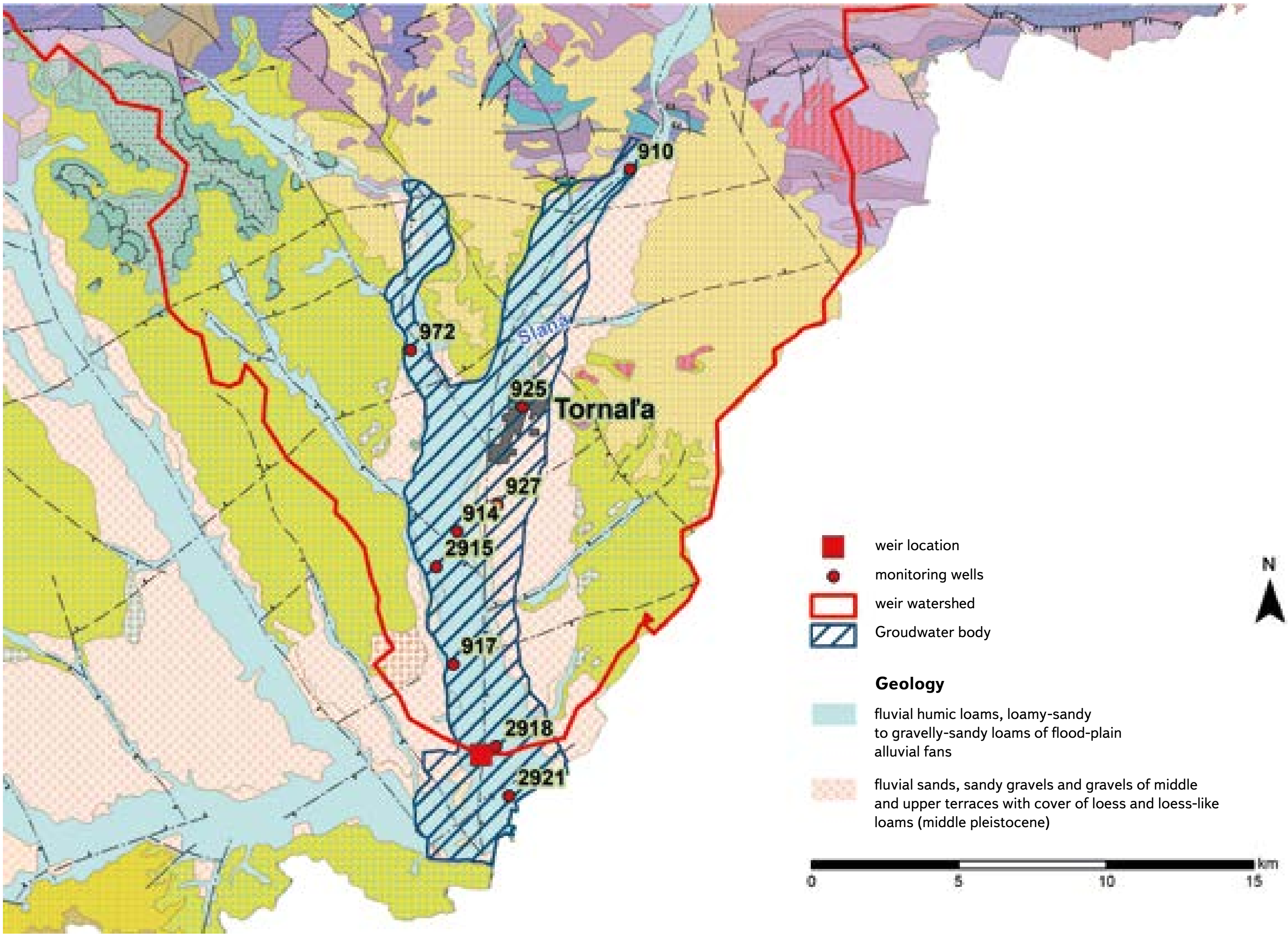

Fig. 2. Quaternary groundwater body (GWB) of the Slaná river (SK1001100P); GWB consists of fluvial sediments (88 %) and other unconsolidated sediments and rocks (7 %), chemical sediments (2 %) and aeolian sediments (3 %) [6]; measuring objects (wells) are marked with a red dot and object number according to the Slovak hydrometeorological institute database

RESULTS

Changes in groundwater level after weir construction near the Abovce weir

Detailed groundwater level changes have been studied on two monitoring wells (2918 – Abovce, 917 – Chanava) nearest to the Abovce weir. However, since the monitoring well 2918 – Abovce is situated only 416 meters above the incremented weir, we provide detailed statistics of groundwater level at this monitoring point in *Tab. 2*.

By applying median values and time-identical 7year intervals ("Before 1 + After 1"), it is evident an increase of the groundwater level up to 1.08 m. A significant increase has been recorded also in maximum and minimum groundwater levels. *Tab. 3* lists all evaluated objects and the calculated difference between the time periods "Before 1" and "After 1". It is evident that the construction of the weir impacted the nearest monitoring wells by evaluation of water level difference. Objects 2918 – Abovce and 917 – Chanava are the most affected. Their distance from the weir is 416 meters by the object 2918 – Abovce and 3,036 meters by the object 917 – Chanava.

Fig. 3 and *4* show all weekly average groundwater level data measured in the most affected objects. The influence of the river weir on water level is evident at both stations. The red line in *Fig. 3* and *4* depict the dynamics of the water level increase in the year 2010 when weir construction was completed. It is obvious that the groundwater level rose immediately after weir construction and remained higher in comparison to the reference period 1986–2009 in both monitoring wells.

The results of groundwater level data subjected to trend analysis are shown in *Tab. 4*. At the time period "Before 1 + After 1", a statistically significant upward trend is evaluated at objects 2918 – Abovce and 917 – Chanava. However, when the time periods "Before 1 + After 1", were evaluated individually, a statistically significant trend was not found.

Tab. 2. Statistical characteristics of groundwater levels for measuring object 2918 – Abovce; values are in groundwater level elevation in meters above sea level [m a.s.l.]; period "Before 2" represents the whole available monitoring period of groundwater level previous to weir construction, "Before 1" represents 7 year long period previous to weir construction, as well as "After 1" represents the same long period after the weir construction; "Before 1 + After 1" represents a period of 7 years before and 7 years after the weir construction

Period	**Whole observation (1986–2018)**	**"Before 2" (1986–2009)**	**"Before 1" (2002–2009)**	**"After 1" (2011–2018)**	**"Before 1 + After 1" (2002–2018)**
	1,670	**1,200**	**417**	**418**	**887**
Number of weekly records	153.60	153.31	153.30	154.38	153.86
Arithmetic mean	**153.40**	**153.26**	**153.25**	**154.33**	**154.11**
Median	155.24	154.44	154.28	155.24	155.24
Max.	152.89	152.89	152.94	154.11	152.94
Min.	0.533	0.252	0.237	0.198	0.580
Standard deviation	153.18	153.13	153.13	154.24	153.26
25th percentile	154.16	153.44	153.44	154.45	154.33
75th percentile	0.98	0.31	0.31	0.21	1.07
Interquartile range					

Tab. 3. Overview of difference in median, max, and min between time periods "Before 1" (2002–2009) and "After 1" (2011–2018) for all measuring objects used in the study (depicted in Fig. 2); values are in groundwater level difference in meters

Name and number of the object	**Abovce 2918**	**Lenartovce 2921**	**Chanava 917**	**Rumince 2915**	**Včelince 914**	**Včelince 927**	**Čoltovo 910**	**Tornaľa 925**	**Žiar 972**
Median	**1.08**	**0.37**	**1.18**	**0.40**	**-0.04**	**0.07**	**0.05**	**0.16**	**0.27**
Max.	0.96	0.17	0.51	0.93	0.09	-0.24	0.11	0.35	0.11
Min.	1.17	0.21	0.90	0.11	-0.18	0.22	-0.13	0.14	0.15

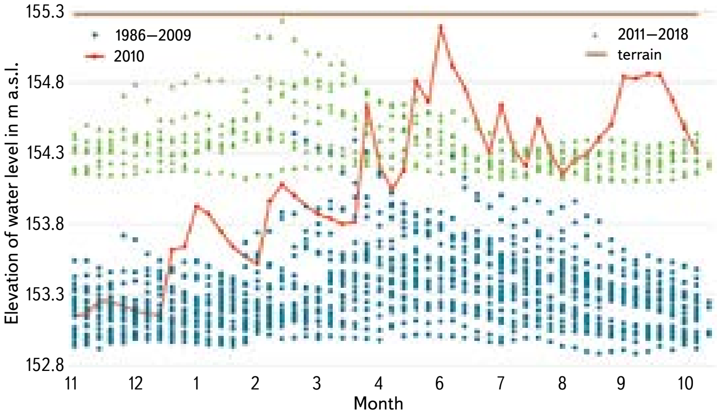

Fig. 3. Difference of the weekly records of the groundwater levels in the period "Before 2" (period 1986–2009 before the construction of the weir) and "After 1" (period 2011–2018 after the construction of the weir) on the measuring object 2918 – Abovce (distance 416 m of the weir); the red dotted line depicts the increase of the groundwater level in 2010 when the weir was accomplished; brown line at 155.3 m a.s.l. represents ground

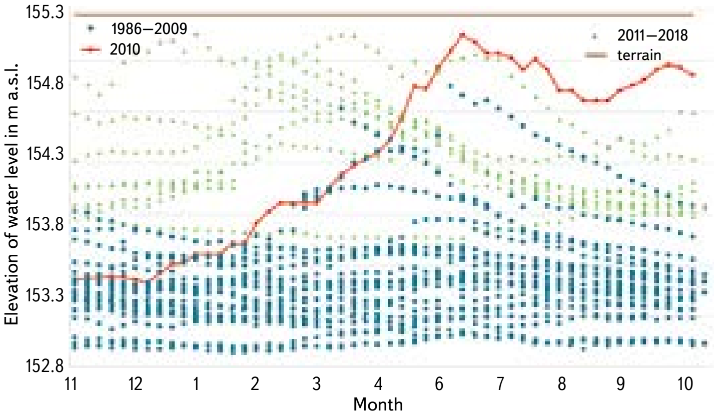

Fig. 4. Difference of the weekly records of the groundwater levels in the period "Before 2" (period 1986–2009 before the construction of the weir) and "After 1" (period 2011–2018 after the construction of the weir) on the measuring object 917 – Chanava (distance 3,036 m of the weir); the red dotted line depicts the increase of the groundwater level in 2010 when the weir was accomplished; brown line at 160.5 m a.s.l. represents ground

Tab. 4. Overview of Mann-Kendall trend test analysis results

Period	Abovce 2918	Chanava 917
"Before 1" (2002–2009)	S = 8.0 Standrz. S = 0.249 Sen's slope = 0.00938 **Result: No trend**	S = 13.0 Standrz. S = 1.496 Sen's slope = 0.0743 **Result: No trend**
"After 1" (2011–2018)	S = 4.0 Standrz. S = 0.371 Sen's slope = 0.0137 **Result: No trend**	S = -14.0 Standrz. S = -1.608 Sen's slope = -0.117 **Result: No trend**
"Before 1 + After 1" (2002–2018)	S = 87.0 Standrz. S = 3.546 Sen's slope = 0.0861 **Result: Upward trend**	S = 69.0 Standrz. S = 2.803 Sen's slope = 0.0866 **Result: Upward trend**

Subsequently, in the case of time period "Before 1 + After 1", data homogeneity test was also performed. Pettitt´s test, Standard normal homogeneity test (SNHT) and Buishand´s test were applied. All tests identified a break point at the beginning of 2010, when the weir in Abovce was put into operation (*Tab. 5*).

The same image is provided by the graph with the identified break point, as a result of Pettitts test, *Fig. 5*. The change in mean values of groundwater level is clearly visible, together with the identified breakpoint.

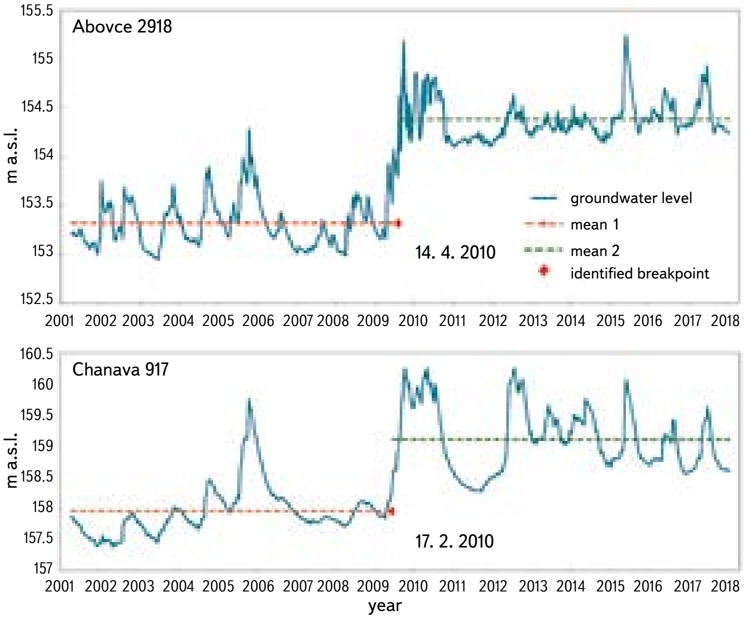

Fig. 5. Pettitt change point detection for groundwater elevation levels in time period "Before 1 + After" on the measuring object 2918 – Abovce and object 917 – Chanava

Spatial extent of Abovce weir influence on groundwater level in quaternary groundwater body of the Slaná river

Fig. 6 clearly shows that the highest difference in groundwater elevation is located right near the constructed weir and by the monitoring wells. Change in groundwater levels in quaternary water body vary from 0.21 m near Rumince monitoring well (2915) to 1.3 m around the constructed weir (monitoring well 2918 Abovce). A relatively high increase in groundwater levels was also observed on monitoring well 917 Chanava at a distance of 3,036 m from the Abovce weir. From the spatial point of view, the river weir of Abovce increased groundwater levels up to 1.3 m on the area of 15.25 km^2 and up to 0.21 m to 0.4 m on the area of 38 km^2. Thus, the Abovce river weir influenced almost 26 % of the waterbody SK1001100P area (an increase of groundwater levels more than 0.21 m). Groundwater levels increase more than 1.1 to 1.3 m was recorded on 11 % of the water body area.

DISCUSSION AND CONCLUSION

The rise of the groundwater level was an expected consequence of constructing a weir on the Slaná river. The rate of increase (up to 1.3 m near constructed weir) of the groundwater level is probably due to the geological conditions at the area, which is formed mainly by Quaternary sediments as stated in [6].

However, quaternary sediments are prone to anthropogenic contamination and pollution [12]. Based on the results presented in the work, it is evident that the construction of even a relatively small weir has a regionally significant impact on the groundwater level. It depends, of course, on the configuration of the terrain, the geological subsoil, and the characteristics of the weir construction structure itself [13]. Nevertheless, in the context of increasing drought risk in the studied area [14] increase in the groundwater levels due to the construction of the Abovce weir could be stated as potentially beneficial for agriculture.

On the other hand, we must not neglect the issue of potential groundwater pollution through industrial activity and agricultural fertilizers [15]. Also, the risk of leaching toxic substances from illegal and historically forgotten landfills can be a risk [12, 16, 17]. Historically, such substances were often buried in pits near farms or the vicinity of municipalities, and no evidence was kept [18]. This concern is valid, as the size of the area on which the groundwater level has increased by more than 1 meter is 15.25 km^2 and includes the cadastral territory of four municipalities. By comparison areas of elevated groundwater level with the Ecological Information System load [19], there is only one potentially risky location in the most affected area registered as a former gas station. However, it is located in the C register, containing records of rehabilitated and reclaimed sites that do not pose any danger. Another danger is the increased level of underground water reaching deep approx. 1 m below the surface (near the villages of Chanava and Abovce), easily reachable by foot construction activities during which toxic substances can leach into groundwater [20]. There may also be a risk of groundwater contamination by oil products in accidents of construction machinery and technology [21]. The above aspects should local and regional authorities to take into account in the process of permitting

Tab. 5. Results of homogeneity test

Abovce 2918				**Chanava 917**		
Pettitt's test	**Standard normal homogeneity test (SNHT)**	**Buishand's test**	**p = < 0,0001 alpha = 0,05**	**Pettitt's test**	**Standard normal homogeneity test (SNHT)**	**Buishand's test**
K = 196359 time = 14. 4. 2010	T0 = 750 time = 17. 2. 2010	Q = 407.937 time = 17. 02. 2010		K = 179993 time = 17. 02. 2010	T0 = 529.096 time = 17. 2. 2010	Q = 342.64 time = 24. 02. 2010

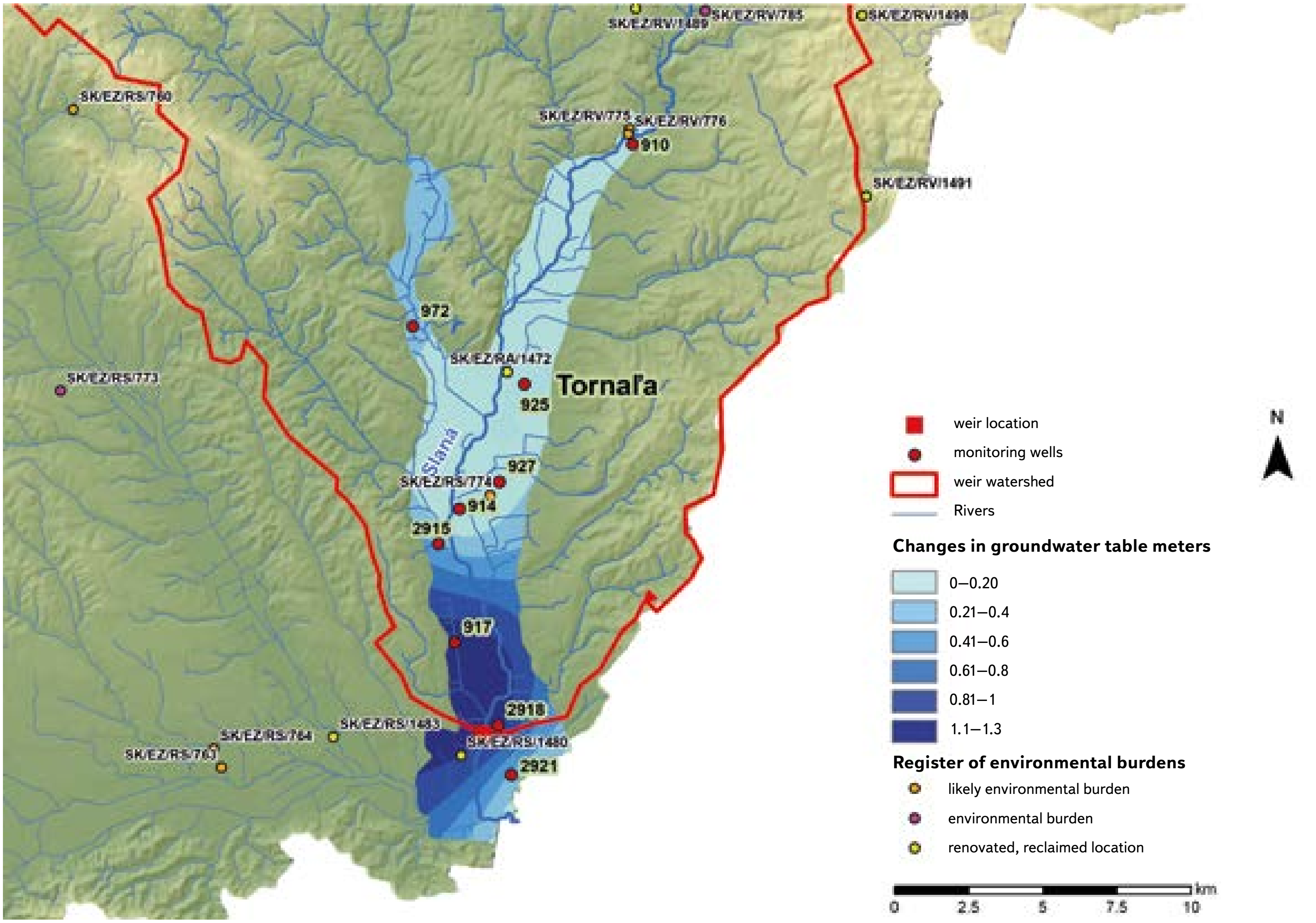

Fig. 6. The difference of groundwater levels for time periods 1986–2009 ("Before 2" – before the construction) and 2011–2018 ("After 1" – after the construction) in the quaternary waterbody of the Slaná river

new buildings activities. The contribution showed not only the significant influence of the construction of the river weir on the water level in the Quaternary groundwater body of the Slaná River (SK1001100P), but also on risks that should be addressed in the future.

