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

VTEI / 2025 / 6

60 years ago in VTEI

In issue No. 3 of VTEI journal in 1959, an article entitled "Further Progress in the Automation of Hydroelectric Power Stations in the Czechoslovak Republic" was published. The author's name is unknown.

The commissioning of the first generating unit at Lipno I Hydroelectric Power Station for fully automatic operation marked the completion of the first stage in the automation of hydroelectric power stations in the Czechoslovak Republic, which focused on the complete automation of individual generating units.

All operations required for the start-up and shutdown of the generating unit are fully automated, so that simple control signals, transmitted either locally or remotely, are sufficient for its operation. Naturally, the development of automation in individual units will continue; however, the results achieved so far have confirmed the effectiveness of the system in use.

The next stage in the automation of hydroelectric power stations will focus on automating the operation of entire facilities, comprising multiple generating units. The start-up and shutdown of the units will be controlled by an automatic group control system, which will start up and shut down individual units automatically according to the required power output, the water level, or a pre-set programme, so that electricity is generated in the power station with the highest possible efficiency.

In addition, the load will be automatically distributed evenly among the individual generating units. A facility equipped in this way will be easy to operate from a remote control centre using only simple commands.

Orlík Hydroelectric Power Station will be the first in Czechoslovakia to be equipped with a system for group control of generating units.

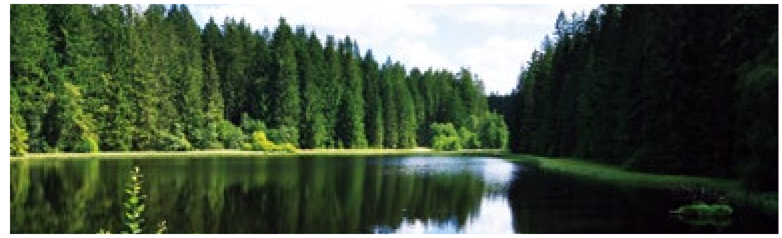
The ultimate goal of hydroelectric power station automation is their integration into an automatic system for frequency and power output control, which will manage the operation of groups of hydroelectric and thermal power stations in such a way that the entire energy system operates with maximum efficiency.

In comparison with other countries, only the first stage of hydroelectric power station automation has so far been implemented in Czechoslovakia. However, this stage is the most important, since without reliable and precise automation of individual generating units, higher levels of automation would not be possible.

VTEI Editorial Office

Orlík hydraulic structure is the highest and most massive structure in the cascade of Vltava reservoirs. Its 450 m long concrete dam reaches a height of 91 m at the crest. The Water Research Institute determined the design of the spillway and stilling basin through model testing. The properties of the intake gates for the power station and the thermal regime of Orlík Reservoir were also examined using physical models. From the construction of Orlík Dam (4 November 1959).

Content



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Dear Readers,
Dear Colleagues,

As the end of the year approaches, it is time to take the opportunity to look back on the past months. When reviewing this year, we can say with certainty that water, as a source of life, once again stood at the centre of many important conferences, negotiations, meetings, and discussions. For example, World Water Day, celebrated each year on 22 March, which this time highlighted the need to protect glaciers as a crucial reservoir of fresh water, and the Magdeburg Water Protection Seminar 2025 held in October, focusing on 'water management in the Elbe basin yesterday, today, and tomorrow'. Within the professional community, new insights also resonated regarding the sustainability of water infrastructure, the potential of digital tools for water resource management, and, not least, the challenges related to educating a new generation of water professionals. It is becoming clear that linking practical experience with the outcomes of research and development is the path towards a resilient and modern water sector.

And what can you look forward to in the December issue? The opening expert article, "Current state of monitoring selected PFAS in surface waters in the Czech Republic" by Diana Marešová and her co-authors, provides an overview of present knowledge regarding the occurrence of PFAS in surface, groundwater, and drinking water. The article summarises the legislative requirements relating to PFAS, outlines analytical methods for determining these substances, and presents techniques for their removal from contaminated water.

The article "From a drop to energy: assessing the hydropower potential of watercourses using results from the 'Pico-Hydropower' project" by Štěpán Marval and his colleagues focuses on the utilisation of energy from water. The authors present a two-stage methodology developed within the 'Pico-Hydropower' project, aimed at identifying locations within the Czech Republic suitable for the installation of micro-hydropower plants.

The third technical article, entitled "Some aspects of catchment protection upstream of future reservoirs" by Helena Nováková and her co-authors, examines several diffuse phenomena that may lead to pollution and thus to limited use of stored water. The paper describes a methodology for identifying critical locations around planned reservoirs through which excessive amounts of sediment enter the aquatic environment during intense rainfall events.

A historical insight is offered by the article "The beginnings of timber floating in the region of Novohradské hory" by Jaromír Florian. It takes readers back to the last quarter of the 18th century, when a unique timber-floating system was built in the Novohradské Mountains. Its uniqueness lay in the fact that it enabled the floating of both loose (log) timber and bound timber (rafts), even on the narrow and low-capacity watercourses of the Novohradské Mountains.

Our December interview features Mgr. Martin Pták, Director of the Water Protection Department at the Ministry of the Environment. He not only reflects on the beginnings of his professional career, but also points out that today's water management sector faces climate-related challenges, the need to modernise infrastructure, and the demands of European legislation. At the same time, however, it offers room for innovation, collaboration, and the involvement of a new generation of specialists, which, he says, are the key to a sustainable future for Czech water resources.