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Potential of areas protected for surface water storage to mitigate the impacts of climate change on drinking water supply

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Keywords: water resources — water scarcity — drinking water supply — water balance — climate change — adaptation

ABSTRACT

In the Czech Republic, areas morphologically, geologically and hydrologically suitable for surface water storage to mitigate the adverse effects of floods and droughts are defined through the *General Plan for Surface Water Accumulation Areas*. In the context of climate change, these locations create potential for possible adaptation measures. This article describes the assessment of the potential of selected sites for water supply under climate change conditions by means of hydrological and water balance modelling.

INTRODUCTION

The Czech Republic has a tradition in water resource planning. The *State Plan of the Czechoslovak Republic* (1954) was the first comprehensive list of possibilities for water management use of water resources in CR. It also became the basis for spatial planning. In 1975, the *Indicative Water Management Plan* (Směrný vodohospodářský plán, SVP) was published, where increased attention was paid to the analysis, documentation of the condition, and the possibility of using water resources. It includes the claimed water needs and their outlook for the next 30 years. A total of 581 potential dam profiles suitable for the construction of water reservoirs were selected as part of the SVP, of which 286 sites suitable for this construction were documented in more detail. In 1988, the *SVP Publication* followed, which updated the data on sites. Due to the limitation of claims for the occupation of agricultural land, protection was cancelled for 253 sites, and 97 sites were completely eliminated. In 1995, another SVP was written, in which it was necessary to take into account the new socio-political situation and the introduction of environmental approaches in water management. The number of protected sites has narrowed to just 35. In 2007, the *Plan of the Main River Basins of the Czech Republic* was created, which served as a long-term concept in the field of water resource planning. One of its goals was the updating of the existing range of prospective reservoir sites and their territorial protection. The updated list included 186 sites, however, due to public opposition and the interests of nature and landscape conservation, the plan could not be approved. Therefore, in 2011, the document *General Plan for Surface Water Accumulation Areas* (hereinafter SWAA General Plan) was prepared. The SWAA General Plan was developed following the territorially protected sites in the SVP 1988. Property law, socio-economic and environmental aspects were assessed for individual sites, and the SWAA General Plan in its final form contains 65 protected sites. In 2020, the next and so far last update of the SWAA General Plan took place. The need to update the SWAA General Plan is included in the "Concept of protection against the consequences of drought for the Czech Republic", which was approved by the government in 2017 and also resulted from the meeting of the National Coalition Against Drought in May 2019. Both the concept and the National Coalition were created as a response to the long-term drought in 2014–2019. As part of the update, the SWAA General Plan is being expanded by another 21 sites. The SWAA General Plan 2020 [1] thus registers a total of 86 sites. of these, 31 are included in category A, i.e. among sites potentially intended for water supply reservoirs.

In the Czech Republic and in the world, considerable attention is paid to proposals for adaptation measures that should mitigate the effects of climate change. One such measure is the long-term sustainable management of water resources. It should be mentioned that adaptation measures should be comprehensive and complement each other. However, it follows from previous studies [2–5] that in the case of ensuring reliable water supplies for industry and the population, one of the appropriate measures is the use of water reservoirs. However, potential reservoirs need to be examined in the context of climate change. In particular, increasing air temperature affects evaporation from the water surface and overall evapotranspiration in the landscape, and as it was shown, for example, in [5], reservoirs in vulnerable sites may have a problem in the future to fulfil supplies with the required reliability. SWAA General Plan 2020 contains only basic data on the possible (potential) volume of reservoirs. In view of the ongoing climate change, it is necessary to check the basic water management function of potential reservoirs on SWAA (Sites for storage of surface water), namely whether these potential reservoirs would be able to compensate for negative changes in the respective catchments. A similar issue was already dealt with [6, 7], however, the results do not include the significant drought period 2014–2019. Therefore, as part of the project "*Water management and water supply systems and preventive measures to reduce risks in the supply of drinking water*", 17 potential water reservoirs from SWAA category a were selected and their assessment was carried out using new data until 2020 and new climate change scenarios. Implementation follows on from the partial outputs of the mentioned project, mainly the evaluation of the security of water abstractions from existing water reservoirs [5] and the balance of resources and needs of groundwater for drinking purposes [8].

METHODOLOGY AND MATERIAL

The assessment of the possible impact of climate change on the provision of water supply by water reservoirs is based on methodology [9]. The procedures from the methodology for processing the hydrological and water management balance are applied, including simulation modelling of the storage function of water management systems. The assessment was prepared for the prospective

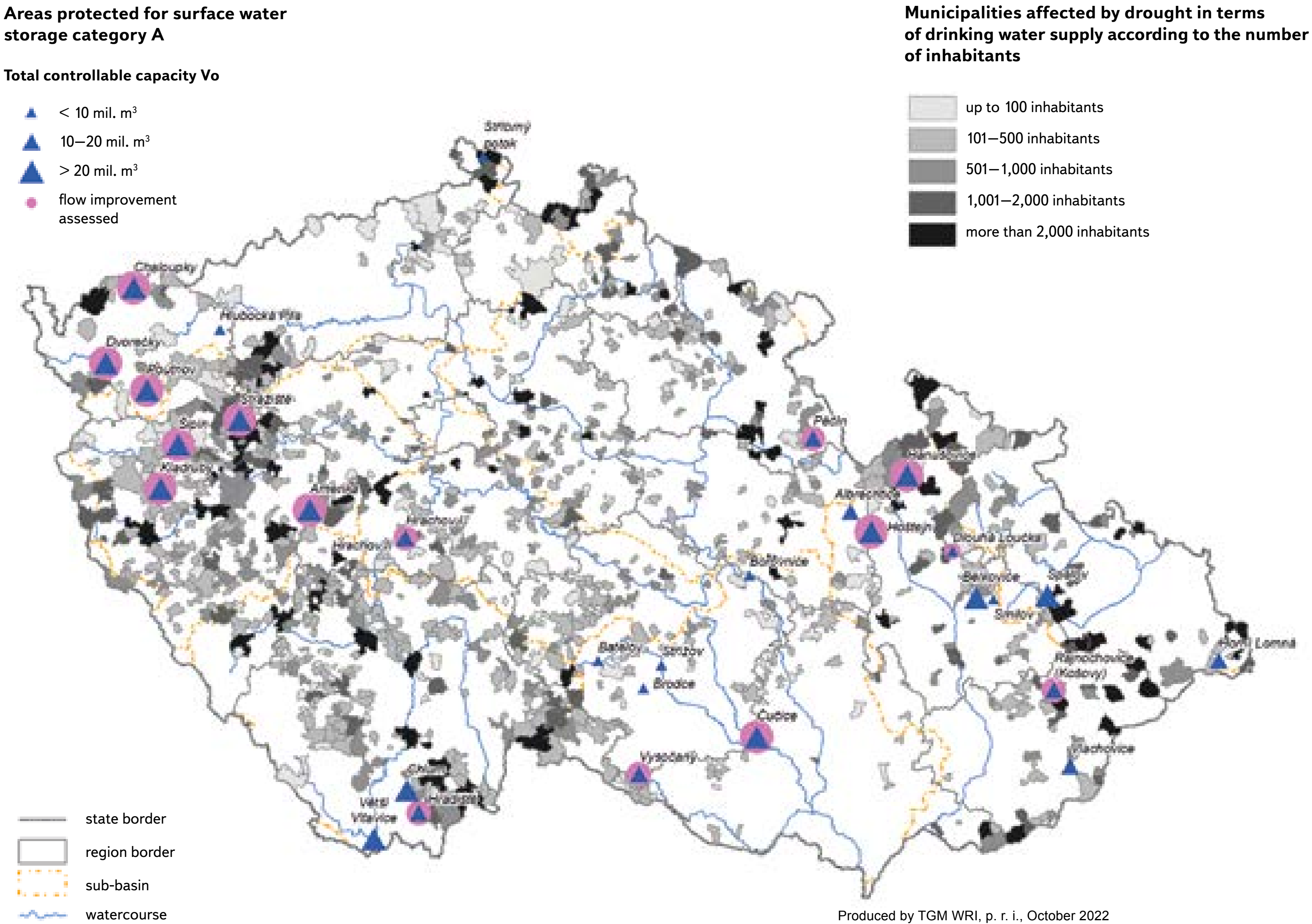

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Fig. 1. Areas protected for surface water storage category A and municipalities affected by drought in terms of drinking water supply; polygons represent municipalities and population affected by drought

period of 2050, the hydrological balance modelling was also carried out for time horizons with centered year 2035 and 2085.

With regard to the solution to the problem of drinking water supply, the selection of evaluated sites was limited to SWAA category A. Out of a total of 31 SWAA recorded in this category, 17 sites were selected. The selection was based on the location of these sites near potentially problematic areas. *Fig. 1–3* show the selection. The selected and evaluated sites are highlighted in purple. *Fig. 1* shows the location of SWAA category A, in which municipalities affected by the drought in 2015 in terms of drinking water supply were identified as part of the Plans for development of water supply and sewerage for the Czech Republic [10] (the vast majority are problems with groundwater supply). *Fig. 2* shows the location of SWAA in relation to ensuring the current requirements for water supply by water reservoirs in conditions of climate change [5]. For easier orientation, abstractions are divided into four groups according to the security achieved by duration and marked using a colour scale, as follows:

a) water abstractions with reliability of current and permitted abstractions in all evaluated scenarios are marked in blue,

b) medium-risk abstractions reliability of only current abstractions in all evaluated scenarios are marked in green,

c) abstractions reliability of current abstractions are marked yellow only in the more favourable scenario of the impact of climate change HadGEM2,

d) abstractions where reliability is not achieved in any of the climate change impact scenarios are marked red as high risk.

Fig. 3 shows the location of the SWAA in relation to the areas – the so-called working units of groundwater bodies –, that are evaluated as (potentially) at risk in terms of the balance of available resources and groundwater abstractions in current conditions or in conditions of climate change [8]. Selected SWAA and their characteristics are shown in *Tab. 1*.

Current climate conditions

Climate data for the period 1961–2020 was used for the actual assessment of current conditions, time series of air temperatures and precipitation. During this period, a significant increase in temperatures can be observed, especially in recent years. This increase reaches high statistical significance. The increasing temperature affects the amount of potential evapotranspiration and, if water

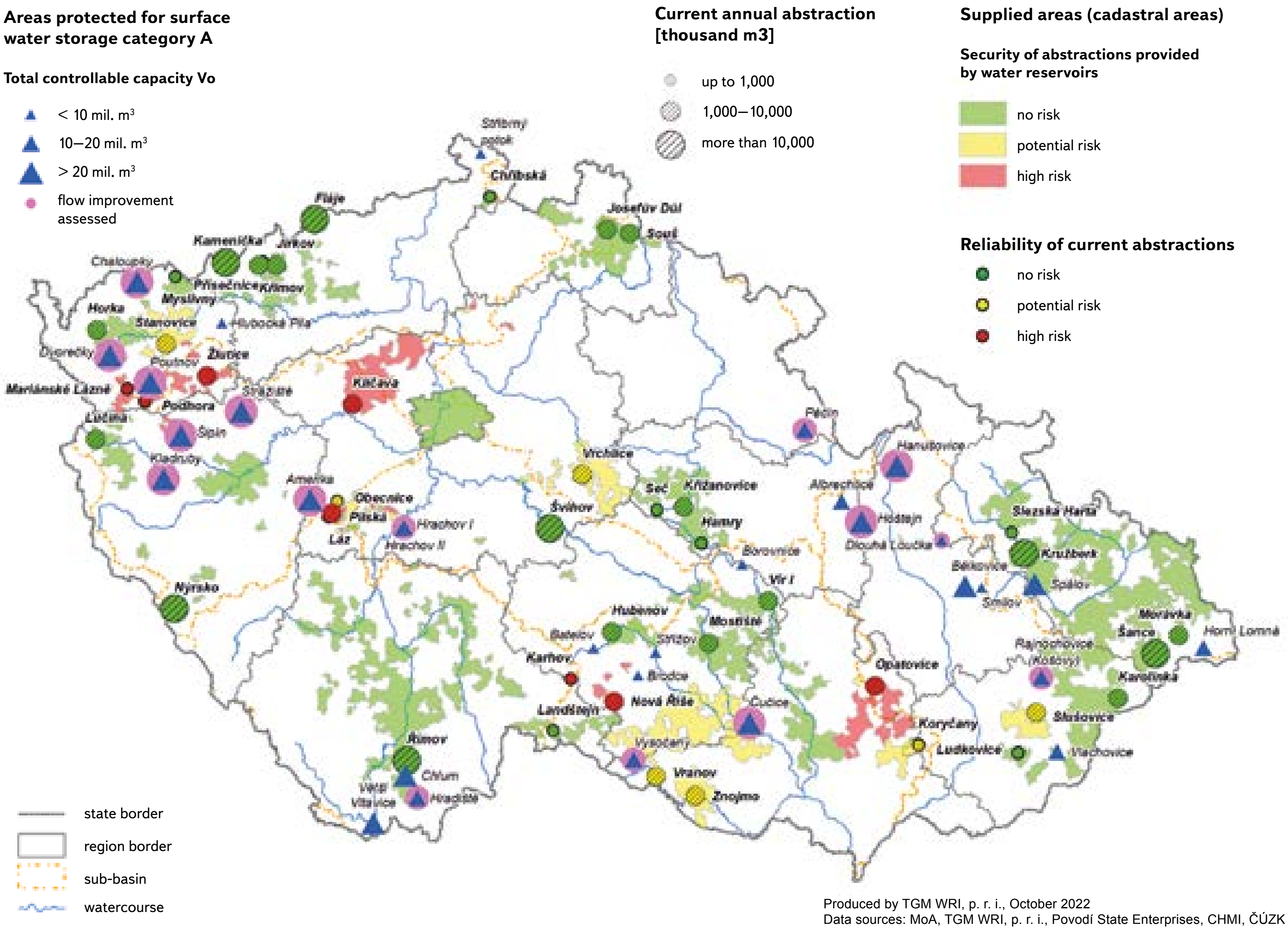

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Fig. 2. Areas protected for category A surface water storage and reliability of water abstractions by reservoirs

is available in the soil profile, then also the current evaporation. The reduced availability of precipitation totals was mainly in the periods 1969–1974, 1989–1994, and 2014–2017. When evaluating annual precipitation totals, it is not possible to trace a trend that would be statistically significant. The same applies for outflows, where no statistically significant trend can be found in the long-term average annual outflows (average for the whole of the Czech Republic). In recent years, however, a significant decrease in runoff can be observed in the summer and spring months and an increase in January, which is mainly due to liquid precipitation and snow melting due to increased temperatures.

Climate change scenarios in water management

For the preparation of climate change scenarios in the context of changes in the hydrological balance, the delta change method is used as standard in the Czech Republic, especially for studies in monthly time steps. This method consists in transforming the observed data so that the changes in the transformed quantities correspond to the changes derived from climate model simulations. Changes in average monthly precipitation totals and average monthly temperature are normally considered in the monthly step. In the daily step, it is also necessary to consider changes in the variability of quantities. Therefore, the advanced delta change method (ADC) was used to create climate change scenarios. The essence of the ADC method is to transform the observed data in a way that guarantees that the changes between the transformed and the original series are the same as the changes derived from the regional climate model. For precipitation and temperature (especially in the daily step) it is desirable that the considered transformations take into account changes in both mean and variability. Simply put, this means that the extremes can change differently than the average. When deriving precipitation changes from the climate model, the ADC method also considers systematic simulation errors. Since the temperature is transformed linearly, systematic error has no effect on the resulting temperature transformation [11].

Selected [12] *Global Circulation Models* (GCM) for sub-basins were transformed by the chosen method, namely:

- NorESM1-M +
- MPI-ESM-LR + HadGEM2-ES +
- GISS-E2-H + MRI-ESM1 +
- CanESM2 + GFDL-CM3

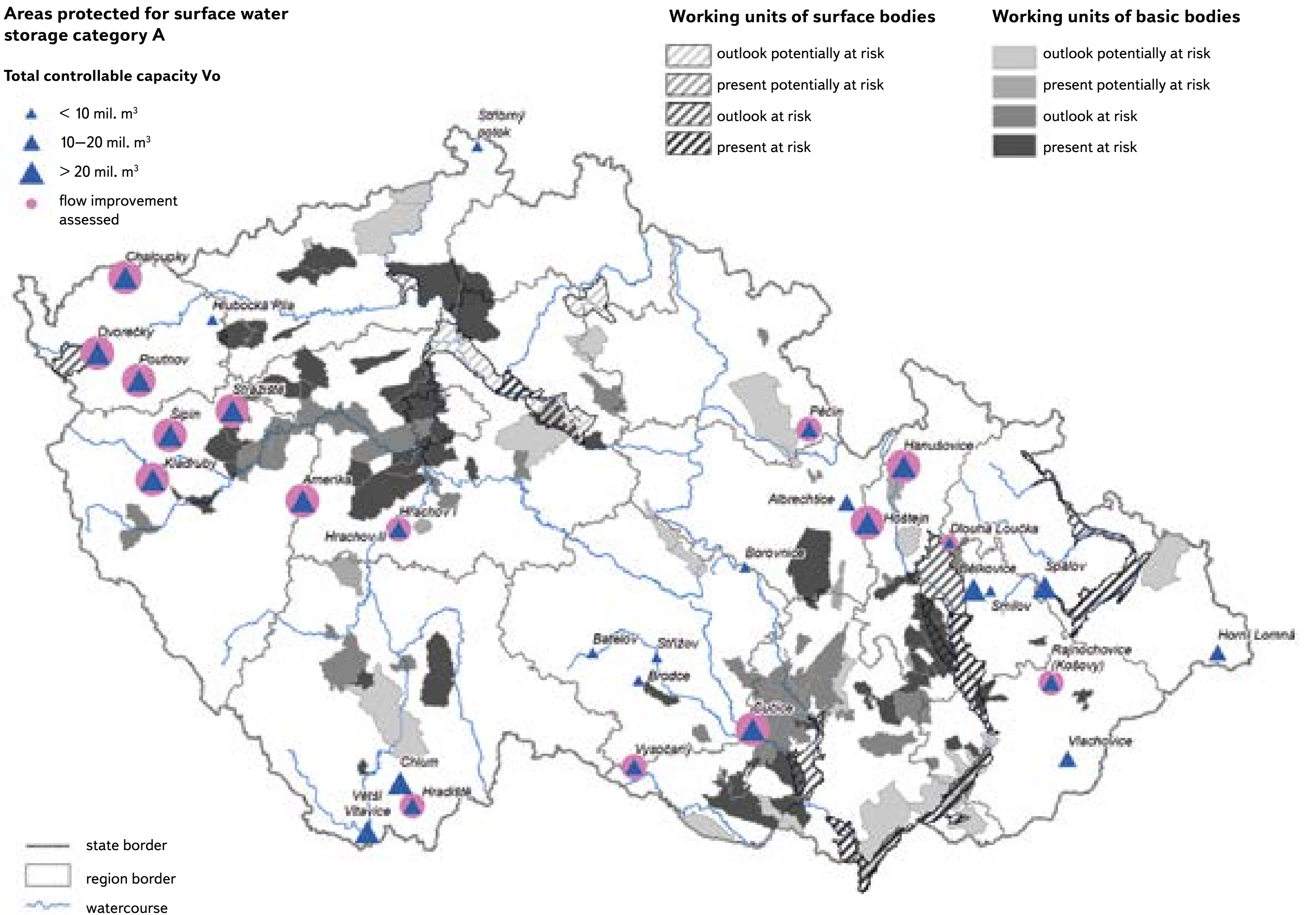

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Fig. 3. Areas protected for the accumulation of surface water category A and balance risk working units of groundwater bodies

The first model (NorESM1-M) represents the centre of the series of all GCM. The MPI-ESM-LR + HadGEM2-ES models act as the driving GCM for several Euro-CORDEX RCM simulations. The same applies to the selected medium model, which is also controlled by one of the Euro-CORDEX RCMs. The GISS-E2-H + MRI-ESM1 models ensure the fulfilment of the condition to cover the inter-model variability, and the CanESM2 + GFDL-CM3 models enable the fulfilment of the last mentioned selection condition. These climate models were further tested for the possibilities of use in water management, mainly by means of hydrological balance modelling by the BILAN model, including historical runs (simulation on the already observed period). Selected RCM models were also tested. For the assessment itself, the HadGEM2-ES model was chosen, which is referred to by studies [13], recommending a medium scenario of the impacts of climate change in water management. The evolution of temperature for individual selected GCM climate models is shown in *Fig. 4*, where the thick black line describes the evolution of average annual temperatures for the catchment area of the analysed sites based on observations, the grey line through individual GCM simulations (analogously the annual average for all sites), and subsequent summarization based on RCP emission scenarios. It is clear that the increase in temperature is mainly due to the choice of the emission scenario, which indicates the boundary conditions of the individual GCM simulations. However, it is different for the precipitation totals, which are shown in *Fig. 5*. Within the simulations, there are also significant differences in the distribution of changes over the course of the year. Most simulations predict an increase in precipitation totals for the Czech Republic, which may be due to the country's location. This phenomenon and the credibility of the above simulations for the Czech Republic are widely discussed within the professional community. Clarifications should be provided by the outputs of the TA CR "*PERUN*" and "*Water Centre*" projects, where this phenomenon is investigated.

The following scenarios were selected for the evaluation of the water management balance:

- **0** – indicating current conditions,
- **2** – the current climate warmed by + 2 °C, this scenario reflects the average warming for the Czech Republic around 2050 and uses unchanged precipitation totals, i.e., it simulates the nature of changes in the hydrological regime if the temperature increase by 2 °C;
- **HadGEM2** – climate based on the outputs of the HadGEM2-ES Global Climate Model and the RCPRCP4.5 emission scenario.

Tab. 1. Selected sites and their basic characteristics

SWAA	Watercourse	Basin area [km^2]	Total controllable space Vo [mil. m^3]	DBC ANLGN	River/ stream ANLGN	Area ANLGN [km^2]	Calibration period	KGE
Amerika	Klabava	69.7	30.9	187500	Klabava	158.45	2002–2011	0.68
Čučice	Oslava	791	53	474000	Oslava	861.03	1961–2011	0.61
Dlouhá Loučka	Huntava	27	5.2	362000	Loučka	80.8	1961–2011	0.71
Dvorečky	Libava	45	30.75	206800	Libava	68.22	1961–1988	0.76
Hanušovice	Morava	217.2	135	345000	Morava	349.9	1961–2011	0.81
Hoštejn	Březná	126.5	166	353000	Březná	130.03	1961–2011	0.74
Hradiště	Černá	125.3	13	112500	Černá	133.24	1971–2011	0.65
Hrachov I	Brzina	132.6	10.5	153800	Brzina	133.24	1984–2011	0.73
Hrachov II	Brzina	115.5	6	153800	Brzina	133.24	1984–2011	0.73
Chaloupky	Rolava	20.1	36.5	209100	Rolava	20.1	1967–2011	0.69
Kladruby	Úhlavka	277.3	27.26	173000	Úhlavka	296.59	1961–2011	0.67
Pěčín	Zdobnice	72.2	17.1	027000	Zdobnice	84.3	1961–2011	0.76
Poutnov	Teplá	91.4	28.1	210900	Teplá	256.12	1961–2011	0.58
Rajnochovice (Košovy)	Juhyně	19.3	11.2	387500	Juhyně	20.24	1978–2011	0.78
Strážiště	Střela	629.8	78.01	190000	Střela	775.02	1961–2011	0.64
Šipín	Úterský potok	173.6	39.7	175000	Úterský potok	297.45	1961–2011	0.66
Vysočany	Želetavka	369.4	17.8	432000	Želetavka	367.69	1961–2011	0.69

ANLGN – hydrological analogue, DBC – database number of CHMI water gauging station, KGE – Kling-Gupta efficiency.

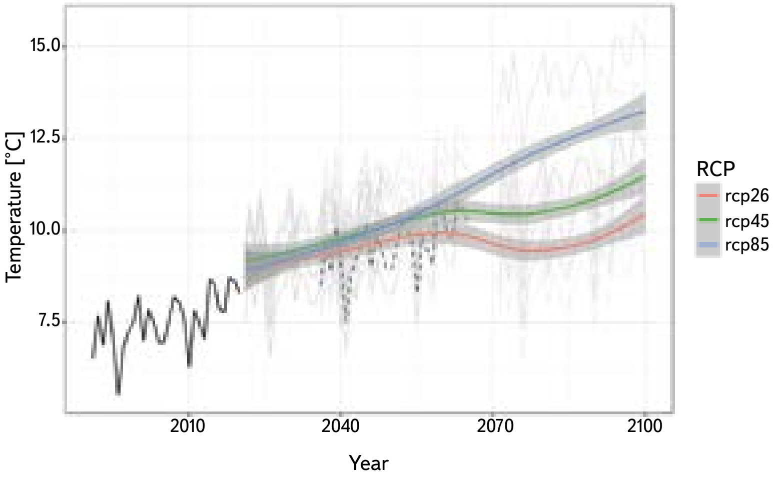

Fig. 4. Air temperatures according to observations, individual GCM and emission scenarios RCP (grey lines describe the simulations of individual climate models, coloured lines the mean of simulations for the selected emission scenario)

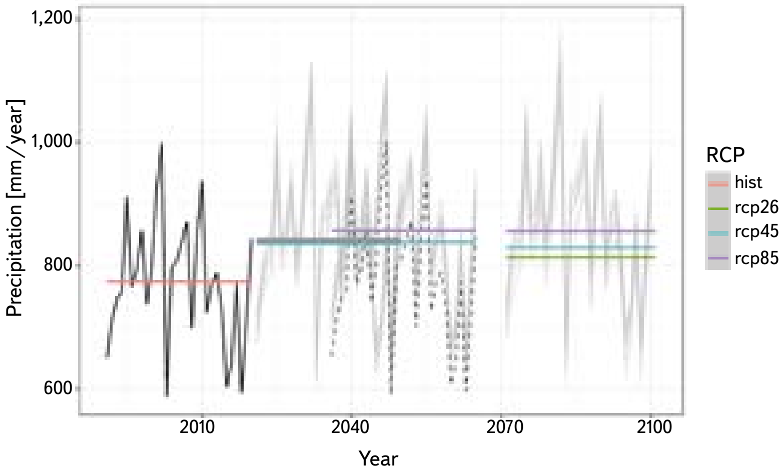

Fig. 5. Precipitation according to observations, individual GCM and emission scenarios RCP (grey lines describe the simulations of individual climate models, coloured lines the mean of simulations for the selected emission scenario)

Hydrological balance modelling

To model the hydrological balance, the BILAN conceptual model was used, which has been developed for more than 15 years in the TGM WRI Department of Hydrology. The model calculates the chronological hydrological balance of the basin or area in daily or monthly time steps. It expresses the basic balance relationships on the surface of the basin, in the aeration zone, which also includes the vegetation cover of the basin, and in the groundwater zone. Air temperature is used as an indicator of the energy balance, which significantly affects the hydrological balance. Potential evapotranspiration, evapotranspiration, infiltration into the aeration zone, seepage through this zone, snow water storage, soil water storage, and groundwater storage are simulated during the calculation. Runoff is modelled as the sum of three components: two components of direct runoff (including hypodermic runoff) and base runoff [14–16]. The monthly version of the model, which is controlled by eight parameters, was used to model the hydrological balance. The model uses linear and non-linear reservoirs to transform precipitation into runoff. The main inputs of the model are precipitation and air temperature (also measured runoff for calibration), the output is the modelled runoff from the basin and other components of the hydrological balance.

In order to assess the impact of climate change for future outlooks, it is necessary to have a built and calibrated hydrological model for the SWAA profiles, which will allow performing variant calculations according to climate change scenarios. As there is usually no direct discharge observation for the SWAA basins, hydrological analogies must be used. The BILAN model is calibrated to an analogue that overlaps with the original basin, and the resulting parameters are transferred to the SWAA basin. Using these parameters and the new precipitation and temperatures, which are interpolated exactly to the SWAA basin, it is then possible to simulate the outflows directly for the profile of the potential reservoir. A similar procedure is used to simulate the affected outflows according to climate change scenarios. In this case, the inputs are formed by the affected precipitation and temperatures according to climate change scenarios and already known model parameters from the previous calibration.

Model calibration was performed on monthly data obtained by interpolation from a regular grid (25 × 25 km) of precipitation and temperatures for the Czech Republic [18]. The period used to calibrate the model on the analogue is shown in *Tab. 1*; except for SWAA Amerika, a calibration period achieved more than 20 years. When calibrating the model, emphasis was placed on a more accurate simulation of outflows in the area of lower quantiles. The goodness of fit between the observed and modelled runoff was assessed by the Kling-Gupta metric [19], the values of which are shown in *Tab. 1*. In general, it can be said that the closer the value is to 1, the greater the fit between modelled and observed runoff.

Hydrological modelling of climate change

The procedure for modelling the impact of climate change on the hydrological regime (*Fig. 6*) can be briefly summarized as follows:

1. The selected hydrological model is calibrated for the selected catchment using observed data. A hydrological model should be based on physics to guarantee that it will provide acceptable results even for unobserved conditions.
2. The input quantities from the global and regional climate model are converted into scenario series for individual basins, namely by:
    (a.i.1.a) statistical downscaling,
    (a.i.1.b) post-processing of the output of the climate model, i.e., using the incremental method or correction of systematic errors.

   It is often necessary to use spatial interpolation to relate the data from the calculation cells of the climate model to the centre of gravity of the given basin. For the correct use of all methods (a–b), it is necessary to have the observed data available.
3. Using a calibrated hydrological model and scenario series, a simulation of the hydrological balance for the scenario period is carried out.
4. Modelled discharge for the present and prospective periods are corrected in individual months using the quantile method [17].

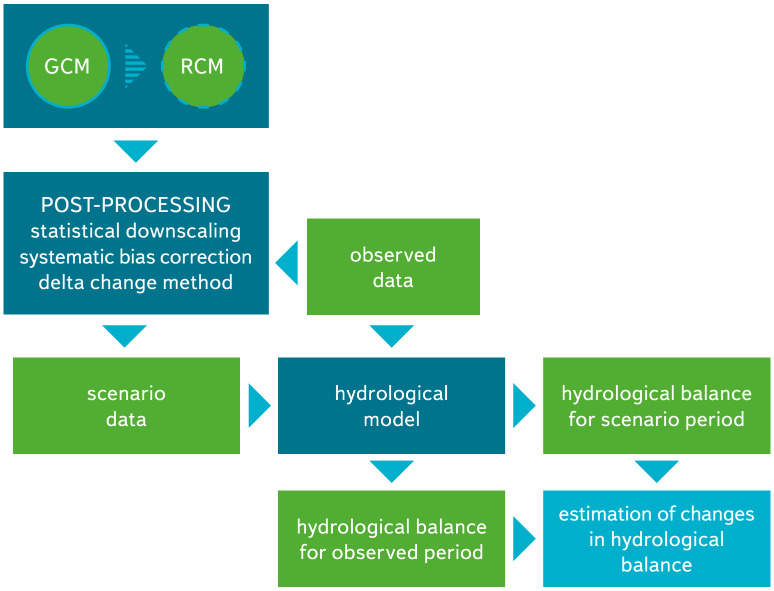

Fig. 6. Scheme of hydrological modeling of climate change impacts

Water management balance

The potential volume of water that can be provided by selected sites with a given reliability for water abstraction or minimum discharge was evaluated using a simulation model of the water management system storage function [20]. The simulation was processed in a monthly step for a total of 39 years (i.e., 468 months) for time series of unaffected monthly mean discharge and evaporation. The time series were processed using the above-mentioned hydrological balance modelling procedure. Variants representing both current hydrological conditions (scenario 0) and climate change impact scenarios were evaluated: the HadGEM2 scenario for the reference year 2050, and a warming by +2 °C scenario (scenario 2). The total controllable volume of the water reservoir listed in the SWAA General Plan [1] was considered as active storage capacity. In this regard, it is necessary to consider the resulting values of reliable abstractions (or improved discharge) as theoretical. Despite this fact, the results give an idea of the possible impact of climate change scenarios on the potential capacity of the assessed sites. In addition to the volume of water, or of the improved discharge, that can be provided by sites with a given level of reliability, other characteristics were also evaluated (see below).

RESULTS AND DISCUSSION

The result of the solution procedure described above was the quantification of the possible impacts of climate change on hydrological characteristics (discharge and evaporation from the water surface and evapotranspiration of the landscape)

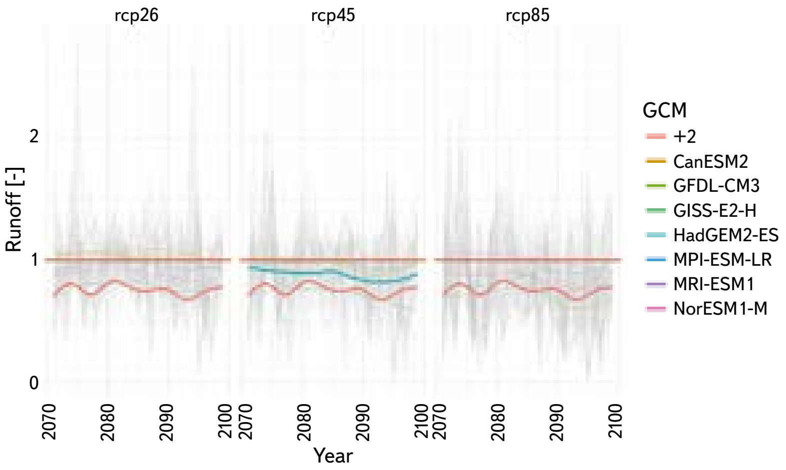

Fig. 7. Reduction of runoff from the catchment area of potential water reservoirs (rcp26, rcp45 and rcp85 indicate groups of emission scenarios, the grey lines describe the individual climate model simulations, the thick red line the + 2 °C warming scenario and the thick turquoise line the selected HadGEM2 scenario)

and the subsequent evaluation of the reliability of water abstractions provided by water reservoirs in these conditions. *Fig. 7* shows the changes in natural runoff (scenario/present) for individual simulation scenarios and emission scenarios, in this case for the period 2071–2100. The grey lines are partial simulations for the given sites, the coloured lines are summaries for individual climate models, and the highlighted ones are the simulations used for water management evaluation. A significant variability of changes can be observed, which are mainly determined by the input climate data and uncertainties in the hydrological model simulations. The latter is calibrated on the basis of available input data, while a number of studies and research deal with the calibration strategies themselves. *Fig. 8* also shows the reduction of runoff from the catchments of the assessed sites due to climate change for the HadGEM2 scenario to the reference year 2050.

Using the simulation of the storage function of water management systems, a uniform improved discharge Q_n was evaluated for individual SWAA and scenarios with reliability according to the duration pt = 99.5 % [21]. The results are shown in *Tab. 2*. The use of SWAA capacity (or the evaluated improved discharge Q_n) for water abstraction is limited by the need to maintain the minimum residual flow rates (MRF) below the water reservoirs. The indicative value of MRF was calculated according to equation (1), where Q_{10} represents the 90 % quantile of mean monthly discharge. The equation was derived from the analysis of the MRF relationship calculated from daily discharge and the relevant quantile of monthly discharge for most water gauging stations in the Czech Republic. As additional characteristics, *Tab. 2* also shows the values of the long-term mean discharge Q_a, (which is calculated here as the arithmetic mean of a series of modelled mean monthly discharge), the improvement coefficient α calculated according to equation (2), the coefficient of variation of annual mean discharge Cv and the standardized inflow m calculated according to equation (3). According to [22], reservoirs with m ≥ 1 or m ≥ Cv have a seasonal nature of management, otherwise multi-year nature of management.

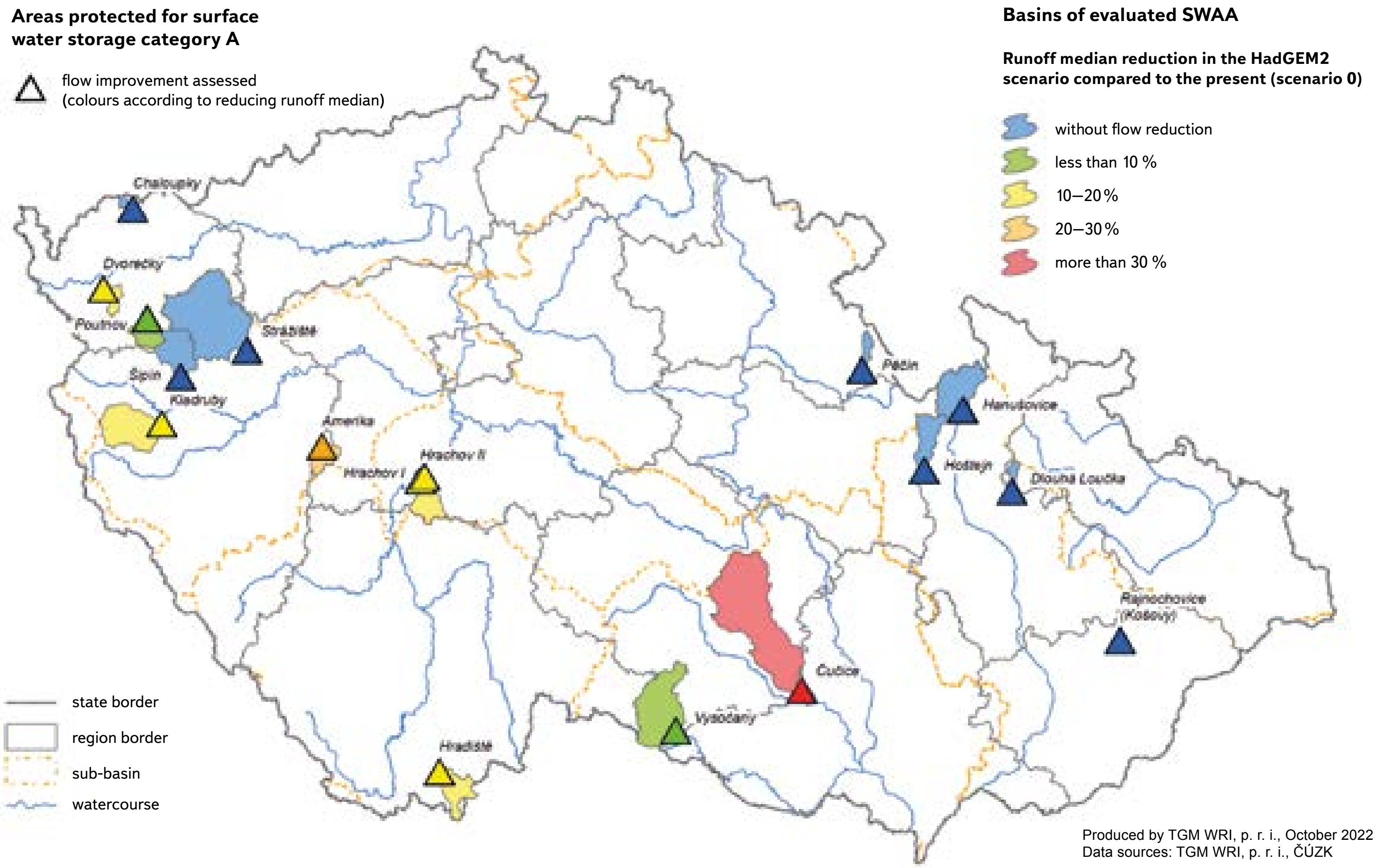

Fig. 8. Reduction of runoff from the catchment area of potential water reservoirs in the HadGEM2 scenario

Tab. 2. Potential for flow enhancement

Location Watercourse	Scenario	Q_a [m³.s⁻¹]	Q_n at $p_t = 99{,}5$ [m³.s⁻¹]	MRF [m³.s⁻¹]	α	Cv	m
Amerika **Klabava**	0	0.592	0.479	0.065	0.81	0.41	0.46
	2	0.479	0.375	0.041	0.78	0.46	0.47
	HadGEM2	0.519	0.396	0.045	0.76	0.43	0.55
Čučice **Oslava**	0	2.872	1.389	0.249	0.48	0.48	1.07
	2	1.984	0.894	0.108	0.45	0.55	1
	HadGEM2	2.362	0.875	0.126	0.37	0.55	1.13
Dlouhá Loučka **Huntava**	0	0.271	0.211	0.05	0.78	0.23	0.97
	2	0.241	0.183	0.038	0.76	0.24	1.01
	HadGEM2	0.273	0.196	0.04	0.72	0.23	1.21
Dvorečky **Libava**	0	0.494	0.438	0.062	0.89	0.29	0.4
	2	0.419	0.371	0.043	0.89	0.32	0.36
	HadGEM2	0.45	0.381	0.044	0.85	0.35	0.45
Hanušovice **Morava**	0	3.729	3.463	1.087	0.93	0.21	0.35
	2	3.393	3.166	0.918	0.93	0.22	0.31
	HadGEM2	3.852	3.425	0.918	0.89	0.22	0.51
Hoštejn **Březná**	0	1.569	1.522	0.238	0.97	0.23	0.13
	2	1.425	1.377	0.185	0.97	0.25	0.13
	HadGEM2	1.684	1.579	0.189	0.94	0.25	0.25
Hradiště **Černá**	0	1.448	0.875	0.423	0.6	0.32	1.23
	2	1.204	0.651	0.291	0.54	0.37	1.23
	HadGEM2	1.223	0.704	0.273	0.58	0.34	1.25
Hrachov I[1] **Hrachov II** **Brzina**	0	0.459	0.352	0.037	0.77	0.47	0.5
	2	0.328	0.247	0.023	0.75	0.58	0.43
	HadGEM2	0.395	0.285	0.025	0.72	0.52	0.54
Chaloupky **Rolava**	0	0.385	0.352	0.101	0.91	0.22	0.39
	2	0.347	0.32	0.071	0.92	0.23	0.35
	HadGEM2	0.376	0.346	0.071	0.92	0.24	0.33
Kladruby **Úhlavka**	0	1.345	0.866	0.191	0.64	0.36	1
	2	1.097	0.584	0.126	0.53	0.42	1.1
	HadGEM2	1.302	0.723	0.152	0.56	0.42	1.06
Pěčín **Zdobnice**	0	0.817	0.693	0.227	0.85	0.23	0.67
	2	0.744	0.647	0.171	0.87	0.25	0.53
	HadGEM2	0.781	0.618	0.137	0.79	0.25	0.84
Poutnov **Teplá**	0	0.703	0.594	0.104	0.84	0.28	0.55
	2	0.578	0.487	0.068	0.84	0.33	0.48
	HadGEM2	0.634	0.487	0.086	0.77	0.34	0.69
Rajnochovice **(Košovy)** **Juhyně**	0	0.239	0.202	0.047	0.84	0.29	0.54
	2	0.211	0.171	0.035	0.81	0.3	0.62
	HadGEM2	0.253	0.198	0.037	0.78	0.29	0.74
Strážiště **Střela**	0	2.899	2.188	0.527	0.75	0.33	0.75
	2	2.379	1.697	0.402	0.71	0.38	0.76
	HadGEM2	2.84	2.036	0.472	0.72	0.36	0.79
Šipín **Úterský potok**	0	0.905	0.784	0.107	0.87	0.34	0.4
	2	0.748	0.622	0.074	0.83	0.38	0.44
	HadGEM2	0.971	0.772	0.106	0.8	0.35	0.59
Vysočany[2] **Želetavka**	0	1.212	0.250	0.205	–	0.45	–
	2	0.927	0.200	0.147	–	0.49	–
	HadGEM2	1.168	0.200	0.219	–	0.47	–

[1] Considered as a system Hrachov I – Hrachov II.