In the information section of the journal, our colleague Zuzana Řehořová takes us to Jáchymov one last time to answer the question of where the local radon water originates. In her article "Jáchymov III: where does the radon water come from?" we learn more about the history of Svornost mine – the oldest functioning mine in Europe and the world's first uranium mine – about the springs still used today for the therapeutic baths of Jáchymov's patients, and about the creation of the Radon Trail in Jáchymov.

In conclusion, allow me, on behalf of the VTEI editorial team, to thank you for your cooperation, inspiration, and goodwill throughout 2025. I wish you a peaceful and joyful Christmas spent with your loved ones, and good health, optimism, and professional success in the new year 2026.

Ing. Josef Nistler

Current status of monitoring selected PFAS in surface waters in the Czech Republic

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Keywords: surface water — PFAS — target analysis — non-target analysis — HPLC-MS — Czech Republic

ABSTRACT

Per- and polyfluorinated compounds (PFAS), a group of fluorinated compounds of anthropogenic origin, have been classified as a persistent organic substances of significant concern due to their chemical properties, widespread use in a number of industrial sectors, environmental spread, long term bioaccumulation potential, and resulting risk to human health. This article brings an overview of current knowledge about the occurrence of PFAS in the environment, mainly in surface, ground, and drinking water and about the methods of their removal from contaminated water. Furthermore, the legislative requirements regarding PFAS at the level of the EU and Czech Republic are summarised here, including the list of compounds according to the Directive of the European Parliament and the Council 2020/2184 and the Proposal for a Directive of the European Parliament and the Council 2008/105/EC. The article also includes an overview of analytical methods for determination of PFAS, including trifluoroacetic acid (TFA), and the determination of total organic fluorine. The methods are generally based on liquid chromatography coupled with mass detection. Differences are primarily in sample pre-treatment. The main attention is focused on a summary of relevant data PFAS monitoring in surface water from all Czech Republic territory. Until 2022, only perfluorooctane sulfonic acid (PFOS) and (except for the Odra and Ohře basins) perfluorooctanoic acid (PFOA) were consistently monitored in surface waters in the Czech Republic. Detection limits of methods used in individual basins were different; therefore, an objective summary of relevant data about PFAS monitoring in the Czech Republic is impossible. Methodologies enabling determination with higher sensitivity and, in particular, a wider range of monitored substances are gradually being introduced with the expansion of analytical possibilities. From 2023, monitoring of substances from PFAS group compounds was introduced in individual basins on a wider scale, including pilot monitoring, which is presented in this article.

INTRODUCTION

The history of per- and polyfluorinated substances (PFAS), the so-called "forever" chemicals, began in 1938, when the chemist Roy J. Plunkett, an employee of DuPont, accidentally discovered polytetrafluoroethylene (PTFE) during the manufacture of Freon. This new fluorinated plastic was patented by Kinetic Chemicals in 1941 (U.S. Patent 2,230,654) [1], and in 1945 the trademark Teflon was registered [2]. More than 7,000,000 compounds fall within the PFAS group. In order to unify and harmonise communication on PFAS among scientific, regulatory and industrial communities, recommended names, acronyms, structural formulae and CAS Registry Numbers have been proposed [3]. The OECD has identified more than 4,700 compounds on the basis of their CAS numbers [4]. PTFE, however, is not a fully typical compound. PFAS include PFOS (perfluorooctane sulfonic acid) and PFOA (perfluorooctanoic acid), which were first detected in the 1950s during the production of Teflon.

Current state of knowledge

PFAS have attracted considerable attention over the past 10 to 15 years. Thanks to their lyophobic and hydrophobic nature, they have found wide use in a range of sectors, for example in the textile and leather industries, in fire-fighting foams, surface protection agents, household products, food-contact packaging, the photographic industry, aviation hydraulic fluids, electroplating, and as surfactants in pesticides and other agricultural chemicals [5]. In the 1990s, these substances were identified at low concentrations in all parts of the environmental (water, soil, air, plants, living organisms) thanks to the development of analytical methods for their determination and advances in instrumentation, particularly the emergence of liquid chromatography coupled with mass spectrometry [3, 6].

Due to the significant expansion of PFAS production, there has also been an increase since 2000 in publications addressing this group of substances, their sources and fate in the environment, and their harmful effects. In 2020, nearly 1,000 publications dealing with this issue were published [6].

The toxicity of PFAS to humans and their impact on ecosystems currently receive extraordinary attention. An increasing number of substances from this group are being monitored regularly, and concentrations considered safe are decreasing. There is a need to gain a better understanding of the fate and impacts of these persistent chemicals on the environment, as it can be assumed that the burden on surface and groundwater by these substances is underestimated [7]. A publication by the authors of the current article [8] addresses a range of existing information on the applications, environmental release, and remediation technologies of per- and polyfluoroalkyl substances.

In connection with the regulation and restriction of PFAS use, attention should also be paid to alternative substances, the monohydrogen-substituted perfluoroalkyl carboxylic acids (H-PFAS), which are also found in surface waters. In the Netherlands, a UHPLC-MS/MS method was developed, validated, and applied for the determination of these contaminants in surface water samples [9].

Very little information is currently available on the PFOA substitute known as GenX. Despite its lower bioaccumulative potential, this alternative substance may still pose a risk to both the environment and human health [10].