[2] Considered as a Vysočany – Vranov – Znojmo system. The Q_n value represents the added improvement potential to the existing Vranov – Znojmo system.

$$MZP = 0,73 * Q_{10} \tag{1}$$

$$a = \frac{Q_n}{Q_a} \tag{2}$$

$$m = \frac{(1- a)}{Cv} \tag{3}$$

From the results, by comparing the values of discharge improvement Q_n in the scenarios of climate change and current conditions (scenario 0), a more significant reduction in the potential of SWAA to ensure water abstractions is evaluated especially at the sites of Čučice (over 30 % in both scenarios), Kladruby, Hradiště, Hrachov I, and Hrachov II. on the contrary, a relatively low reduction (up to 10 %) of the potential to secure water abstractions was evaluated at the sites of Hoštejn, Hanušovice, Chaloupky, and Pěčín.

Due to its location on the tributary of the Želetavka to the Vranov water reservoir, the Vysočany site was assessed in the Vysočany – Vranov – Znojmo water reservoir system. Therefore, Q_n values in *Tab. 2* indicate the added potential for improvement to the existing Vranov – Znojmo system for this site. Considering the total capacity of the Vranov water reservoir (in the current conditions of improvement at pt = 99.5 %, it exceeds 4 $m^3.s^{-1}$), the added effect of the Vysočany site is relatively low. The Vranov water reservoir is multi-purpose and current water abstractions from the Vranov – Znojmo system make up a smaller share of the total requirements placed on its storage function. Hrachov I and Hrachov II water reservoirs, on the Brzina river, were also considered as a system.

As part of the water management solution for reservoirs, the entire potential volume of the reservoir listed in the SWAA General Plan [1] was considered as active storage capacity. In this regard, it is necessary to take the resulting values of reliable abstractions (or improved discharge) as theoretical. For example, the volume of dead storage, the values of which are not currently available, was not considered. The improved discharge will thus be lower in real terms. However, despite this fact, the results give a good idea of the possible impact of climate change scenarios on the potential capacity of the assessed sites.

CONCLUSION

The goal of the solution described above was to evaluate the possible impacts of climate change on the capacity of areas protected for surface water storage (SWAA). Considering the significant uncertainties in the prediction of climate change scenarios, a variant solution was chosen: the HadGEM2 climate change scenario for the reference year 2050, and the (less favourable) scenario of a current climate warming of 2 °C were assessed. The evaluation was done for 17 sites considered to ensure water abstractions and located near potentially problematic areas in terms of drinking water supply. Hydrological and water management balance modelling procedures were applied during the assessment of SWAA capacities. The solution results are shown in *Tab. 2*. A more significant reduction in the capacity to ensure water abstractions due to climate change was evaluated especially at the sites of Čučice, Kladruby, Hradiště, Hrachov I, and Hrachov II. In contrast, a relatively low reduction in capacity was evaluated at the Hoštejn, Hanušovice, Chaloupky and Pěčín sites. With the exception of the Čučice and Kladruby sites, the reduction in capacity compared to current conditions did not exceed 30 % for any site. The results in the form of variant scenarios therefore draw attention to a possible reduction of the improved discharge and an increase in the coefficient of variation, which is an indicator of the fluctuation of the hydrological regime. A more detailed study of the area, including possible water transfers, prospective water needs, etc., is needed to decide whether a given reservoir could help a deficit region.

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Small headwater catchments – spatial delimitation and their classification in terms of runoff risks

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Keywords: hydrological response – small headwater catchments – first order catchments – direct runoff – erosion event monitoring

ABSTRACT

This article presents an aerial delineation of small headwater catchments up to 5 km^2 in the Czech Republic. The aim was not only to present the delineation of these catchments, but also their categorization in terms of the characteristics affecting the formation of direct runoff. Direct runoff caused by torrential rainfall is a very dynamic process of episodic nature and has a major impact specifically in small catchments. The delineation of small headwater catchments, where the aforementioned processes take place, can complement the standard hierarchical classification of basins in the Czech Republic. These basins make up 80 % of the Czech Republic.

The delimited catchments were further classified according to a number of characteristics related to the risk of direct runoff. A cluster analysis was performed in order to classify these catchments. The catchment characteristics that influence the hydrological response were included in the analysis. These are mainly rainfall data, hydro-morphological characteristics of the relevant basin, land use, and soil hydrological characteristics. One negative impact of direct runoff is erosion. Erosion monitoring can be indirectly used as an indicator of the state of a specific area in terms of the occurrence of direct runoff (https://me.vumop.cz). As part of this initiative, which completed ten years of operation in 2022, erosion events are recorded. The database contains more than two thousand records. However, the records within the Czech Republic are inconsistent, which is due to the involvement of branches of the State Land Office (Státní pozemkový úřad, SPÚ). However, it is a relatively extensive evidence of erosion.

INTRODUCTION

River catchments in the Czech Republic are divided into four levels by default. However, the smallest of them, the 4th order basins, are quite different in terms of size – from basins with a size exceeding 20 km^2 to additional basins with an area of less than 1 km^2. Fourth order basins were categorized in terms of their potential hydrological response according to the method described in [1]. Categorization of the 4th order basins in terms of hydrological response is influenced specifically by the different size of the area. Another factor is the combination of headwater (upstream) and flow catchments.

Upper – non-flow catchments form a specific group of catchments, sometimes they are called "first order catchments" [2], other times these catchments are referred to as headwater catchments. These catchments form the basis of the hydrographic network and are the primary areas for capturing or reducing flood damage. Simultaneously, these upper basins provide often diverse ecosystem services to the areas below them [3]. They tend to be very sensitive to changes and are the fastest developing parts of the landscape. For these reasons, planning and management within these areas is a complex task [4]. In the past, a number of authors dealt with the similarities, characteristics and response of basins from different points of view. For example, [5] are motivated to classify basins rather with regard to long-term processes in basins. on a similar principle, basin attributes are defined, classified and shared within CAMELS [6] and others. Data sets are created for basins that describe six main groups of attributes – topography, climate, hydrological characteristics, land cover, and soil and geological data.

There are relatively few verification data of the hydrological response in the Czech Republic. CHMI operates less than twenty observation profiles on small catchments of up to 10 km^2. In addition, the creation of most of these basins was motivated by the monitoring of water in the basins of water supply reservoirs, and thus they are mainly forest basins. Geochemical monitoring of 14 small forest basins is dealt with by the GEOMON project [7]. It is focused primarily on the material composition of precipitation, soil and runoff, but it also records precipitation totals and flow values in the closing profiles. The monitored basins of GEOMON overlap in some places with the basins operated by CHMI. on agricultural land, the number of monitored basins operated by a professionally oriented organization is incomparably smaller, and the time series of data are also significantly shorter.

Practically the only tool for designing objects on small watercourses and modifications in the catchment area are hydrological models. They are most often based on the empirically derived SCS-CN method [8], which is constantly being developed and tested; from recent works, for example [9, 10]. The sensitivity of the method to available data for the Czech Republic was dealt with by Strouhal [11, 12]. By default, design data is provided according to ČSN 75 1400.2014. *Hydrological data of surface waters*. In the lowest class, which includes small catchments, data are also derived using a model based on the SCS-CN method. In addition to this regulation, TNV 75 2102 – *Modification of streams from 2010* states that modelling can be used for proposals for modification of small watercourses in catchments of up to 5 km2. A boundary of 5 km^2 was adopted for the derivation of the upper basins that this article is presenting. For a more detailed description of the runoff response, it is also possible to use physically based models such as SMODERP [13] and EROSION 3D [14].

A specific feature of small catchments is the speed of their hydrological response. The speed of response to causative precipitation and the associated risks are influenced by a number of parameters. The biggest threat in terms of flows and associated risks in these catchments is torrential rainfall. Kašpar [15] recently dealt with the distribution of precipitation in the Czech Republic.

The most frequently used tool for describing rainfall are IDF (Intensity-Duration-Frequency) curves, which describe the relationship between rain intensity, its length and recurrence time [16]. on a global scale, e.g. Courty [17] deals with the distribution of the above mentioned statistical attributes of rain. In addition to the intensity of the precipitation event, its shape also significantly affects the hydrological response at the local scale of small catchments [18, 19].

Other important parameters that influence the runoff response of individual basins include properties of soils, soil cover, and morphological characteristics. The properties of the hydrographic network, described by the number of coefficients, also play a role. The nature of the terrain – morphology – primarily affects the shape of the runoff wave, and thus the overall response of the basin to increased runoff, including soil erosion. There are several parameters for describing the morphology of the basin; the most frequently reported values are the average slope, the length of the slope, and the topographic index [20].

One of the negative impacts of the surface component of direct runoff is erosion. on the scale of source areas from 0.3 km^2 to 10 km^2, the so-called critical points are determined, which are defined as points of entry of concentrated runoff paths into the urban areas [21]. The critical points are determined on the DMR derived from the ZABAGED contour model and the risk rate is determined based on the ratio of arable land, average slope and using CORINE Land Cover. A different approach to the threat not only to the urban areas, but also to other elements of critical infrastructure was assessed within the project VG20122015092 – "*Erosion – increased risk of endangering the population and water quality in connection with expected climate change*" implemented in 2012 and 2015. The resulting map of points is available at https://heis.vuv.cz. In both cases, it is a certain view of the riskiness of the points, which is based on the characteristics of the contributing small headwater catchments, however, these are still model situations. Another perspective can be the recorded occurrence of an erosion event, which is part of erosion monitoring [22] and the map portal (https://me.vumop.cz/). As part of this initiative, which completed ten years of operation in 2022, erosion events are recorded. The database contains over two thousand records. Although the records within the Czech Republic are spatially uneven, which is due to the involvement of branches of the State Land Office, it is nevertheless a relatively extensive record of erosion manifestations.

METHODOLOGY FOR DERIVATION OF CATCHMENT BOUNDARIES AND THEIR CLASSIFICATION

Small headwater catchments (SHC) [23] are so-called non-flow catchments that have no tributaries, and thus correspond to the definition of "first order catchments" [2]. This property was used in deriving their borders in the whole of the Czech Republic based on DMR 4G data at a resolution of 5 × 5 m [24], water courses and water reservoirs. The parameters that influence the hydrological response were subsequently determined for the areas of the basin defined in this way, especially with regard to the possible risk of runoff from short-term extreme rainfall.

Definition of catchment boundaries

SHC according to [23] are not only catchments with a size of only 5 km^2, but also all smaller catchments. This means, for example, that two catchments with a size of 3 km^2 after the confluence already exceed 5 km^2, but separately they are two catchments that fall within the SHC. to define the SHC, six size categories listed in *Tab. 1* were chosen. Basins have been derived for all these classes, which allows their further mutual comparison.

Tab. 1. SHC categories (a range of area sizes was chosen for each category)

Category	From km^2	To km^2
005	0.3	0.7
010	0.7	1.3
020	1.7	2.3
030	2.7	3.3
040	3.5	4.5
050	4.5	5.5

Areas smaller than category 005 can be considered elementary runoff areas and are not evaluated as separate catchments. At the same time, the lower limit of 0.3 km^2 corresponds to the lower limit of the derivation of critical points [21].

To define the SHC, three data sources were used – a digital model of the terrain, watercourse axes, and water reservoir axes. The main input for determining the SHC was the DMR 4G with a resolution of 5 × 5 m. Since in some places the watercourse axes, due to human intervention and changes in the landscape, do not correspond to the runoff lines generated on the terrain model itself, the current watercourse axes that are part of ZABAGED® are included in the solution. These are based on measurements of detailed scales and reflect the current state of the water network. When creating the SHC, these lines are taken as more accurate than DMR-based runoff routing. When deriving basins, these watercourse axes must be included in the solution. Watercourse axes were projected into the DMR. The value of the pixels of the terrain model through which the axis of the watercourse passes has been reduced so that the resulting direction of the runoff corresponds to the axes of the current watercourses. In the following step, any non-runoff areas were removed on the terrain model modified in this way and a runoff routing layer was created. A one-way runoff routing tool (D8) was used to route the runoff. Accumulation in each pixel was then derived from the runoff directions.

For each catchment category (see *Tab. 1*), the accumulation layer was reclassified so that the values of the accumulation area outside the group boundaries have the NoData value and the values of the accumulation area corresponding to the given category the value 1. In cases where the runoff lines classified in this way end or intersect with water reservoirs, the runoff lines were shortened to the point where the drain line crosses the water reservoir. In these cases, therefore, basins at the entrance to water reservoirs are considered. For modified lines in individual categories, the endpoints of these lines were determined, which form the closing profile of the basin. on the basis of the runoff direction derived above, the boundary of the basin was derived for these points, taking into account the axes of the watercourses.

Characteristics of small catchments

The hydrological response from the SHC is determined by its morphological characteristics, soil properties, land use, and causative precipitation. It can be assumed that the hydrological response of similar basins will be similar. Therefore, for the above SHC categories, parameters were derived for their classification in terms of possible hydrological response.

The morphological characteristics were determined based on the model of the terrain and watercourses. In particular, these are the characteristics of altitude, slopes and length of runoff paths, as well as several shape coefficients.

Average width of the basin

$$b = \frac{A}{L} \tag{1}$$

where A is the area [m^2]

L maximum length of the runoff path [m]

Basin shape

$$\alpha = \frac{A}{L^2} \tag{2}$$

where A is the catchment area [m^2]
L maximum length of the runoff path [m]

Shape coefficient according to Gravelius [25]

$$gra = \frac{O}{2\sqrt{A \cdot \pi}} \tag{3}$$

where O is the circumference [m]
A area [m^2]

All three shape coefficients describe the shape of the basin. In the case of Gravelius coefficient, it is a comparison of the shape of the basin to a circle. The average width and shape coefficient of the basin determines the extent to which the shape of the basin departs from a square, or its power.

The standard description is the parameter of the water network density. This parameter determines the ratio of the total length of watercourses to the catchment area.

$$SND = \frac{\Sigma L_T}{A} \tag{4}$$

where L_T is the length of the watercourse [m]
A area [m^2]

One of the parameters that are influenced by the morphology and affect the course of the runoff is the time lag (T_{lag}). The T_{lag} value is used to describe the unit hydrograph according to the SCS-CN method [26]. T_{lag} is then calculated using [27].

$$T_{lag} = L^{0,8} \cdot \frac{(S+1)^{0,7}}{1900 \cdot \sqrt{Y}} \tag{5}$$

where T_{lag} is the time lag [hours]
L length of the longest runoff path [foot]
Y average slope of the basin [%]
S maximum potential retention [inch]

The direct runoff volume potential of a given basin can be described by the average value of CN. CN integrates information about surface properties and soil infiltration properties. In the example given here, the CN values are taken from the derivation within the *Strategy of protection against the negative effects of floods and erosion phenomena by semi-natural measures in the Czech Republic* [28].

The last group of parameters is precipitation data. Since short-term precipitation is the dominant source of runoff in small headwater catchments, six-hour design precipitation derived from rain radars with a spatial resolution of 1 × 1 km were selected [19, 15]. These data are available at rain.fsv.cvut.cz.

Tab. 2 includes an overview of monitored parameters. These are values describing the mean value, variance, and minimum or maximum value, depending on the type of parameter.

Tab. 2. List of parameters that enter the SHC cluster analysis. Parameters 1–16 were derived from DMR and vector lines of water courses, catchment slope was derived using unconditioned DMR. Parameters 20–24 derived according to Eq. (1–4)

1	P	Periphery
2	A	Area
3	E_M	Elevation mean – average altitude of the basin
4	E_{STD}	Elevation STD – altitude deviation, describes the flatness of the basin
5	Fa_M	Mean accumulation
6	Fa_{STD}	Fl_acc_STD – runoff accumulation deviation
7	Fl_X	Fl_len_max – maximum length of the runoff path
8	Fl_M	Fl_len_mean – mean length of the runoff path
9	Fl_{STD}	Fl_len_STD – standard deviation of the length of the runoff path
10	Fs_X	Fl_len_noStream_max –maximum length of the runoff path of the surface runoff
11	Fs_M	Fl_len_noStream_mean – mean length of the runoff path of the surface runoff
12	FS_{STD}	Fl_len_noStream_STD – standard deviation of the runoff path of the surface runoff
13	Sl_M	Slope_mean – mean slope
14	Sl_{STD}	Slope_STD – standard deviation
15	S_M	Slope_stream_mean – mean slope of watercourses
16	S_{STD}	Slope_stream_STD – deviation of the slope of watercourses
17	L_T	Total stream length – total length of watercourses
18	CN_M	Mean CN of the basin
19	CN_{STD}	CN_STD – standard deviation
20	b_M	Mean basin width
21	α	Shape coefficient alpha
22	gra	Gravelius coefficient – shape coefficient
23	SND	Stream network density
24	T_{lag}	Time lag
25–28	P_{xx}	Six-hour draft rainfall with recurrence periods of 2, 10, 20, and 100 years

In total, there are 28 parameters that were subsequently tested in all size categories in terms of mutual dependence using regression analysis. The aim was to obtain a set of independent parameters and classify the basins into groups according to their similarity using cluster analysis.

Delineation of small catchments, assignment and calculation of characteristics from the DMR, and CSC-CN basins was processed in the ESRI environments (ArcGIS and ArcGIS Pro), subsequent statistical analyses were processed in the R environment. Descriptive statistics and regression analysis tools were used for the solution. Cluster analysis was performed using the K-mean method. The individual clusters were subsequently aggregated in terms of the relative riskiness of key parameters to create the direct runoff component into five risk classes. The verification was carried out using recorded erosion events. The aim was to monitor whether the classification of the basin in terms of risk coincides with the location of erosion events.

RESULTS

SHC definition

Basic data on SHC derived according to the methodology described above are shown in *Tab. 3*. As the SHC categories are always derived separately, the resulting catchments overlap between the categories – a smaller catchment may be part of a larger one in the parent categories. Therefore, in addition to the described categories, a group of basins was created in which only the largest basins are preserved. Interconnected catchments have been eliminated. In this way, catchments smaller than 5 km^2 in the monitored area of the Czech Republic are preserved. This group of catchments is referred to as "Set of Largest Catchments" – "SoLC" and is also listed in *Tab. 3*. For clarity, it is added how much representation individual size categories have in the resulting SoLC group; the table contains data on the number of elements of the given category that are part of it. The representation of the areas of individual catchment categories in the SoLC group is shown in *Fig. 1*.

Tab. 3. Number and the total area of catchments in each category. For individual categories (1st column) the number of elements (2nd column) and the total area of the given class (3rd column) are given. The 4th and 5th columns show the representation of the elements of the given class in the SoLC class and the per-centage expression

			Representation of elements in SoLC	
Category	**Number of elements**	**Total area [km²]**	**Number**	**[%] elements in the SoLC class**
005	72,621	37,632	16,894	23
010	31,287	33,046	10,907	35
020	11,560	24,179	3,938	34
030	6,530	20,289	2,187	33
040	5,431	22,610	2,271	42
050	3,957	20,479	3,957	100
SoLC	40,154	63,031		

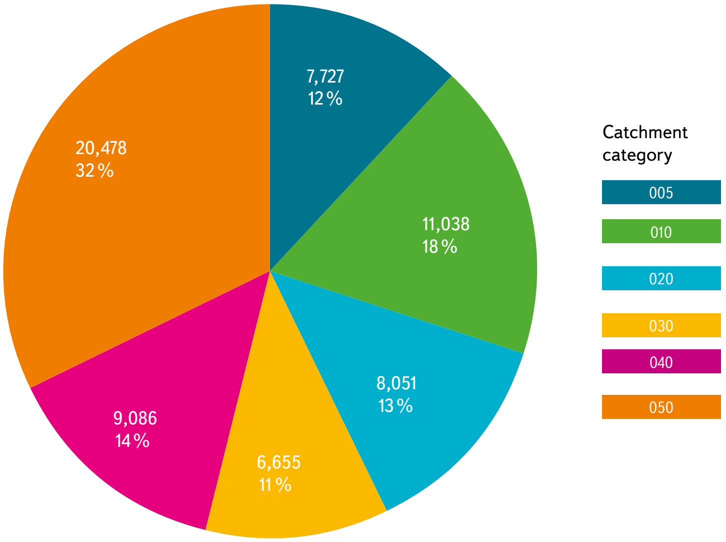

Fig. 1. Summary of the area of the catchments in SoLC categories

Selection of parameters

For individual basins in all size categories, parameters were derived according to *Tab. 2*. For the needs of cluster analysis, representative and independent parameters are sought in the first step. Dependent parameters must be discarded. The search for the degree of agreement between monitored parameters was carried out both for individual categories (including SoLC) and for all basins together. From the point of view of the groups of dependent parameters, the individual categories do not differ from each other. It is therefore the fact that the links between monitored parameters are similar for all size categories. A visually adjusted parameter match calculated using Pearson's correlation coefficient is in *Fig. 2*.

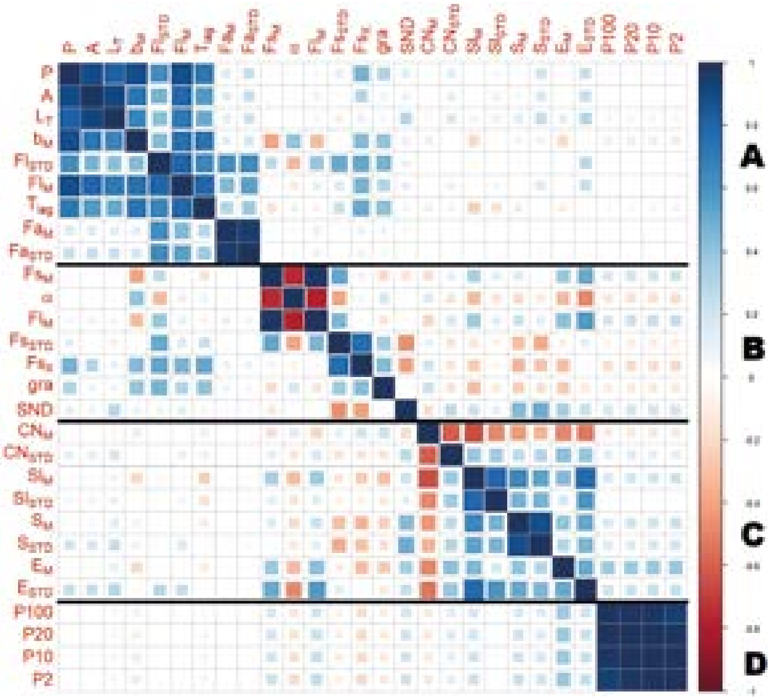

Fig. 2. Visualization of the correlation between individual parameters for all catchments regardless of size category. A negative correlation is shown in red, and a positive correlation is shown in blue. The stronger the bond between two parameters, the darker and larger the symbol. Similar parameters are grouped together to visualize groups of similar parameters A to D [29]

Five parameters were chosen from groups of elements grouped according to their mutual dependence, which can be considered independent and sufficiently representative. Appropriate representative parameters were selected using principal component analysis (PCA), namely:

- *Six-hour draft rainfall with a 20-year recurrence period (P_{20})* – parameter representing group D. There is a significant correlation between individual six-hour rainfall values due to the derivation of this data.
- *Mean CN of the basin (CNM)* – parameter represents group C of several other parameters. The CN value shows agreement with both inclination and altitude.
- *Time lag (T_{lag})* – this parameter characterizes group A. It affects the shape of the runoff hydrograph, and thus the size of the peak flow.
- *Stream network density (SND)* – is a parameter that represents the proportion of the length of all watercourses in the basin and the area of the basin. Together with the *shape coefficient alpha* (α), they include both the characteristics of the length of the runoff paths and the shape of the basin. These two parameters together represent group B.

The stream network density (SND) and shape coefficient alpha (α) parameters are jointly correlated with the surface runoff path standard deviation (FS_{STD}) parameter. The SND is also related to the slope characteristics and the parameter α is related to the altitude. At the same time, SND directly describes the characteristics of the watercourse network. For this reason, these two parameters were used.

Distribution of parameters

To classify basins into groups in terms of potential response, it is important to compare the distribution of classification parameters between individual basin categories. If the chosen classification parameters had a different distribution for individual groups of basins, it would mean that different size categories have a different character of the hydrological response to precipitation. The aim was to compare the differences between individual size categories. Article [29] deals with this issue in more detail.

Since the parameter distribution differences between categories are not significant and do not differ from SoLC, cluster analysis was performed only on the SoLC group, in which all size categories are represented by at least 20 %. Cluster analysis using the K mean method was performed in the R environment, in the range of clusters from two to eight with a setting of 25 initial training points. Each catchment in the SoLC was assigned to a group according to five selected parameters each time the clusters were created. The formation of individual groups of basins is described in *Fig. 3*. The groups are marked with letters. If a group is formed only by separating from a previously formed group, a numerical designation is added.

The groups formed during the gradual creation of clusters can be characterized by the following description. The geographical clustering is then shown in *Fig. 4*.

- 2 Clusters – When creating the first two clusters, group a is formed, which is characterized by a higher CN_M with a lower volume of precipitation P20. Group B is characterized by higher precipitation P_{20} and a larger CN_M value (*Fig. 4a*).
- 3 Clusters – Group a is divided primarily in terms of shape characteristics of the basin, in terms of stream network density (SND) and in terms of lag time (T_{lag}) (*Fig. 4b*).
- 4 Clusters – From group B, group B1 is separated, which is characterized by lower precipitation P_{20} while maintaining a lower CN_M value, and, on the contrary, group B2 with higher precipitation totals P_{20} and a higher CN_M value (*Fig. 4c*).
- 5 Clusters – Group A1 divides dominantly based on time lag. The resulting A12 group is characterized by a significant time lag (T_{lag}), while the A11 group retains the original characteristics of A1 group. Groups A11 and A12 defined in this way are then preserved even after dividing the basin into several clusters (*Fig. 4d*).
- 6 Clusters – a completely new group D is formed, which is characterized by a relatively high SND as well as relatively low precipitation totals P20 while maintaining a relatively high CN_M value. The group D created in this way remains even after dividing the basin into several clusters (*Fig. 4e*).
- 7 Clusters – Group B2, which is characterized by relatively high precipitation P_{20}, is widely divided. Together with part of the basin from group A2, it forms a new group C, which is characterized by relatively higher precipitation totals and, at the same time, higher CN_M values. Part of the catchment from the original

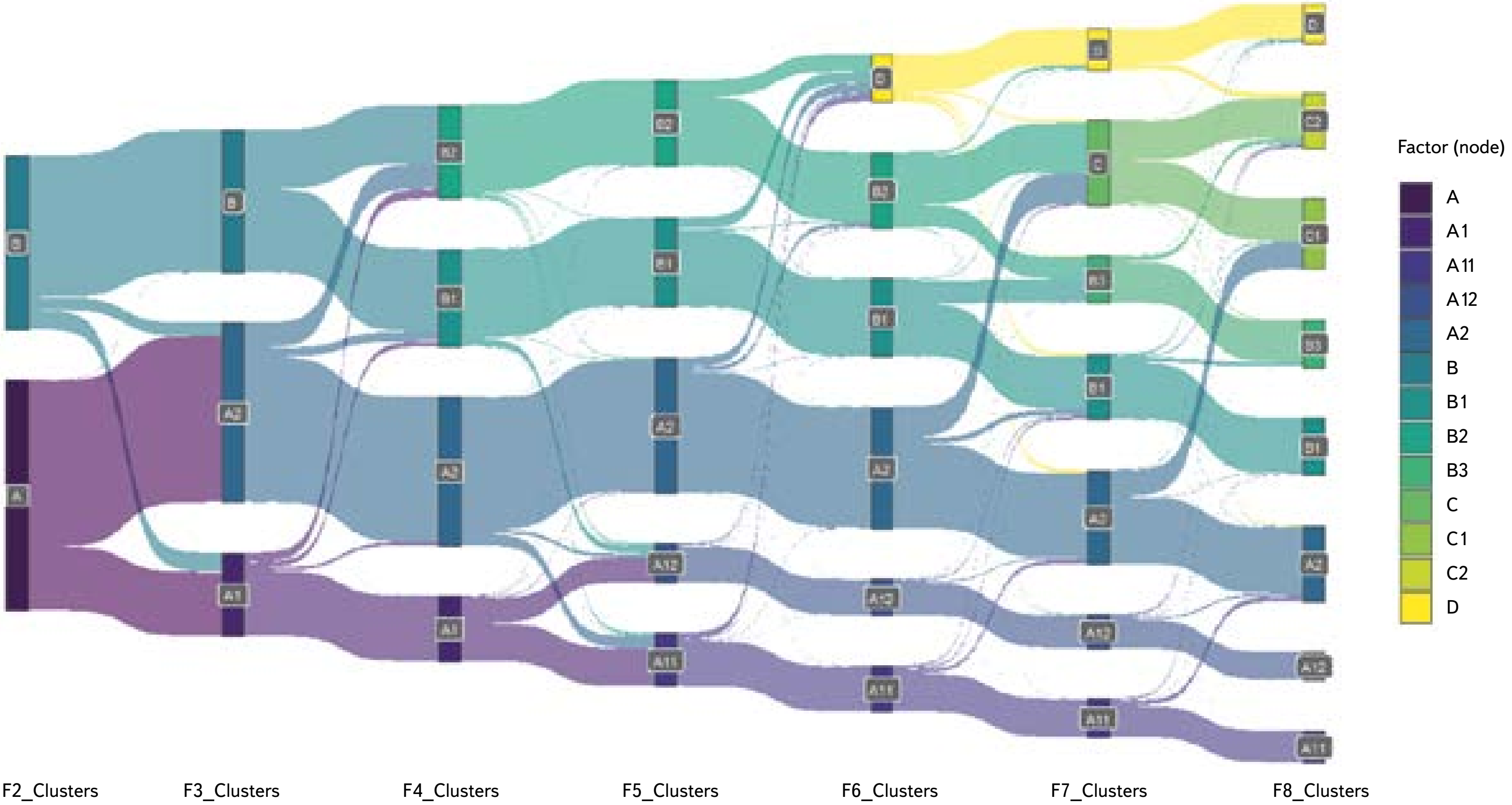

Fig. 3. The Sankey diagram shows the evolution and regrouping of SoLC classes with increasing number of clusters. The number of elements in a given group corresponds to a belt. At the same time, the diagram shows how individual watersheds are oversubscribed according to the number of clusters. The basic division is already visible in the formation of two clusters (A, B). From the number of clusters six to the development of groups that are created by combining the basic division into A, B and subgroups. At six, group D is formed, which is a combination of all previously formed groups. With the number of clusters 7 and 8, groups C are created, which are a combination of parts of groups A2 and B2 [29]

group B2 and part of the catchment from group B1 form group B3, which maintains similar parameters to the original group B2. The number of basins from the original group B2 is so small that the group is renamed B3 (*Fig. 4f*).

- 8 Clusters – There is a redistribution within the newly created group C into groups C1 and C2. The newly formed group C1 is also made up of a part of the catchment area of group A2 and is characterized, like the original group C, by higher values of P_{20} and CN_M. It is distinguished from group C2 by the difference in the SND and (α) parameters; this division no longer brings new information to the basin classification.

The gradually formed groups of basins are characterized by the mean values of the selected five parameters mentioned above. Parameters and cluster analysis are discussed in more detail in article [29].

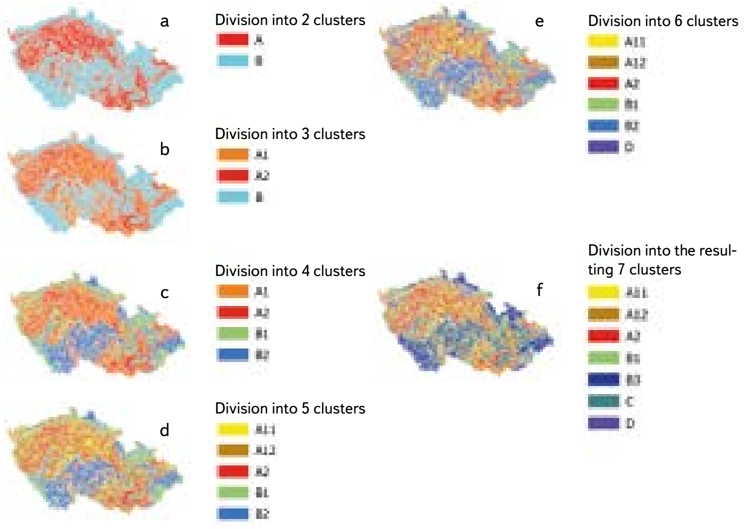

Fig. 4. Geographical representation of group evolution when forming clusters from two (a) to seven (f)

The created basin clusters are further classified according to the possible risk of direct runoff. From the point of view of the influence of the parameters on the risk associated with the emergence of direct runoff, the following applies for individual parameters:

- SND – The higher the value, the denser the permanent water network, any runoff will tend to concentrate in these paths where the runoff is expected. A larger value therefore means a lower level of risk.
- T_{lag} – The longer the time lag, the lower peak flows can be expected.
- α – The more complex the shape of the catchment area, the more the runoff paths are lengthened, and thus also the culmination is reduced.
- CN_M – The smaller the mean CN value, the greater the retention rate in the basin and the lower the potential risk of threat.
- P_{20} – The higher the rainfall, the higher the risk of possible runoff response.

For individual parameters, a mean value was calculated in the SoLC category, which is taken as medium risk. The degree of risk was determined for individual parameters relative to this mean value of the given parameter. For each value of the parameter corresponding to the centre of gravity of the individual clusters, the proportion with this mean value was determined, thereby determining the riskiness of each parameter in the given cluster. Those combinations of five parameters are considered at risk where a negative assessment prevails, and vice versa. The level of overall risk is divided into five categories from low to high risk as described below:

- Low risk – the combination of possible runoff response parameters assumes a low risk in terms of direct runoff affecting the basin. These areas appear to be unproblematic from a direct response point of view and the need for measures in these areas is not anticipated.
- Reduced risk – the combination of possible runoff response parameters assumes a rather small risk in terms of affecting the catchment area by direct runoff. These areas are unproblematic from the point of view of direct response and taking measures in these areas is not needed.
- Medium risk – the combination of possible runoff response parameters is average and a medium level of risk is assumed in terms of direct runoff affecting the catchment.
- Increased risk – the combination of possible runoff response parameters presupposes a greater degree of risk in terms of affecting the catchment area by direct runoff.
- High risk – the combination of possible runoff response parameters assumes a high risk in terms of direct runoff affecting the basin. In these areas, a more detailed investigation and monitoring of the possible negative impact of the risk caused by direct runoff should be carried out.

The parameter values for determining the risk level are shown in *Tab. 4*.

Tab. 4. Individual parameters used to express the degree of risk in relation to the mean values of the parameters

Risk	**Low**	**Reduced**	**Medium**	**Increased**	**High**
Risk coefficient	**< 0.85**	**< 0.95**	**< 1.05**	**< 1.15**	**> 1.15**
SND	1.19	1.09	1.03	0.98	0.88
$\mathbf{T_{lag}}$	3.75	3.43	3.26	3.10	2.77
α	4.29	3.92	3.73	3.55	3.17
$\mathbf{CN_M}$	58.5	65.4	68.9	72.3	79.2
$\mathbf{P_{20}}$	42.8	47.8	50.3	52.8	57.8

The classification of the groups of catchment areas of the cluster analysis according to the level of risk is shown in *Tab. 5*, where groups from the number of clusters 2–8 are included.

The geographical expression of the level of risk is then shown in *Fig. 5*. Groups A2 and C together form a group with a high risk, groups A11, B1, B3 a group with a medium risk, and A12 and D a group with a lower risk.

The classification of small catchments in terms of the risk of direct runoff is expressed relatively between individual parameters. A certain validation criterion of the results can be a comparison of the classification according to the degree of risk with recorded erosion events in the Monitoring of agricultural soil erosion. Monitoring has been ongoing since 2012, and by the end of 2021, over 2,200 erosion events have already been recorded [30].

The intersection of the affected land listed in the monitoring with the boundaries of the defined small catchments is shown in *Fig. 6.* to assign the event to the relevant basin, the centre of gravity of the polygon delimiting the recorded event was taken.

Of the total number of 2,220 recorded events until 2021, half of them were in high-risk catchments. Most of the recorded erosion events are recorded in Vysočina Region and South Moravia. In other regions, where erosion events are not recorded, it is more about the completeness of the database of erosion events than about parts of the Czech Republic without occurrence of events.