Given the global distribution of these chemicals, studies have been conducted to monitor their presence in developing countries in water samples and other samples from the abiotic environment and biota. PFAS were identified in 72 % of the samples [11, 12].

PFAS clearly represent a global problem. Levels of four selected perfluoroalkyl acids (PFAA) – perfluorooctane sulfonic acid (PFOS), perfluorooctanoic acid (PFOA), perfluorohexane sulfonic acid (PFHxS), and perfluorononanoic acid (PFNA) – have been tested in various global environmental media, namely rainwater, soils, and surface waters. Among other findings, it has been shown that PFOS levels in rainwater in some inland areas of the European Union often exceed the environmental quality standard for surface waters. It is therefore crucial that the use of these substances is restricted as rapidly as possible [13, 14].

Current efforts by the European Commission to initiate discussions on the largest proposal to restrict PFAS in history reflect the poor global situation regarding PFAS accumulation in the environment and their health impacts. However, a comprehensive analysis is still lacking. Interest in the issue has been successfully raised, with the focus of research gradually shifting towards ecological questions. The involvement of developing countries, however, is limited, despite the fact that PFAS exposure in these regions is extremely high. It is therefore necessary to pursue globally interconnected and multidisciplinary approaches to address issues related to PFAS [15]. Other studies also provide a critical review of the global occurrence and distribution of these persistent chemicals in waters, including wastewater [16, 17].

In Sweden, PFAS have been detected in both raw and drinking water, as well as in groundwater [18, 19].

In the Czech Republic, PFAS were tested in tap water. In 192 drinking water samples from across the country, 28 PFAS were analysed using high-performance liquid chromatography coupled with tandem mass spectrometry following solid-phase extraction. It was found that the occurrence of PFAS in drinking water in the Czech Republic is very low compared with other European studies. Approximately 1 % of the analysed samples could present a potential health risk [20, 21]. In seven locations on the Svitava and Svratka rivers in the Brno urban development, the occurrence of perfluorinated substances in water and fish blood plasma was monitored. Concentrations of PFHxS, FHUEA, FOSA, and N-methyl FOSA were below the detection limits. The main component in fish blood was PFOS, followed by PFNA and PFOA. In water, the primary detected compound was PFOA, followed by PFOS and PFNA. A significant correlation was observed between PFOA concentrations in blood plasma and in water (r = 0.74) [22]. Arnika has also monitored the occurrence of PFAS together with brominated flame retardants in Prague and its surroundings. High concentrations were measured in the Kopaninský stream. The values were significantly higher than those commonly found in surface waters in Europe. In this case, the source of pollution may be Václav Havel Airport [23].

As early as 2010, contamination of the Rhine river was monitored. Seventy-five water samples were collected along the entire course of the Rhine river, from Lake Constance to the North Sea, including several major tributaries such as the Neckar, Main, and Ruhr rivers, and waters from the Rhine–Meuse delta, specifically the Meuse and Scheldt rivers. The aim was to identify possible sources of contamination [24].

PFAS were also monitored in the Danube river basin. A total of 82 PFAS and 72 other suspected compounds were identified in 95 samples. Many of the substances detected are not currently regulated [25].

With the increasing information on toxicity and population exposure, concerns arose regarding the impact on human health. Several studies have been conducted examining the relationship between PFAS concentrations in blood serum and in drinking water [26, 27]. PFAS have also been detected in breast milk and infant formula [28].

Trifluoroacetic acid (TFA), which belongs to the ultrashort-chain subgroup of PFAAs, is included in the revised European Commission directives. It is a highly persistent compound, with concentrations in parts of the environment (soil, water, air, plants, plant-based foods, and human serum) increasing significantly. TFA is a transformation product of many PFAS and is also released into the environment from industrial TFA production. Studies on the occurrence of TFA in the environment, including surface waters, show that over the past 20 years its concentrations in all parts of the environment have increased severalfold and are currently many times higher than those of other per- and polyfluoroalkyl substances. Data on the toxicity and ecotoxicity of TFA are limited, but it is nevertheless clear that there is a potential global risk of its irreversible accumulation [29, 30].

Removal of PFAS from wastewater

One of the key tasks is to identify a suitable sorbent for removing PFAS from contaminated water. Biochar appears to be a cost-effective and environmentally friendly adsorbent for the elimination of PFAS [31]. Other potential methods for removing not only perfluorinated substances include ozonation, granular activated carbon, and membrane processes using reverse osmosis. However, PFAS were not removed by ozonization; these chemicals were effectively eliminated using physical methods, such as adsorption on activated carbon and processes based on reverse osmosis membranes [32]. Several magnetic materials, including iron oxides, ferrites, and magnetic carbon composites, also appear to be effective adsorbents for the removal of PFAS from water. These substances have demonstrated considerable potential for use in various environmental remediation applications, as well as in the treatment of PFAS-contaminated water [33]. Mixed-matrix membrane technology removes more than 99 % of PFAS from wastewater [34]. A concise summary of the occurrence, transformation, and removal of poly- and perfluoroalkyl substances in wastewater treatment plants (WWTPs) was prepared by Lenka et al. [35]. They also highlight that information on PFAS is particularly scarce for developing countries. Another study provides a comprehensive review of PFAS sources and their remediation [36].

Another study focused on the fate and transport of PFAS and inorganic fluoride in a municipal WWTP operating a sewage sludge incinerator (SSI). A robust statistical analysis characterised concentrations and mass flows across all primary influents and effluents of the WWTP and SSI, including emissions from thermal treatment into the air. A PFAS removal efficiency of 51 % indicates that the SSI can only partially eliminate PFAS [37]. An overview of the current state of research on treatment technologies suitable for the removal of PFAS from the environment, particularly from water, is provided in the publication Per- and Polyfluoroalkyl Substances Treatment Technologies [38].

PFAS Legislation at the EU and Czech Republic levels

Legislative instruments are the primary means of limiting perfluorinated organic compounds in the environment. One of the first measures was the inclusion of selected perfluorinated organic compounds on the list of persistent organic pollutants (POPs) under the Stockholm Convention [39]. Under Article 3 of the Convention, parties and organisations (signatories) are required to prohibit and/or adopt the legal and administrative measures necessary to eliminate: the production and use of the chemicals listed in Annex A; the import and export of the chemicals listed in Annex A; and to restrict the production and use of the chemicals listed in Annex B of the Convention. The Annex A list (Elimination) of the Stockholm Convention includes perfluorohexane sulfonic acid (PFHxS), its salts, and related compounds that may potentially degrade to PFHxS, as well as perfluorooctanoic acid (PFOA), its salts, and related compounds that may potentially degrade to PFOA. In the case of PFOA, certain uses or products are subject to specific exemptions, including applications in the photographic industry, some medical uses, the textile industry (production of protective clothing for environments where there is a risk of adverse effects on human health), and in fire-fighting foams for the suppression of flammable liquid vapours and the extinguishing of flammable liquid fires (Class B fires). However, by 2025 at the latest, the use of fire-fighting foams containing or potentially containing PFOA, its salts, and PFOA-related compounds must be restricted to locations where all releases can be fully captured. The Annex B list (Restriction) of the Stockholm Convention includes perfluorooctane sulfonic acid (PFOS), its salts, and perfluorooctane sulfonyl fluoride. Use is permitted in electroplating processes within closed systems, in fire-fighting foams for the suppression of flammable liquid vapours and the extinguishing of flammable liquid fires (Class B fires), and in insect baits containing the active substance sulfluramid (CAS no. 4151-50-2) for the control of ants of the genera *Atta* spp. and *Acromyrmex* spp., strictly for agricultural purposes.

Another measure is Regulation (EU) 2019/1021 of the European Parliament and of the Council [40], which sets restrictive conditions for the use or placing on the market of products containing perfluorinated substances within the European Union. According to Article 3 of this Regulation, the manufacture, placing on the market, and use of the substances listed in Annex I – whether as such, in mixtures, or in articles – are prohibited. In the case of PFOS, its salts, and related substances that degrade to PFAS, these substances may be present in mixtures or articles only as unintentional trace contaminants (Article 4, paragraph 1(b)), in quantities specified in Annex I to the Regulation. This annex has been amended several times for PFOS to tighten the limits on unintentional contamination. The use of PFOS in hexavalent chromium (Cr^{6+}) electroplating processes in closed systems was permitted until 7 September 2025. A Member State could apply for an exemption for the above purpose by 7 September 2024, which could be granted for a maximum period of five years. Under an exemption pursuant to Regulation 2019/1021, the manufacture, placing on the market, and use of PFOA, its salts, and PFOA-related compounds could be authorised for the following purposes:

A. photolithographic production and etching processes in semiconductor manufacturing, until 4 July 2025;

B. photographic coatings applied to films, until 4 July 2025;

C. oil- and water-resistant textiles for the protection of workers against hazardous liquids posing a risk to their health and safety, until 4 July 2023;

D. invasive and implantable medical devices, until 4 July 2025;

E. the manufacture of polytetrafluoroethylene (PTFE) and polyvinylidene fluoride (PVDF) for the production of:
- high-performance, corrosion-resistant membranes for gas filtration, water filtration, and medical textile applications,
- equipment for heat exchangers to recover heat from industrial waste,
- industrial sealing materials capable of preventing the release of volatile organic compounds and $PM_{2.5}$ (particulate matter 2.5) into the environment, until 4 July 2023;

F. In fire-fighting foam for the suppression of vapours released from flammable liquids and for extinguishing flammable liquid fires (Class B fires), until 3 December 2025.

However, a number of products containing PFAS that were placed on the market prior to the entry into force of the above Regulation are still in circulation (in use).

Derivatives of the above-mentioned substances are also subject to restrictions under REACH [41]. These include, for example, ammonium perfluorohexane sulfonate or tridecafluorohexane sulfonic acid in a 1:1 mixture with 2,2'-iminodiethanol. Perfluorobutanesulfonic acid (PFBS) is classified as a substance of very high concern [42]. In 2024, Commission Regulation (EU) 2024/2462 [43] established new restrictive conditions concerning perfluorohexanoic acid (PFHxA), its salts, and related substances that may degrade to PFHxA. From 10 April 2026, the placing on the market or use of fire-fighting foams and foam concentrates for public fire brigades containing PFHxA and its salts at concentrations equal to or greater than 25 ppb, or PFHxA-related substances at concentrations equal to or greater than 1,000 ppb, will be prohibited – except where these brigades respond to industrial fires at facilities covered by European Parliament and Council Directive 2012/18/EU [44]. From 10 October 2029, the same restrictions will apply to fire-fighting foams and foam concentrates used in civil aviation. From 10 October 2026, PFHxA may no longer be placed on the market or used at the above concentrations in textiles, leather, furs, and hides, in clothing and related accessories for the general public, in footwear for the general public, in paper and cardboard materials intended to come into contact with food under the scope of Regulation (EC) No 1935/2004 [45], in mixtures for the general public, and in cosmetic products as defined in Article 2(1)(a) of Regulation (EC) No 1223/2009 [46].