Tab. 5. Development of the risk classification of catchment groups produced by cluster analysis

Number of clusters		Relative risk of individual parameters					Average	Risk
		SND	T_{lag}	α	CN_M	P_{20}		
2	A	1.68	1.07	0.92	1.09	0.95	1.14	increased
	B	0.65	0.92	1.14	0.88	1.07	0.93	reduced
3	A1	0.90	0.67	0.68	1.05	0.95	0.85	low
	A2	1.93	1.30	1.09	1.09	0.96	1.27	high
	B	0.65	0.99	1.20	0.86	1.08	0.96	medium
4	A1	1.02	0.65	0.65	1.06	0.94	0.86	reduced
	A2	2.31	1.29	1.09	1.10	0.93	1.35	high
	B1	0.79	0.94	1.19	0.78	0.99	0.94	reduced
	B2	0.61	1.11	1.07	1.03	1.16	0.99	medium
5	A11	1.14	1.06	0.60	1.09	0.94	0.97	medium
	A12	0.97	0.46	0.91	1.00	0.94	0.86	reduced
	A2	2.31	1.30	1.15	1.10	0.94	1.36	high
	B1	0.79	1.02	1.20	0.78	0.99	0.96	medium
	B2	0.60	1.12	1.08	1.02	1.16	1.00	medium
6	A11	1.56	1.05	0.59	1.08	0.95	1.05	medium
	A12	1.03	0.45	0.91	1.00	0.94	0.87	reduced
	A2	2.92	1.30	1.14	1.10	0.93	1.48	high
	B1	0.89	1.00	1.22	0.76	1.01	0.98	medium
	B2	0.79	1.11	1.10	1.02	1.19	1.04	medium
	D	0.41	1.15	0.99	1.02	0.95	0.91	reduced
7	A11	1.48	1.02	0.57	1.09	0.95	1.02	medium
	A12	1.00	0.45	0.90	1.01	0.96	0.86	reduced
	A2	2.59	1.23	1.10	1.11	0.89	1.38	high
	B1	1.10	1.04	1.10	0.79	0.93	0.99	medium
	B3	0.63	0.95	1.37	0.81	1.19	0.99	medium
	C	1.24	1.27	1.10	1.09	1.11	1.16	high
	D	0.39	1.15	0.95	1.03	0.98	0.90	reduced
8	A11	1.43	1.01	0.55	1.09	0.96	1.01	medium
	A12	1.03	0.43	0.90	1.00	0.95	0.86	reduced
	A2	2.11	1.13	0.98	1.11	0.86	1.24	high
	B1	1.18	1.03	1.07	0.78	0.92	1.00	medium
	B3	0.67	0.96	1.44	0.79	1.17	1.01	medium
	C1	2.83	1.43	1.32	1.10	1.04	1.54	high
	C2	0.74	1.06	0.93	1.08	1.16	0.99	medium
	D	0.39	1.16	1.01	1.00	0.95	0.90	reduced

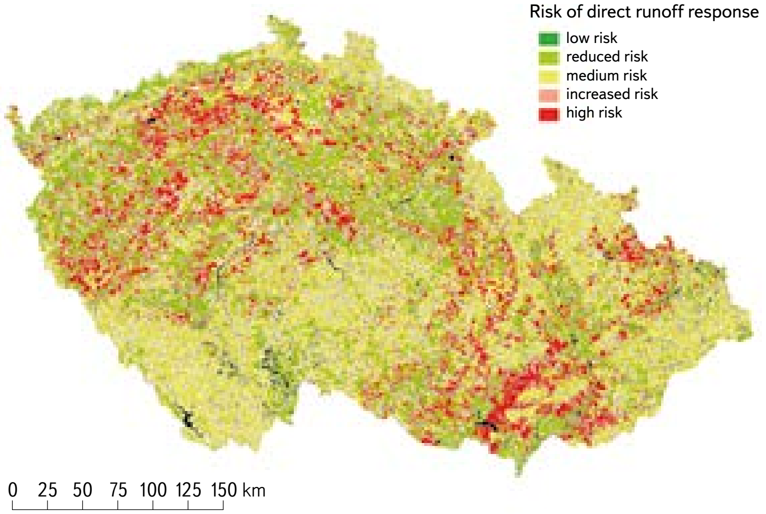

Fig. 5. Distribution of the area of the Czech Republic according to the identified level of risk in the case of dividing the basin into seven clusters

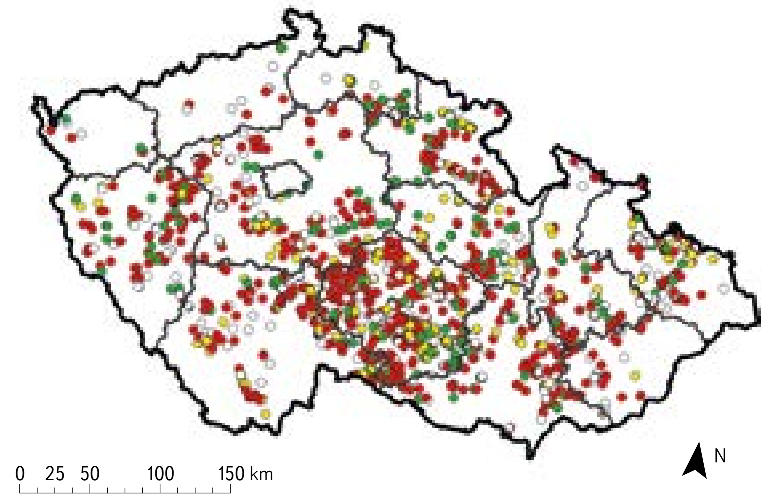

Fig. 6. Recorded erosion events with the risk level of the respective SoLC indicated (high risk in red, medium risk in yellow, reduced risk in green, events outside the SoLC in white)

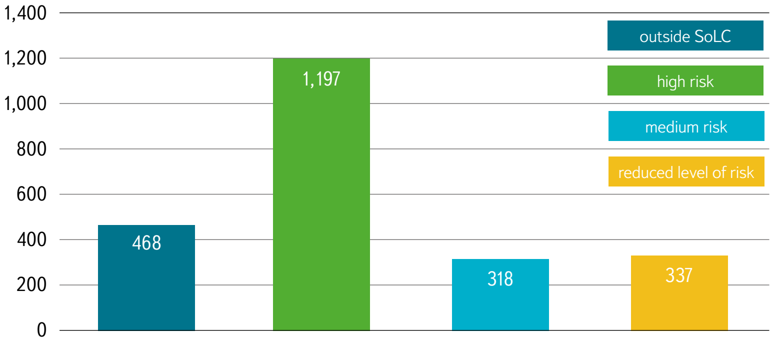

Fig. 7. Number of recorded erosion events in monitoring classified by SoLC risk

DISCUSSION

Basin classification is more commonly used in experimental hydrology. Basins are also classified in the expanding CAMELS database. In these cases, the list of parameters is larger. In contrast to the selection of parameters presented here, it includes hydrological data of long-term balances and parameters that affect long-term runoff and other components of the balance [6]. In most cases, it monitors larger basins. Long-term series of observations in small basins are significantly less frequent than in larger basins. The small catchments presented here bring information about the upper non-flow basins to the standard classification. At the same time, these upper catchments are classified according to key characteristics affecting the direct component of runoff.

Input data with different spatial resolutions were used to create basin boundaries and their properties. The delineation of the basin boundaries was created on the basis of a terrain model with a resolution of 5 × 5 m, which is sufficiently detailed even for the delineation of small catchments in the considered size category 005. Based on the terrain model, other morphological characteristics were then derived at the same resolution. When using the D8 method at a lower resolution, the creation of basin boundaries could be affected, especially for the smallest category.

The parameters that enter the cluster analysis do not differ significantly in terms of the distribution of values between the categories. Smaller basins are also part of larger basins and together they form SoLC, where at least 20 % of the number of basins from each category is represented. The total area of the upper basins included in the SoLC is 63,000 km^2, which is about 80 % of the area of the Czech Republic (78,000 km^2).

Several of the 28 parameters considered are mutually correlated. The first group (A, see *Fig. 2*) of mutually correlated parameters are the geometric parameters of the basin (size, area, runoff path length, runoff accumulation) with T_{lag}. The shape coefficients (group B) are linked in a mutual correlation with the SND and the length of the runoff paths outside the watercourse. From this group, the parameters SND and α are the least interconnected. Another important group (C) is the intercorrelated parameters describing the slope ratios of the basin, the slopes of the watercourses, the altitude in relation to the land use and soil characteristics of the CN_M. This connection corresponds to the use of land in mountainous, mostly steeper sloping areas, which are mainly forested. A separate group of parameters is precipitation (D), which have a mutually strong link. They do not show a significant link with the other parameters.

From the point of view of response and, possibly, from the point of view of the risk of increased flows, mainly short-term rains are key in small headwater catchments. The occurrence of a flood and possible threat is a combination of the current conditions of the basin and the course of the causative precipitation. Especially short-term torrential rains are difficult to predict. However, it is a fact that two differently classified basins, which will have the same initial state and will be loaded with the same rainfall, will have a different response to causative rainfall. The classification of basins according to parameters has a practical impact on possible prioritization in terms of the implementation of measures.

The subsequent cluster analysis of the basins from the point of view of their hydrological response shows that, according to the selected parameters, there is a basic division of the basins into two groups, in which the categories A2 and B2 are gradually separated, which according to their parameters fall into the group with the risk of increased runoff from torrential rains. Above all, risk group C is then separated from these two groups. The independently created group D is created from the previously created groups a and B, and the basins with the lowest risk in terms of threat are separated within it. The creation of two clusters C1 and C2 from group C and partly from group A2, with a total number of clusters of eight, no longer brings new information in terms of possible threat. For the classification of SHCs in terms of their potential threat, it is therefore appropriate to classify them into seven clusters.

Clusters of small catchments were assigned a risk level value on a five-point scale. When divided into seven clusters, the lowest risk is in group A12. Together with D, it falls into the "reduced risk" category, however, it is on the borderline of values for inclusion in the "low" category. Groups A11, B1 and B3 have a medium risk. High risk A2 and C, where A2 is the highest risk of all groups and C is on the borderline for inclusion in the "increased risk" group.

Some validation of the resulting risk can be done by comparing the locations of the actual observed erosion events and the boundaries of the resulting SHC. The result shows that more than half of the recorded events are in the high risk class. Less than 15 % are in the medium and reduced risk classes, and 20 % of the recorded events are on land outside the SoLC, i.e. in inter catchments.

CONCLUSION

The presented derivation and subsequent classification of SHC (small headwater catchments) from the point of view of the level of threat bring insight into their possible hydrological response. It can be said that up to the number of five clusters, the primary division into two groups a and B is preserved, which are already created during the creation of the first two clusters. In both, two groups are gradually formed, which are rather risky. We can consider seven clusters a sufficiently explanatory classification of SHC, where both group D (a very low risk), consisting of elements of groups a and B, and a group C (very threatened) by delineation from groups A2 and B2, will be formed. With seven clusters from the area of the Czech Republic, this approach assesses 28.5 % of the area as at risk, 29.4 % of the area with medium risk, 22 % with below average risk, and 20 % of the area of the Czech Republic is not assessed – it does not fall into the SHC category.

Headwater catchments cover a significant part of the Czech Republic. With the selected limit of up to 5 km^2, the SoLC (Set of Largest Catchments) make up about 80 % of the Czech Republic. SHC are a space for the primary accumulation of rainwater. At the same time, these basins are most affected by direct runoff, which subsequently reduces the availability of water in their area. The classification of small headwater catchments in terms of potential threat from torrential rains is one of the possible perspectives. Another use of the spatial delineation of these basins can be subsequent classification, for example, from the point of view of water availability for irrigation, or the application of other adaptation measures with expected climate change.

Within the Czech Republic, it is possible to consider the agriculturally used parts of South Moravia and the western part of the Bohemian-Moravian Highlands and north-western Bohemia to be more at risk. Alternation of high-risk and lower-risk basins is also typical in these areas. The region of South Moravia and Western Bohemia is a typical agricultural landscape. Areas with medium risk are mainly mountainous (Šumava, Krkonoše, Jizerské hory, Jeseníky), which are characterized by increased precipitation totals, the impact of which is reduced by increased afforestation. This group also includes the Beskydy Mountains and northern Moravia. The Ore Mountains fall within an area with a lower risk, which is due to lower precipitation totals. Areas with a lower risk include foothill areas, with the exception of Orlické hory foothills and south-western Pilsen Region, which fall within areas with an increased risk. The largest area of the basin with a reduced risk is Polabí, partly Třeboň Region, and the hilly areas of Brdy and western Bohemia.

Derived boundaries of small catchments are available as a web service on the rain.fsv.cvut.cz portal.

Acknowledgements

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Modelling flow distribution in inlet galleries

JIŘÍ PROCHÁZKA

Keywords: flow distribution — CFD — Flow 3D — inlet galleries

ABSTRACT

The main objective of the article was to optimize the facilities used to distribute flows in inlet galleries, which are used not only in water treatment plants, but also in wastewater treatment plants (WWTP). While working in the field of WWTP, it was found that there are no optimized facilities in the Czech Republic or globally for uniform distribution of flows to any number of inlet branches into reservoirs of the same flow rate. Currently, in most unregulated facilities, there are significant differences between the various inlet branches to the reservoirs. In regulated facilities, the outlets must be regulated at each change in flow rate and, for changes in the number of inlets to the reservoir (e.g., due to reservoir shutdown), each outlet must be manually adjusted (e.g., using a sluice gate) so that all inlets to reservoirs have the same flow rate. In more modern cases, the sluice is equipped with an electric motor for changing the position and a probe sensing the level. The central unit then calculates the flow rate in the individual reservoir inlets and adjusts the position of the sluice gates so that the same flow rate is achieved everywhere. The objective of the research was to optimize the distribution facility so that the inlets to the reservoirs reach similar values for the flow rate when both the inflow to the distribution facility and the number of inlet branches to the reservoirs are changed, without significant regulation at the distribution facility. In order to make the research easily applicable to as many distribution facility as possible, the most commonly used flow distribution facilities (fountain spillway, flume with outlets fitted with a sluice gate and probe for level monitoring, etc.) were selected to address the issue. Different flow conditions were simulated on the selected facilities (in different variants and shapes); after their analysis the facilities were optimized in order to achieve the most similar flows at the inlets to the individual reservoirs.

INTRODUCTION

This article presents a CFD (Computational Fluid Dynamics) model of a selected facility distributing flows at a WWTP. This facility was chosen because it is one of the most used at the WWTP. The facility divides the flow from the aeration tanks into four reservoirs. Observations during operation showed that the flow is not evenly distributed – there are significant differences between the inlets to individual reservoirs.

Single-phase flow with pure water was simulated on the model. Air bubbles and sludge flocs were not included. The sensitivity analysis showed some influence of the inflow turbulence characteristics on the final results. Since the inflow comes directly from the aeration tank with fine bubble aeration, the determination of turbulence is very difficult. All results are from the uncalibrated model.

Since the flows to be simulated were not explicitly specified, the following flows were chosen:

Tab. 1. Simulated flows

Description	**$0{,}75 * Q_{24}$**	**Q_{24}**	**$0{,}5 * Q_{max}$**	**Q_{max}**
Flow [l/s]	377.2	565.8	3,000	6,000

The geometry of the model was set according to the available drawings of the most used facilities at the WWTP. A 10 m long section of the aeration tank was simulated together with the flow distribution structure in order to achieve a fully developed flow field at the beginning of the flow distribution structure [1].

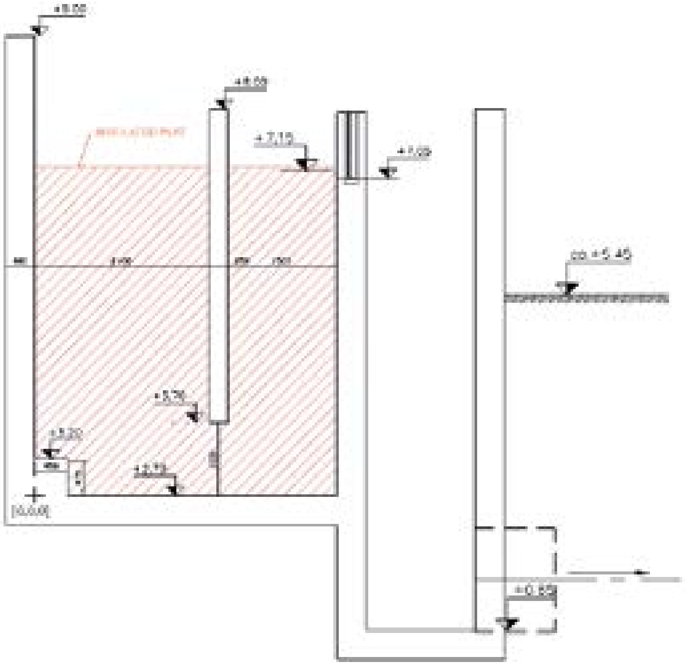

Fig. 1. CFD model – cross section – simulated part marked in red

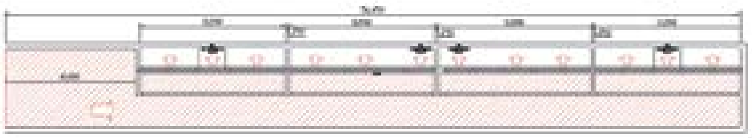

Fig. 2. CFD model – floor plan – simulated part marked in red

METHODOLOGY

Before any simulation, it is important to have a general understanding of how the structure works and to establish the most important phenomena taking place there. Flow distribution facilities are usually based on outlet openings. The overflow velocity of the outlet opening is determined by the hydraulic elevation in front of it. Therefore, if openings of the same length have the same overflow height, the flow rate must be the same. However, even a small change in water level causes large differences between the flows.

And that is the problem with this facility. The channel, which distributes the flow to the four outlet openings, is quite long and a backflow is formed along it. The water level in the facility will therefore not be constant. The openings in the bed that drain the water into the reservoirs are relatively large and therefore do not contribute to an even distribution of the flow.

Water levels at the facilityt

Four different simulations of the distribution facility with different flow rates were performed. The results show that the above considerations are correct. At the beginning of the channel, the water level drops. As the water flows from the aeration tank into the narrow channel of the distribution facility, the velocity gradient increases and therefore the water level must drop. Further along the channel, part of the water flows through side openings into the reservoirs, the flow rate decreases and the water level increases [2].

The model shows this at all flow rates. At low flow rates (377 and 566 l/s) the difference is so small that this effect is only theoretical and in reality the more significant difference in water level is caused by other factors (waves, wind). However, at high flow rates (3,000, 6,000 l/s), this effect is quite significant. This is shown in the following figures (*Fig. 3–7*). The colour scale shows the difference between the constant level approximation and the simulated water level in metres.

All described effects can be seen even better in *Fig. 7*. The height of the water level is shown in metres.

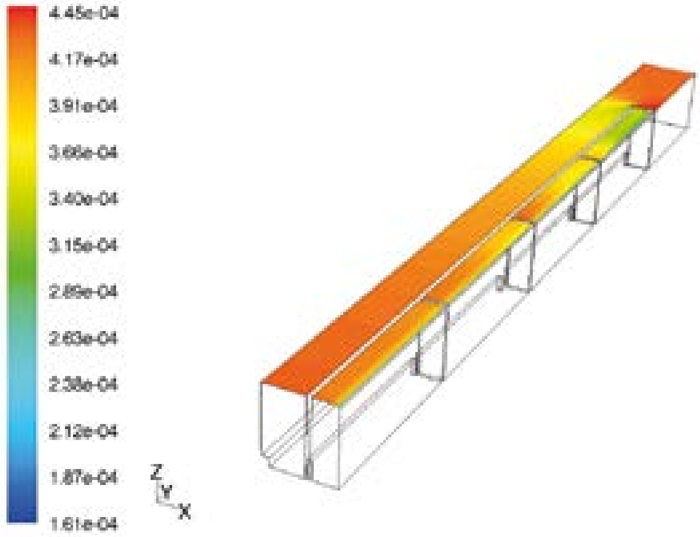

Fig. 3. Simulated water level difference Q = 377 l/s

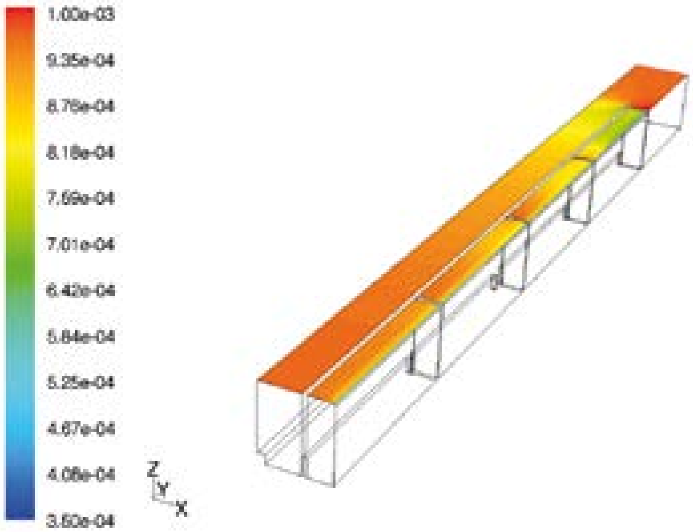

Fig. 4. Simulated water level difference Q = 566 l/s

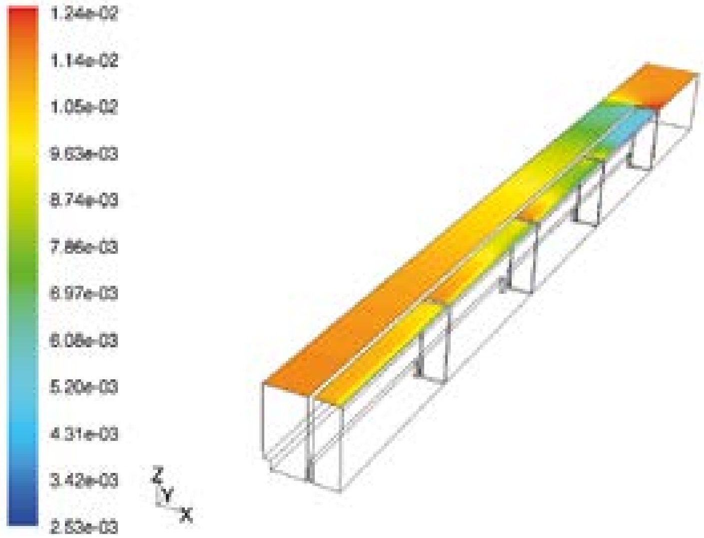

Fig. 5. Simulated water level difference Q = 3,000 l/s

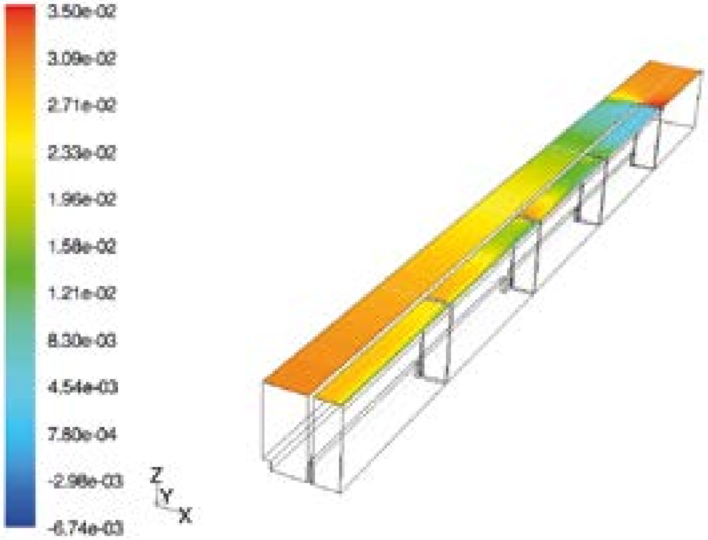

Fig. 6. Simulated water level difference Q = 6,000 l/s

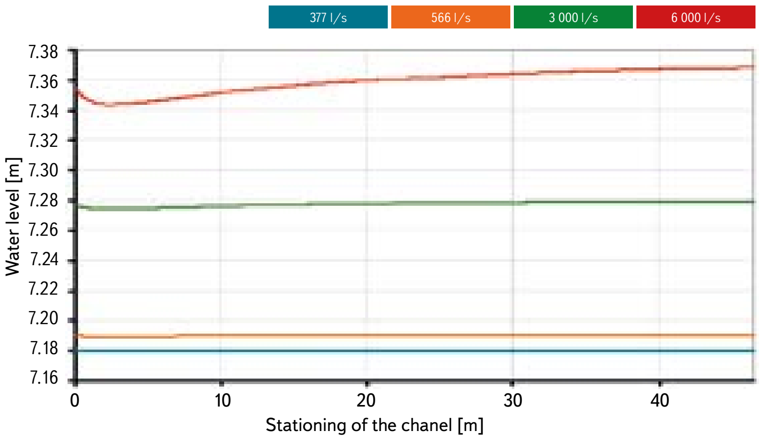

Fig. 7. Simulated water level in the flow distribution object

RESULTS

Fig. 8–11 show the contours of the simulated flow velocities in the channel cross-sections and in the openings, which can give some idea of the general flow pattern.