In the area of human health protection, European Parliament and Council Directive 2020/2184 [47] was adopted at the EU level, which in Annex I, Part B, sets limit values for perfluorinated substances in water intended for human consumption. The limit values are established for the sum of 20 selected perfluorinated substances (0.1 µg/l) or for total PFAS, including the sum of all per- and polyfluoroalkyl substances (0.5 µg/l). Member States are required to take the necessary measures to comply with the above limits by 12 January 2026. These substances are monitored when, following a risk assessment and management of catchment areas related to abstraction points carried out in accordance with Article 8 of the Directive, it is concluded that the presence of these substances in the water source is probable.

As of June 2024, the European Commission prepared an amendment to several EU water policy directives [48]. The amendment to European Parliament and Council Directive 2008/105/EC proposes a new list of priority substances for the aquatic environment, along with the corresponding environmental quality standards (EQS). Under number 65, a group of per- and polyfluoroalkyl substances (PFAS) was listed, comprising 24 chemical perfluorinated compounds. For this sum of PFAS, an EQS has been set – annual average (EQS-AA) of 0.0044 µg/l (4.4 ng/l) for the surface water matrix and 0.077 µg/kg wet weight for biota. In contrast to Directive 2020/2184, the amendment to Directive 2008/105/EC assigns a conversion factor for each PFAS relative to perfluorooctane sulfonic acid (PFOS = 1), against which the toxic risk of each additional PFAS is assessed. The analytically determined concentration of each PFAS is then multiplied by its respective factor, and the resulting sum is compared with the EQS. It should be noted that the PFAS lists in Directives 2020/2184 and 2008/105/EC do not fully overlap; 16 PFAS are common to both lists (*Tab. 1*).

The draft amendments to the directives prepared by the European Commission were discussed in the European Parliament in autumn 2024. From January 2025 until early autumn, during the Polish and Danish Presidencies, a so-called trialogue took place between the Member States and the Council of the European Union, aimed at reaching a consensus on the legislative proposals for the amended water protection directives, including Directive 2008/105/EC. At the time of writing this article, the trialogue process had not yet been completed, but its conclusion was approaching. In the final stages of the trialogue, trifluoroacetic acid (TFA) was also included in the PFAS sum. It has been found that this perfluorinated organic compound, with the shortest hydrocarbon chain, also exhibits persistence in the environment [49]. TFA concentrations in surface waters vary widely, ranging from a few to several hundred ng/l [50].

Environmental quality standards are also proposed in the amendment to European Parliament and Council Directive 2006/118/EC on the protection of groundwater against pollution and deterioration. In light of the latest scientific knowledge, Annex I of this Directive is supplemented with a quality standard for the sum of the four most problematic PFAS (PFHxS, PFOS, PFOA, PFNA) and TFA, in accordance with the value proposed by the European Food Safety Authority (EFSA). To account for differences in the toxicity of the four PFAS and TFA, relative potency factors are applied when calculating the sum of these five substances. The EQS is also 0.0044 µg/l (4.4 ng/l), the same as for surface water. The Directive notes that, in light of the latest scientific knowledge, it is important that the parameters for PFAS, including TFA, set out in Directive 2020/2184/EC be reviewed and, if necessary, revised in the near future, and that any such revisions be harmonised with the EQS set out in Annex I of Directive 2006/118/EC. Legislative approval of the amended directives is expected by the end of 2025.

Within the EU, there is also an ongoing intensive discussion on how to harmonise EQS for PFAS across surface water, groundwater, and water intended for human consumption, which will be important for the further development of legislative instruments. It is also noted that the current EQS cover only selected PFAS, even though many more (potentially several thousand) are present in the aquatic environment. For these reasons, the European Commission is preparing to establish EQS for the total PFAS load in surface waters. This is expected to take place during the next review of Directive 2008/105/EC. As part of the documentation for the review, six proposals for addressing total PFAS have been prepared [51]. The greatest consensus currently exists around the proposal setting an annual average EQS-RP of 0.05 µg/l of total organic fluorine for surface waters. The Joint Research Centre (Italy) proposes measuring total organic fluorine, or "total PFAS", only if the corresponding EQS for the sum of 24 PFAS (for both surface waters and biota) has been met (not exceeded).

Tab. 1. Comparison of lists of PFAS substances according to Directive 2020/2184 of the European Parliament and of the Council and the draft amendment of Directive 2008/105/EC of the European Parliament and of the Council

PFAS according to Directive 2020/2184	PFAS according to the draft amendment to Directive 2008/105/EC (as of 10/2025)	CAS	RPF
	Trifluoroacetic acid (TFA)	76-05-1	0.002
	2,2,3-trifluoro-3-(1,1,2,2,3,3-hexafluoro-3-(trifluoromethoxy)propoxy)propanoic acid	919005-14-4	0.03
	2,3,3,3-tetrafluoro-2-(heptafluoropropoxy)propionic acid (HFPO-DA)	13252-13-6	0.06
Perfluorobutanoic acid (PFBA)	Perfluorobutanoic acid (PFBA)	375-22-4	0.05
Perfluoropentanoic acid (PFPeA)	Perfluoropentanoic acid (PFPeA)	2706-90-3	0.03
Perfluorohexanoic acid (PFHxA)	Perfluorohexanoic acid (PFHxA)	307-24-4	0.01
	2- (Perfluorohexyl)ethyl alcohol (6:2 FTOH)	647-42-7	0.02
Perfluoroheptanoic acid (PFHpA)	Perfluoroheptanoic acid (PFHpA)	375-85-9	0.505
Perfluorooctanoic acid (PFOA)	Perfluorooctanoic acid (PFOA)	335-67-1	1
	2-(Perfluorooctyl)ethanol (8:2 FTOH)	678-39-7	0.04
Perfluorononanoic acid (PFNA)	Perfluorononanoic acid (PFNA)	375-95-1	10
Perfluorodecanoic acid (PFDA)	Perfluorodecanoic acid (PFDA)	335-76-2	7
Perfluoroundecanoic acid (PFUnDA)	Perfluoroundecanoic acid (PFUnDA or PFUnA)	2058-94-8	4
Perfluorododecanoic acid (PFDoDA)	Perfluorododecanoic acid (PFDoDA or PFDoA)	307-55-1	3
Perfluorotridecanoic acid (PFTrDA)	Perfluorotridecanoic acid (PFTrDA)	72629-94-8	1.65
	Perfluorotetradecanoic acid (PFTeDA)	376-06-7	0.3
	Perfluorohexadecanoic acid (PFHxDA)	67905-19-5	0.02
	Perfluorooctadecanoic acid (PFODA)	16517-11-6	0.02
	2,2-difluoro-2-((2,2,4,5-tetrafluoro-5-(trifluoromethoxy)-1,3-dioxolan-4-yl)oxy)acetic acid (C6O4)	1190931-41-9	0.06
Perfluorobutane sulfonic acid (PFBS)	Perfluorobutane sulfonic acid (PFBS)	375-73-5	0.001
Perfluoropentane sulfonic acid (PFPS)	Perfluoropentane sulfonic acid (PFPeS)	2706-91-4	0.3005
Perfluorohexane sulfonic acid (PFHxS)	Perfluorohexane sulfonic acid (PFHxS)	355-46-4	0.6
Perfluoroheptane sulfonic acid (PFHpS)	Perfluoroheptane sulfonic acid (PFHpS)	375-92-8	1.3
Perfluorooctane sulfonic acid (PFOS)	Perfluorooctane sulfonic acid (PFOS)	1763-23-1	2
Perfluorononane sulfonic acid (PFNS)			
Perfluorodecane sulfonic acid (PFDS)	Perfluorodecane sulfonic acid (PFDS)	335-77-3	2
Perfluoroundecane sulfonic acid (PFUnS)			
Perfluorododecane sulfonic acid (PFDoS)			
Perfluorotridecane sulfonic acid (PFTrS)			

RPF = Relative Potency Factor = Relative Potency Factor the toxic effect of a given compound relative to the toxic effect

The relative potency factor (RPF) is used in the risk assessment of mixtures of perfluoroalkyl and polyfluoroalkyl substances to express their potential harmfulness relative to a specific index compound, typically PFOA, for a given health-relevant endpoint. By assigning an RPF of 1 to the index compound, the equivalent exposure of any PFAS in the mixture can be calculated as "PFOA equivalents." This allows for a more accurate assessment of the cumulative health risk posed by multiple PFAS, which often co-occur in environmental contamination.

The requirements of Directive 2008/105/EC, as amended by Directive 2013/39/EU, have been transposed into national legislation on the protection of surface waters through Government Regulation No 401/2015 Coll. [52]. Currently, environmental quality standards have been established only for PFOS, set at $6.5 \cdot 10^{-4}$ µg/l (annual average EQS) and 36 µg/l as the maximum allowable concentration.

The amended Decree No. 428/2001 Coll. [53] already incorporates a quality limit for raw surface water (intended for treatment to drinking water) for the sum of 20 PFAS in accordance with European Parliament and Council Directive 2020/2184 (0.1 µg/l) for all three categories of raw water treatment: A1, A2, and A3.