At the beginning of the channel, the flow narrows quite significantly. It means that the first half of the first opening is not fully utilized hydraulically. This is again more important under high flow conditions. This effect could actually be less significant than in the model because there is high turbulence in the aeration tank, which is difficult to assess in the model.

The colours represent the overall velocity. Therefore, the velocity in the last opening is the lowest. The "y" component of the velocity is quite significant in the first three openings [3].

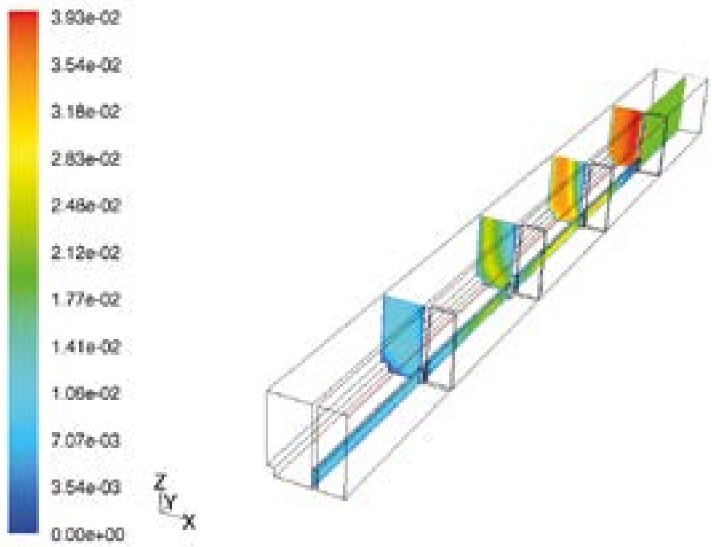

Fig. 8. Flow velocity contours Q = 377 l/s

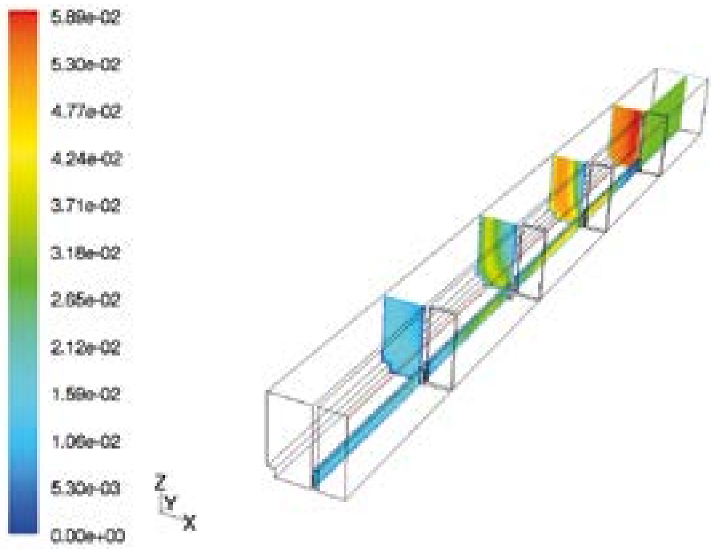

Fig. 9. Flow velocity contours Q = 566 l/s

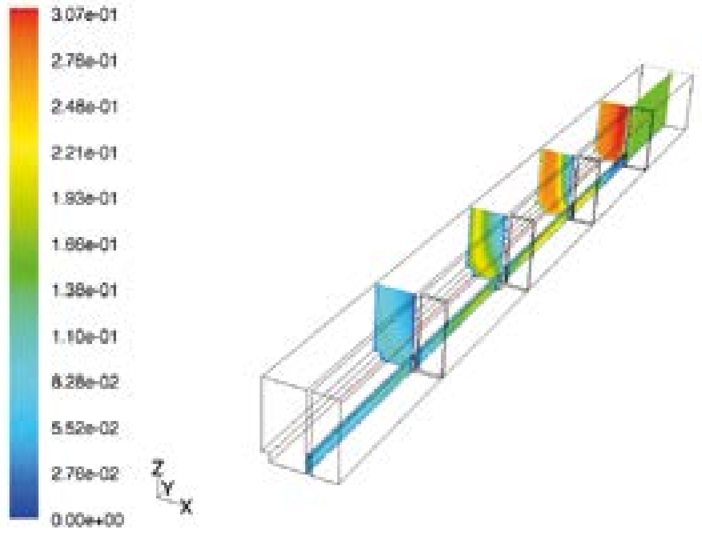

Fig. 10. Flow velocity contours Q = 3,000 l/s

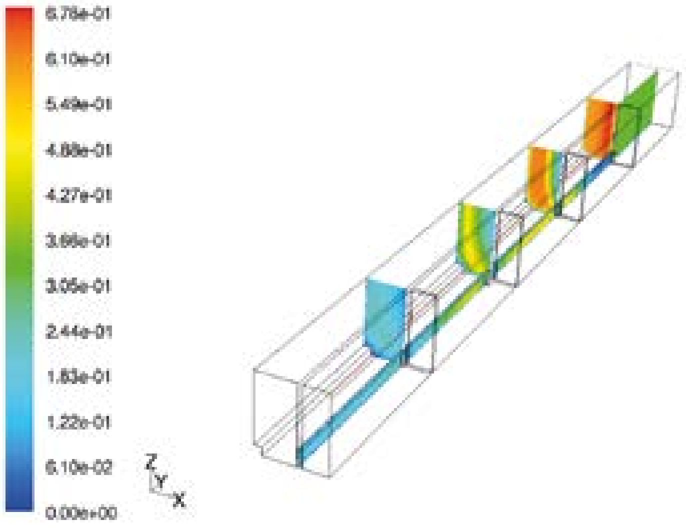

Fig. 11. Flow velocity contours Q = 6,000 l/s

Flow distribution

Tab. 2 and *Fig. 12* show the flow distribution under different flow conditions. Since no measured data were available, the model could not be calibrated. The sensitivity of the flows to the overflow height was adjusted only according to the theoretical flow curve. Preliminary results showed a similar distribution of flow under all flow conditions; however, at low flows the overflows were found to be too sensitive to overflow height. The final results after appropriate adjustment of this sensitivity are shown in *Tab. 2*.

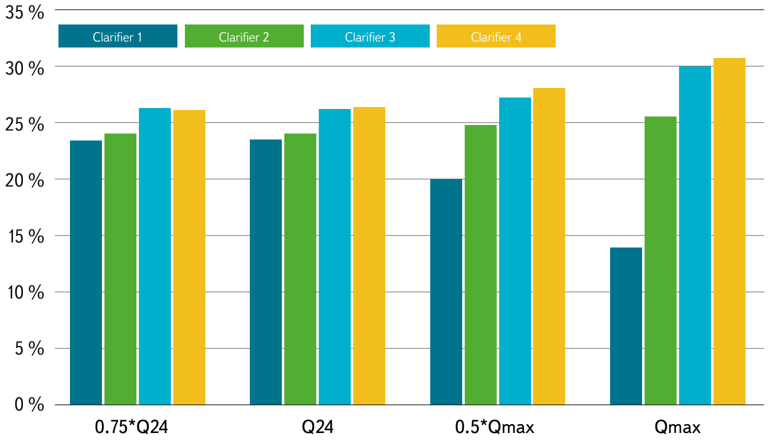

Fig. 12. Flow distribution

The results show that the flow distribution is fairly evenly distributed at low values; however, with increasing flow, the unevenness of the distribution increases, which is caused by the differences in the water level described above [4].

DISCUSSION

Since the results showed that the flow distribution is not dependent on the flow itself, it was proposed to solve the problem by adjusting the lengths of the overflows.

The introduction of baffles across the channel does not seem like a good idea either. The channel itself is quite narrow and introducing any major obstructions into it would reduce its hydraulic capacity and rather make the problem worse.

The best solution is probably adjusting the size of the openings at the channel bed to distribute the flow. Smaller openings at the end of the channel will cause a hydraulic loss that will compensate for the higher water level at high flow rates. At low flow rates, the hydraulic loss will be small and the flow distribution will not be affected.

Setting the size of the lower openings

Several simulations were performed to find the best possible combination of opening sizes. The optimization was based on the maximum flow rate (6,000 l/s) and a flow rate of 566 l/s was used to confirm the good performance of the design at low flow rate.

The simulations were performed iteratively. First, the size of the openings was reduced to half the original size. The original openings were very large (velocity 0.136 m/s at maximum flow rate), and although their size was halved, they did not cause much energy loss. The flow through the modified structure was simulated and the flow rates into the individual reservoirs were obtained.

Optimization process

Tab. 3 and *Fig. 13* show the simulation results of the above versions and show the iteration process.

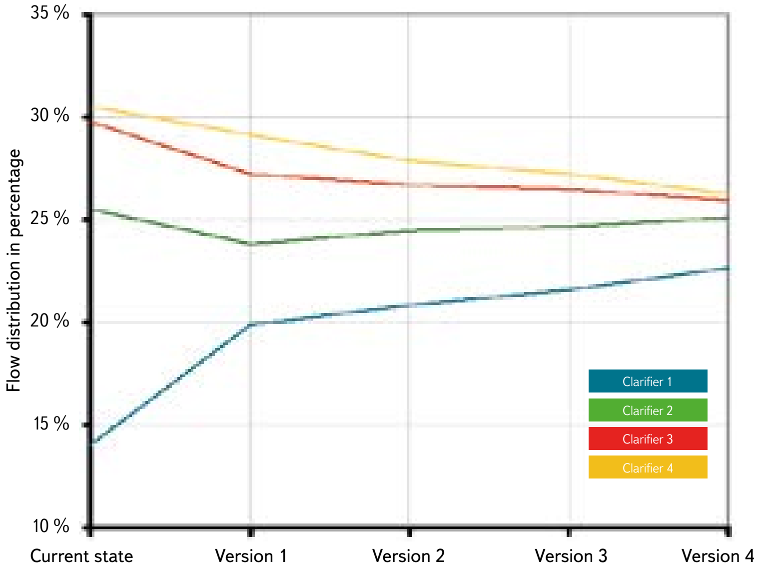

Fig. 13. Example of iterative process

Proposed improvement

The proposed improvement is shown in *Fig. 14*. The red hatched areas show the placement of the plates that close the parts of the openings. In the simulations, these baffles were placed on the side of the channel and were aligned with the channel wall.

Tab. 2. Flow distribution

	$0.75*Q_{24}$		Q_{24}		$0.5*Q_{max}$		Q_{max}	
Inflow [l/s]	377.2		565.8		3,000		6,000	
Clarifier 1	88.2	23.40 %	133.2	23.50 %	601.5	20.00 %	845.3	14.10 %
Clarifier 2	90.6	24.00 %	136	24.00 %	742.1	24.70 %	1,530.5	25.50 %
Clarifier 3	99.4	26.40 %	148.3	26.20 %	816.8	27.20 %	1,789.7	19.80 %
Clarifier 4	98.9	26.20 %	148.8	26.30 %	839.9	28.00 %	1,835.4	30.60 %

Tab. 3. Comparison of the different phases of the iterative process (Q_{max})

	Inlet [l/s]		Current state	Version			
				1	2	3	4
Q_{max}	6,000	Clarifier 1	14.10 %	19.90 %	20.90 %	21.60 %	22.60 %
		Clarifier 2	25.50 %	23.80 %	24.50 %	24.70 %	25.10 %
		Clarifier 3	29.80 %	27.20 %	26.70 %	26.40 %	26.00 %
		Clarifier 4	30.60 %	29.10 %	27.90 %	27.20 %	26.30 %

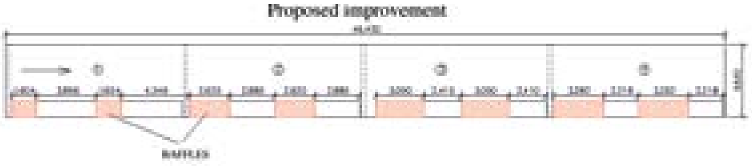

Fig. 14. Final dimensions of the proposed openings

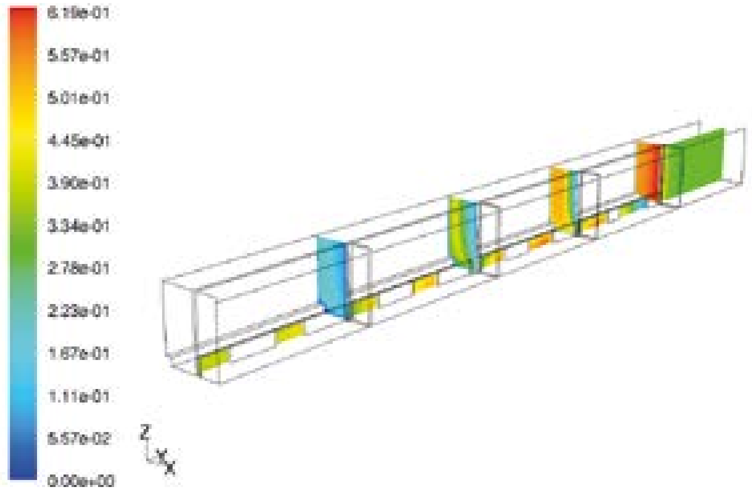

Fig. 15. Velocity contours of the flow pattern Q = 6,000 l/s

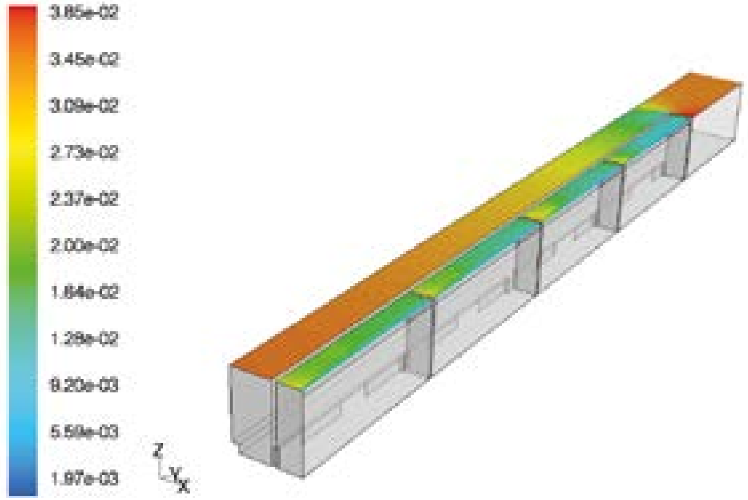

Fig. 16. The water level in the distribution object

Function principle

The following figure (*Fig. 16*) shows the function of the baffles in the lower openings. Although the water level rises along the channel, the water levels in the still chambers are almost equal. The difference between the water levels in the channel and in the still chamber is due to hydraulic losses caused by the baffles. The colours in the figure show the difference between the approximate constant water level and the calculated level.

CONCLUSION

The following table and diagram (*Tab. 4*, *Fig. 17*) show a comparison of the simulation results for the current state and the final proposed improvement. For improvement, only the maximum flow (Q_{max}) and the mean daily flow (Q_{24}) have been simulated so far. It can be seen from the results table that the proposed state of the distribution facility meets the conditions for an even distribution of flows, and the objectives of the research have thus been fulfilled. Considering the fact that the selected distribution facility is commonly used in the field, the results of the research can be easily applied in practice, namely to a larger number of WWTP.

Tab. 4. Comparison of the current situation and proposed improvements

			Clarifier 1	Clarifier 2	Clarifier 3	Clarifier 4
Q_{24}	566 l/s	Current state	133.0	135.8	148.3	148.9
			23.50 %	**24.00 %**	**26.20 %**	**26.30 %**
		Proposed state	135.5	139.9	146.5	144.0
			23.90 %	**24.70 %**	**25.90 %**	**25.40 %**
Q_{max}	6,000 l/s	Current state	845.3	1,530.5	1,789.7	1,834.4
			14.10 %	**25.50 %**	**29.80 %**	**30.60 %**
		Proposed state	1,358.7	1,507.1	1,558.1	1,576.1
			22.60 %	**25.10 %**	**26.00 %**	**26.30 %**

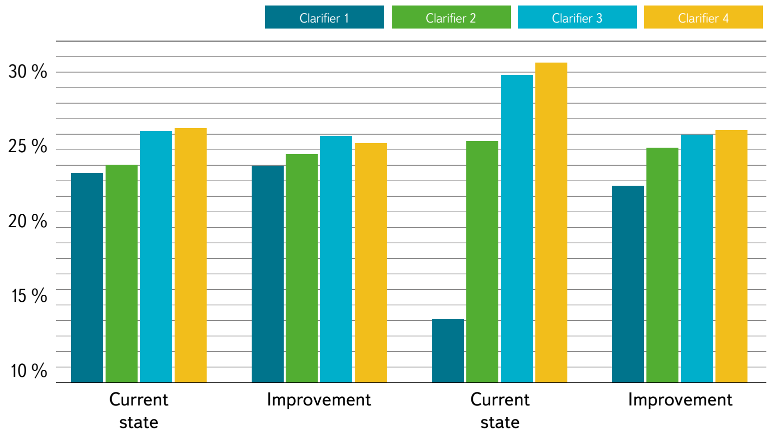

Fig. 17. Comparison of the current situation and proposed improvements

Other possible improvements

This improvement shows that it is possible to reduce the problem of uneven flow distribution by introducing baffles into the openings, the installation of which is quick, simple, and without the need for building modifications. Further attention in possible follow-up research should be paid to the shape of the baffles. It cannot be ruled out that some sediments could accumulate in the quiet zones behind these baffles and especially in the corners (*Fig. 18*), which could cause a problem with sediment clogging the inlet branches into the reservoirs in the future. Clogging with sediment will most probably affect the hydraulics of the distribution facility so that the uneven flow distribution will occur again.