An overview of analytical methods for PFAS determination

A range of analytical methods has been developed for PFAS monitoring, enabling their determination at sub-nanogram levels. Most methods employ liquid chromatography coupled with mass spectrometric detection. They mainly differ in the sample preparation approach – direct injection, online and offline solid-phase extraction (SPE), or dispersive magnetic solid-phase extraction (DMSPE) are all possible. The method applied for analysing water at the inlet and outlet of a drinking water treatment plant in Catalonia is based on the direct injection of 900 µl of sample without any prior preparation [54]. A similar method, also based on the direct injection of 100 µl of centrifuged water sample without any further preparation, using UHPLC-MS/MS for the analysis of several perfluoroalkyl acids (PFAA) across a wide range of water matrices, demonstrated high sensitivity (sub-nanogram quantification), speed, accuracy, and low matrix effects [55]. A direct injection method of 150 µl of water sample using an Agilent 1100 HPLC coupled to a Waters Quattro Micro tandem mass spectrometer is described in a study analysing both water and soil samples [56]. Another analytical method applicable for the determination of these contaminants is based on solid-phase extraction (SPE) followed by gas chromatography with negative chemical ionisation and mass spectrometric detection. The method is highly sensitive, and the results are fully comparable with those obtained using HPLC–MS/MS. Using this method, surface water samples from the Vltava and Elbe rivers were tested, and the target substances were detected in all samples [57]. A further review study [58] is devoted to analytical methods for PFAS determination developed and applied between 2018 and 2023. For PFAS extraction, solid-phase extraction is most commonly used, followed primarily by liquid chromatography coupled with mass spectrometry for quantification [58]. A solid-phase extraction method using 100 ml of water sample was applied to determine 22 PFAS in drinking water in the Czech Republic. High-performance liquid chromatography coupled with mass spectrometric detection was used for the actual analysis. Using this method, 67 tap water samples and 31 bottled water samples were analysed. PFAS intake by an adult from tap or bottled water amounted to a few per cent of the tolerable weekly intake established by the European Food Safety Authority and therefore did not represent a significant risk [59].

Another direct injection method for the analysis of PFAS in environmental water samples uses centrifugation and membrane filtration of small sample volumes, which are then analysed by UHPLC-ESI-MS/MS using a delay column to reduce interference from background PFAS contamination. For the actual analysis, an AB Sciex 6500 plus Q-Trap mass spectrometer is used, operated in negative multiple reaction monitoring (MRM) mode. The instrument system includes a delay column positioned between the pumps and the autosampler to reduce interference from background PFAS. The method monitors eight short- and long-chain PFAS, which are identified by tracking specific precursor–product ion pairs and their retention times, and quantified using calibration curves based on isotopically labelled internal standards. The method is technically robust and provides sufficient sensitivity and reproducibility for use as a primary screening approach to detect and quantify PFAS at levels typically observed in surface and drinking waters. It can accurately detect and quantify common PFAS, including PFOA and PFOS, at concentrations below the commonly recommended screening level of 70 ng/l [60].

Another study [61] addresses the determination of PFAS in accordance with Directive 2020/2184/EU using the prescribed methods. In this paper, three different methods were developed and evaluated for the determination of 20 PFAS in tap and bottled water, based on online and offline solid-phase extraction (SPE) and direct injection. In all cases, ultra-high-performance liquid chromatography coupled with tandem mass spectrometry (UHPLC-MS/MS) was used as the analytical technique. Offline SPE using Oasis Weak Anion Exchange (WAX) cartridges provided the best performance in terms of quantification limits (LOQ ≤ 0.3 ng/l) and accuracy (R ≥ 70 %) in drinking water samples. Online SPE and direct injection had certain drawbacks, such as background contamination issues and lower accuracy for the least polar compounds. The offline method was applied to the analysis of 46 drinking water samples, including 11 commercial bottled samples, 23 Spanish tap water samples, and 12 international tap water samples [61].

In Greece, a method combining ultra-performance liquid chromatography (UPLC) with Orbitrap mass spectrometry (Orbitrap-MS), using an electrospray ionisation (ESI) interface in negative mode, was developed, validated and applied to real samples. Samples of lake and seawater, as well as wastewater from municipal and hospital WWTPs, were analysed. The concentrations in surface waters were below the limit of detection or significantly lower than those in wastewater [62].

Another emerging method aimed at accelerating and simplifying PFAS determination applies dispersive magnetic solid-phase extraction (DMSPE) to enrich PFAS in various surface water samples. For the preconcentration and extraction of PFAS from various river water samples, magnetic Fe_3O_4 @ MIL-101 (Cr) was used for the first time as an adsorbent in MSPE. Concentrations of the target analytes in the water samples were determined using high-performance liquid chromatography with a diode-array detector and ultra-high-performance liquid chromatography – tandem mass spectrometry [63].

To assess PFAS contamination levels in sludge originating from selected PFAS at 43 WWTPs in the Czech Republic, an analytical screening method was developed and validated for 32 PFAS representatives, including new substitutes (e.g. GenX, sodium dodecafluoro-3H-4-oxanonanoate, 8-dioxanonanoate – NaDONA). For the risk assessment of agricultural use of WWTP sludge commonly applied as fertiliser, human exposure to PFAS was calculated for various types of vegetables grown in soil potentially fertilised with realistically contaminated sludge in the Czech Republic [64].

A method for the quantitative determination of PFOS was also developed using high-performance liquid chromatography (HPLC) coupled with Orbitrap mass spectrometry (Orbitrap-MS), employing a heated electrospray ionisation (HESI) interface operated in negative mode. HPLC separation of the analytes was achieved using a reversed-phase C18 analytical column (RP-C18). The method enables reliable monitoring of PFOS and its derivatives in environmental samples in accordance with the criteria of the environmental quality standard, taking into account the maximum permissible concentrations and the annual average concentrations specified in Directive 2013/39/EU. The method was applied for the routine analysis of selected PFAS in environmental samples from the Baltic Sea region [65].

A non-target screening (NTS) approach based on high-resolution mass spectrometry (HRMS) is also essential for the comprehensive characterisation of PFAS in environmental, biological, and technical samples, due to the very limited availability of authentic PFAS reference standards. Since MS/MS information is not always achievable in trace analysis and only selected PFAS are present within homologous series, additional techniques for prioritising HRMS-measured data according to their probability of being PFAS are highly desirable. The procedure proposed in the study could also be applied to the monitoring of other groups of compounds [66].