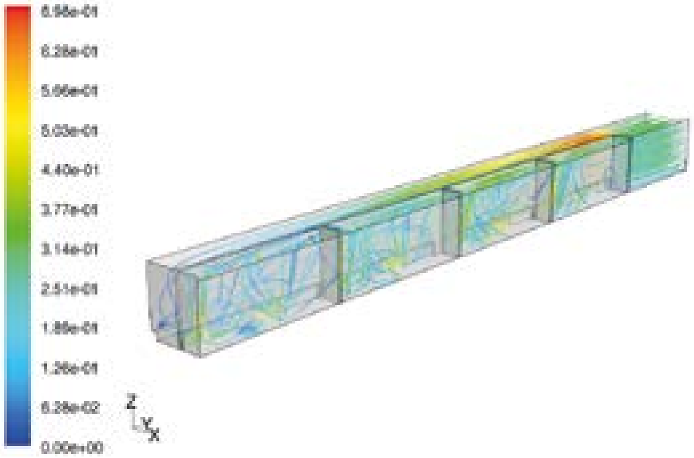

Fig. 18. Sediment is likely to accumulate in dead zones in the corners

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Jaroslav Pollert senior, Olympic Games Barcelona 1992, leader of the canoeist expedition

Interview with Jaroslav Pollert, professor at the Faculty of Civil Engineering at CTU and a successful Czechoslovak representative in canoeing

Do you remember the first time that water appealed to you so much that you decided to dedicate your professional and private life to it?

It is quite a difficult question. to say that the motive was building "dams" in the streams after the rain would probably be untrue. My interest in the field arose roughly at the moment when my brother, who was five years older, took me to the shipyard at the confluence of the Vltava and Čertovka rivers in Prague in 1957. The view from the shipyard over the river all the way to Vyšehrad was breath-taking. Just like the first descent of the Lower Sázava in the summer of 1957 with my brother on a double canoe during a minor flood, when the Vrané reservoir was also flowing, so we managed to reach the Malá Strana shipyard from Krhanice in one day. I made quite rapid progress in technical and competitive skills in water slalom, and so in 1959 I won the youth championship of Czechoslovakia both in single canoe and in kayak. Practical knowledge of the flow of water probably helped me to the fact that, after graduating from a secondary school, I agreed with my parents to go to an extension course at a technical school in Dušní street, majoring in water management. My parents didn't have an easy time with me. When I graduated from

All beginnings are difficult – wild water was stronger, Staroměstský jez, Prague 1959

First gold from the World Championships, Dresden 1961

technical school, I resisted and didn't want to go to university. At that time, being a TV repairman was financially better than being an engineer. However, the fear of compulsory two-year military service and also my friends, almost all university students, changed my view of life, and I applied to CTU – water engineering and water management. In retrospect, I can say that I barely passed through secondary school, but finishing university on time was not a big problem, even though it was already connected with top-level sport.

You have gained a lot of success in sport. Which do you value the most?

Sport taught me to understand one important thing: to be able to accept victories, but also defeats, and there are many more of them in life. This truth has also been transferred into professional life, as not every application for a new project or grant, for example, comes through. Those "unnecessary" pages of writing are a loss. But then comes the acceptance of a project – and that is victory. But the question is: sporting achievements. of course, these would be all three gold medals from the World Water Slalom Championships – 1961 (Dresden, Germany), 1965 (Spittal, Austria), and 1973 (Muotathal, Switzerland). My active sports career ended in 1974, when my partner from double canoe immigrated to Switzerland, and indirectly started my professional career. That last world victory was probably the biggest sporting success for me. After 1989, I was invited by our sporting public and elected chairman of the Czechoslovak and later Czech canoeing. At the same time, I was drawn into the Olympic movement, where I have been a member of the executive of the National Olympic Committee since 1990.

In 1992, I was elected to the Executive Committee of the International Canoe Federation (ICF) and, in autumn 1996, I was elected the chairman of the whole world water slalom. During the 1996 ICF Electoral Congress, the news came that water slalom would be removed from the programme of the Olympic Games in Sydney in 2000. As chairman, I could not allow this dark scenario. Together with friends, we have prepared a worldwide campaign to save and also to change the slalom course project. The removal occurred for financial reasons. The original project was 13.5 million Australian dollars (AUD), but, probably due to my contribution as an expert on water structures, the price came to 6.5 million AUD, and we reduced the price for Australia by the contributions from the national canoeing federations to 3 million AUD. As part of the campaign, I got to know the Internet and e-mail for the first time. It was in 1996 that CTU got its first connection from Linz via CESNET, and I quickly convinced the head of the computer centre that I needed it. It was the first connection outside the computer centre. From there I sent manuscripts of letters to various friends for statesmen – Jacques Chirac, Al Gore, but also for President Václav Havel. I like to remember it. It's still like winning an Olympic gold medal for me. Nowadays, not having an Olympic credit unfortunately means "barely surviving" in sports.

Do you still go canoeing?

Another tough question. Sometimes I use a tourist canoe, but only on calm or slow-flowing water. Last year at the end of August I decided that at the age of 79 I needed to feel real wild water at least one more time. After finishing my duties as Vice-President of the European Canoeing Association in Slovenia, I decided to experience the descent of the beautiful mountain river Soča. The water level was quite high after several days of rain, so the waves and holes had their power. Even on the raft, I discovered that the habits from my youth remained in me – where to lean out, how to catch and read the water. It made me very happy inside.

At the faculty, among other things, you deal with designing new channels for water slalom. How many channels have you designed? Which one are you most proud of and which was the most interesting?

My main professional focus is on topics related to hydraulics in sanitary engineering, especially the flow of dispersion systems, for which I was nominated for a state award for meritorious service to the state in the field of science in 2017. As for water slalom, the first physical model for slalom course design was Prague's Troja in 1978. This was followed by designs of Czech slalom course s (Trnávka, Roudnice, Brandýs nad Labem) and expert opinions and recommendations for foreign countries – Nottingham (England), Tres Coroas (Brazil), Idaho Falls (USA), and others.

Olympic Games 2000 in Sydney, Jaroslav Pollert st. – design and implementation of an artificial runway for water slalom, stadium layout

Of course, the most significant slalom course designs with 100 % implementation were for the Olympic Games in Sydney in 2000. I am personally most proud of this project, as it included an unconventional stadium layout where the spectator sees the competitor practically from the start to the finish line.

Other major design projects were for Auckland, New Zealand (2013), Rio de Janeiro (2014, for the 2016 Olympics), and Tokyo (2017, for the 2020/2021 Olympics) where my son was the main person responsible, bringing a whole range of innovative elements to the designs.

Now back to your main specialization: what is your personal view on the interest of students in the study fields of water management?

Recently, it seems that interest in studying the field has increased slightly. However, it is not yet possible to determine from the statistics whether this is really due to interest or a demographic curve influenced by growing up of children of the strong years of 1970s. Perhaps it is also a secondary effect of global interest in climate change, which may bring problems with droughts and floods.

Can you compare the development of water management fields of study in the Czech Republic and abroad?

I think that, overall, the level of the individual subjects that are included in the basic curriculum of the field of water engineering and water management is still at a good level. I have more experience and the possibility of comparison in doctoral studies. Here, the interest is quite high in studies and scientific research among students, mainly from Europe and especially from the southern part of Europe. I don't know why, but there are very few bachelor's or master's students, even though today it is possible to graduate in English at CTU. It is not financial reasons. Erasmus programmes fully ensure the stay. Unfortunately, the lack of interest in our bachelor's, master's, and sometimes doctoral students in the field to go somewhere for a longer period of time also contributes to this. More foreign stays and feedback from students would help to improve the quality of our teaching and increase the prestige of the entire field of study in the Czech Republic.

What would contribute to making the field of water management more attractive?

That is a very difficult question. Those who fall for water management for the reason of its connection to water element and nature do not need to be convinced about its attractiveness. The question concerns a field that is part of studies at the Faculty of Civil Engineering of CTU. I believe that it is perhaps unfortunate for young people leaving secondary school, as well as their parents, that the field is not specialized at the beginning of the studies and is part of the Civil Engineering programme. Under this title, many applicants see pure construction work, with higher specialization only occurring in the third year of study. When reading materials about the faculty, applicants and their parents often do not get that far. This may be my personal impression, but I answered the above questions several times during the open days: "And will the students learn about water if it's called Civil Engineering?"

The topic of water is widely discussed among experts and the lay public. Does it help when more and more people talk about water? Or, what do you miss most in this discussion?

It is true that water as one of life's essentials is perceived by people as something common. That is why "almost everyone" understands the problems associated with it. I would like to supplement it with my own experience in designing artificial slalom course s for water slalom. I often hear: "After all, I did canoeing, so I know how to design a slalom course." But these people lack technical knowledge and the result, i.e. the design, is a "mess" and has to be complicatedly redone. But unfortunately, these people are often closer to financial resources than a real expert.

It is almost immoral to say that people only begin to understand the main problems with water on a wider scale after certain major catastrophes, such as floods or major ecological disasters connected with water, for example fish poisoning in the Bečva. It is also bad that, in general, technical problems related not only to water are not discussed much in the media. A possible cause may also be a very narrow group of media workers who are able to ask questions in a well-founded manner and further elaborate them for the layperson. Fortunately, there is Daniel Stach on Czech Television, who is able to translate expert explanations into a form understandable for the lay public.

Thank you for the time you devoted to our interview.

Ing. Josef Nistler

Prof. Ing. Jaroslav Pollert, DrSc.

Prof. Ing. Jaroslav Pollert, DrSc., born on 16 August 1943, is a professor at the Faculty of Civil Engineering at CTU, where he mainly focuses on experimental research related to the hydrodynamics of dispersion systems. He is the author or co-author of 112 professional publications and lectures at domestic and foreign professional conferences. He is also a member of international scientific committees of prestigious world conferences and a coordinator or leader of international projects and programmes of the Agency for International Development, "Reducing Energy Costs in District Heating Systems" and "Assessing Infiltration and Exfiltration on the Performance of Urban Sewer Systems" within the fifth EU framework programme for the development of science and technology.

Apart from his professional work at the Faculty of Civil Engineering of CTU, prof. Jaroslav Pollert is a former Czechoslovak representative in canoeing and world champion in wild water slalom. At the ICF Canoe Slalom World Championships he won three gold medals – in 1961 (C-1 team), 1965 (C-2 team), and 1973 (C-2); in 1973 he added C-2 team silver with Jiří Krejza. After his career ended, he became a sports official. From 1990 to 1992 he was chairman of the Czechoslovak Canoeing Association, from 2006 to 2014 chairman of the Czech Canoeing Association. Since 1990, he has continuously been a member of the executive committee of the Czechoslovak and subsequently the Czech Olympic Committee. In 2015, he became vice-president of the European Canoeing Association and defended the position four years later. Together with his son Jaroslav, he participated in designing new channels for water slalom, including for the 2020 Summer Olympics in Tokyo.

The history of the grey water footprint, or let's quote the originator of the idea

The water footprint was introduced in 2002 [1] and quickly became a popular tool for assessing anthropogenic impacts associated with human activities. The basic methodological document that describes the water footprint methodology is the *Water Footprint Assessment Manual* from 2011 [2]. The water footprint consists of three components, depending on the source and type of water use:

1) the blue water footprint represents water consumption from water sources, i.e. taken from rivers, lakes, and aquifers,

2) the green water footprint represents the consumption of water that comes from precipitation and is stored on the surface of the soil or plants or as soil moisture, and is consumed mainly by evapotranspiration,

3) the grey water footprint represents the amount of water needed to assimilate anthropogenic pollution based on the natural background concentration and existing environmental water quality standards.

The grey water footprint is calculated by dividing the amount of discharged pollutant L [mass/time] by the so-called assimilation capacity of the receiving water body, i.e. the difference between the ambient water quality standard for the pollutant (maximum acceptable concentration) C_{max} [mass/volume] and the natural concentration of the pollutant in the receiving water body C_{nat} [mass/volume]. The grey water footprint is thus not tied to the amount of water in the receiving water body, but is the theoretical amount of water that is needed to "dilute" the pollution discharged in wastewater. In other words, the grey water footprint is the sum of the volume of polluted wastewater discharged into a watercourse and the additional amount of water needed to dilute the pollutant to an acceptable concentration in a watercourse [3]. It is surprising that many authors do not include the amount of wastewater discharged into the grey water footprint, which can be considered a mistake [4]. However, cases where only waste water is included in the grey water footprint can be considered the same error (unfortunately, such cases can also be found and we deliberately do not cite these works here).

When the water footprint was introduced in 2002, only the blue and green water footprint were introduced. The grey water footprint did not become part of the water footprint concept until a few years later. Nevertheless, we encounter cases where, for the definition of grey water footprint, a document is cited that does not contain the grey water definition ; sometimes the grey water footprint is not even mentioned. At the same time, the correctness of references is one of the pillars of scientific publishing because a well-written argument is based on existing scientific knowledge in the given field; it is supported by important assumptions, technical information, and opinions with precise identification, i.e. citing source material [5].

The question of water pollution in the context of the water footprint was first addressed in a 2005 cotton water footprint study [6], which was subsequently published as an article in the journal *Ecological Economics* in 2006 [7]. Neither the 2005 study [6] nor the follow-up article [7] include the concept of grey water footprint, but the idea that the impact of water pollution can be expressed by converting the volume of emitted chemicals to the volume of dilution needed to assimilate the pollution. The term grey water footprint only appears a year later, i.e. in 2007, in an article by Hoekstra and Chapagain [8]. According to the information attached to the article [8], the revised manuscript of this article was submitted to the editors in February 2007. This is quite an interesting fact because both the *Water Footprint Assessment Manual* [2, p. 31] and Hoekstra himself [9] state that all the three components of the water footprint were only presented in a comprehensive framework in a book from 2008 [10]. This is probably because the book allows for a much more detailed description of the links between the individual components of the water footprint. The methodological issues of the grey water footprint were then elaborated by the *Water Footprint Network* working group, whose work resulted in a number of refinements, including taking into account the quality of the water abstracted, and a multi-level approach to distinguish different levels of detail when assessing the grey water footprint of diffuse pollution. The work of this group was reflected in the *Water Footprint Assessment Manual* [2].

Two important documents should be mentioned in connection with the grey water footprint. The predecessor of the *Water Footprint Assessment Manual* [2] was a working "live" report published in 2009 called *Water Footprint Manual: State of the Art 2009* [11]. Although this document assumed an annual update, the already mentioned *Water Footprint Assessment Manual* [2] followed only in 2011 and further updates did not take place.

The *Water Footprint Assessment Manual* [2] recommends (on the basis of the above-mentioned outputs of the working group) a three-step approach to estimating the load of diffuse pollution entering a water body. In 2013, the *Water Footprint Network*, which advocates the development of water footprint methodology, published a methodological guide on the use of Tier 1 to estimate the load of diffuse pollution entering a water body [12].

Either way, the origins of the grey water footprint idea are well documented in the literature. In relation to the grey water footprint definition, there is therefore no reason to cite other articles than those that first dealt with the grey water footprint [6–8, 10]. An understandable alternative to these articles is the *Water Footprint Assessment Manual* [2], which is the basic methodological framework of the entire water footprint methodology, or a subsequent methodology for Tier 1 applications [12].

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Circular sample 2022

A circular sample is a sample that allows laboratories in particular to compare their professional skills with each other. Officially, it is a test of the competence of laboratories, which takes place under the auspices of the Centre for Assessment of Laboratory Competence (ASLAB), in the field on which the given laboratory focuses (hydrobiological, microbiological, chemical, or radiochemical). The compliant laboratory subsequently obtains a certificate.

The last multiparametric circular sample in the field of hydrobiology was prepared at WRI TGM in Prague under the ASLAB auspices by RNDr. Ladislav Havel, CSc., and RNDr. Blanka Desortová, CSc., in 2019.

The opportunity to prepare a circular sample for the year 2022 was offered to me at the Determination Course of Copepods, which is organized every spring by a group of zooplankton specialists of the Czech Limnological Society (Limnospol). Due to the great interest in the sample from among the zooplankton specialists from the water management laboratories of the Povodí state enterprises, there was no reason to hesitate, and together with the Department of Ecology – Hydrobiology of Charles University in Prague and Limnospol, preparations began. First, I consulted Ing. Hana Kohoutová from ASLAB. Since it was supposed to be a sample focused exclusively on the qualitative determination of zooplankton, we agreed to evaluate a circular sample outside the ASLAB system. The preparation of the samples itself was preceded by a consultation with RNDr. Blanka Desortová, CSc., who has extensive experience with such samples. Species that were represented by a large number of individuals had to be selected for the samples. Simultaneously, it was necessary to separate these species from the original sample in which they were located, so that the resulting circular sample was as clean as possible and it was clear to the participants at a glance which species they were to determine. Part of the preparation for me was also the creation of an "advertising" sticker "Circular sample 2022", by which the laboratory or office could show their involvement in testing the circular sample. Once the samples were ready, one of them went to RNDr. Martin Černý, Ph.D., to the Department of Ecology – Hydrobiology, where my work was checked, and subsequently with the financial support of Limnospol (RNDr. Michal Šorf, Ph.D., bursar) I was able to send a sample and a sticker to all participants. Seven samples travelled to the water management laboratories of the state enterprises of the Vltava, Elbe, Ohře, Morava, and Odra basins. One went to Mendel University in Brno. The whole preparation took me about a month. Participants received their sample on 20 July 2022, and the deadline for submitting results was set for 30 September 2022.

Each sample contained 11 species, which consisted of representatives of *Cyclopoida*, *Calanoida*, water fleas (*Cladocera*), and *Rotifera*. The resulting evaluation was very varied. Only one laboratory identified all species correctly. Three labs achieved 91 %, one achieved 82 %, followed by three participants who were not as successful this year, achieving 64 % and 55 % success rates.

Finally, I would like to thank everyone who trusted me and helped me make this year's circular sample; at the same time, I look forward to a large participation in 2025.

Daphnia pulicaria

Macrocyclops fuscus

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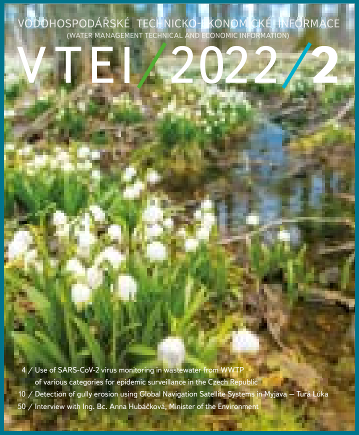

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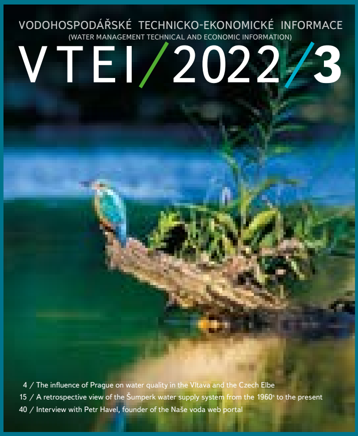
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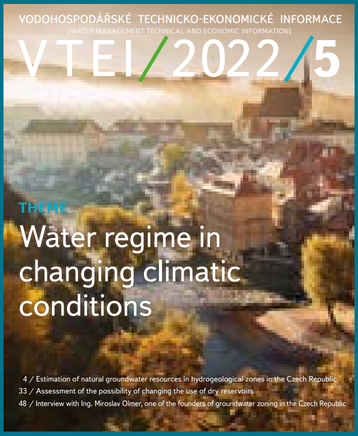
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UNDERGROUND WARTER TANKS IN ŽLUTÝ KOPEC IN BRNO

The complex consists of two brick reservoirs from the last third of the 19th century and a concrete two-chamber reservoir from the beginning of the 20th century. It represents a valuable document of the technical solution to the water supply of the city of Brno in the 19th and 20th centuries. The oldest of the three reservoirs (in the photo) was built according to the project of London builder Thomas Docwra between 1868–1874. Its supporting system consists of ten massive brick walls relieved by window-like openings, through which water poured between the individual spaces. Apart from the concrete floor, the building has never been repaired; the material is authentic from the time the reservoir was created.

The underground reservoirs are roofed with a system of barrel and cross vaults supported by pillars, which we will not find anywhere else in the Czech Republic. The operation of the reservoirs was terminated in 1997, when they were disconnected from the water supply network. They have been listed since 2019. Similarly spectacularly designed underground water tanks can be found, for example, in London, Copenhagen, and Budapest.

Text: Ing. Miriam Dzuráková, photo: Mgr. Marek Havlíček, Ph.D.

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