Given the approaching obligation to regularly monitor the concentrations of selected PFAS, methods enabling highly sensitive analysis for the routine determination of PFAS in various types of water (drinking water, surface water, and groundwater) are being developed rapidly [67, 68]. Simultaneously, methods for the quantification of short-chain and ultra-short-chain PFAS are being developed [69].

Due to the fact that there is a very large number of PFAS and it is rather demanding to identify or quantify all of them in a sample, simpler methods for determining total organic fluorine are increasingly being adopted for screening purposes. The most commonly used method for this purpose is the determination of adsorbable organic fluorine (AOF), which provides non-specific information on the amount of organofluorine compounds. A procedure using combustion ion chromatography (CIC) covers a wide range of organofluorine compounds that are currently not detectable by LC-MS/MS. AOF is important for estimating unknown PFAS concentrations, screening PFAS contamination, and assessing PFAS exposure [70, 71].

As noted above, the number of publications addressing PFAS is enormous. The main challenges that must be addressed when analysing PFAS are high background levels, which require strictly followed procedures at the very stage of sample collection, and the careful selection of suitable sampling containers and other tools used during sample processing. Given the very strict environmental quality standards proposed in European legislation, methods for determining PFAS are highly demanding in terms of instrumentation. Due to their widespread presence, background levels of the target compounds can be high even in standard laboratory equipment. Some components of analytical instruments also need to be replaced with PFAS-free equivalents.

Sampling

Due to the ubiquitous presence of PFAS, even the simple act of sampling is complicated, including the choice of materials for the sample containers. The influence of storage and sample preparation conditions – such as storage duration, solvent composition, storage temperature (4 °C and 20 °C), and sample mixing technique (shaking or centrifugation) – on PFAS losses into container materials was studied for commonly used HDPE materials, including polypropylene (PP), polystyrene (PS), polypropylene copolymer (PPCO), polyethylene terephthalate (PET), polytetrafluoroethylene (PTFE), and glass. The highest losses of long-chain PFAS in aqueous solutions were observed with polypropylene. Sorptive losses of long-chain PFAS decreased in an 80 : 20 water : methanol solution (%, v/v). Sorption losses of PFAS with temperature were dependent on the solvent composition [72]. When sampling for these compounds, strict procedures must be followed to prevent secondary contamination. Sampling equipment and accessories must not contain materials such as PTFE, PVDF, PCTFE, ETFE, or FEP (e.g., commercial brands Teflon®, Hostaflon®, Kynar®, Neoflon®, Tefzel®). LDPE must not be used in direct contact with the sample medium (e.g., for sample containers) but may be present in, e.g., protective bags. HDPE is most commonly used for sample containers and should be pre-tested for the presence of PFAS.

Field clothing and footwear used by sampling personnel must not contain Gore-Tex® or other waterproof materials, nor materials with stain-repellent surface treatments. Suitable clothing and footwear include items made of cotton, PVC, or polyurethane that have been repeatedly washed beforehand without synthetic softeners. PFAS may also be present in a wide range of personal care products, including cosmetics, creams, shampoos, repellents, etc. Therefore, it is recommended not to apply such products on the day of sampling or during sampling activities, in order to avoid any contact between these products and the sampling equipment and materials. Provided that all other principles are observed, these products may be used before sampling work begins, but their application in the field during sampling (for example, sunscreens or insect repellents) should be avoided. The basic precaution is thorough hand washing and the use of powder-free nitrile gloves.

Sample contamination may also occur during transport. It is therefore essential to avoid all of the above-mentioned materials, water-repellent labels on sample containers, and permanent markers. To check for possible contamination during sampling and transport, field blanks and transport blanks are collected [73].

Current monitoring of PFAS in surface waters in the Czech Republic

Substances from the PFAS group are not yet monitored systematically across the entire Czech Republic. An analysis was carried out of the available monitoring data for individual substances from this group obtained from the river basin authorities, which conducted monitoring of surface water quality. When calculating average values (annual averages or overall averages for the period during which PFAS compounds were monitored), values below the limit of quantification (LOQ) were included at the LOQ level.

In the **Ohře river basin**, PFOS was measured annually from 2012 to 2023 at 42–110 profiles. During 2012–2017, the limit of quantification (LOQ) was 0.010 µg/l, and from 2018 onward it was 0.020 µg/l. Throughout the entire monitoring period, the majority of measurements were below the LOQ, ranging from 70 % to 100 % in individual years. Positive values therefore ranged from 0 % to 30 % in individual years. Overall, 83 % of measurements were below 0.020 µg/l, 16 % were between 0.020 and 0.100 µg/l, and 2 % exceeded 0.100 µg/l, with the maximum recorded value reaching 0.600 µg/l. The annual mean values evaluated for the entire basin ranged from 0.010 to 0.021 µg/l in individual years, with an overall mean of 0.017 µg/l for the entire period. In 2024, monitoring of PFAS in the Ohře basin was initiated in accordance with Directive 2020/2184 on the quality of water intended for human consumption in drinking water reservoirs. The LOQ used was 0.006 µg/l for PFBA and 0.001 µg/l for all other PFAS. Only a few values above the LOQ were detected for PFPeA, PFHxA, PFHpA, PFOA, PFDA, PFTrDA, PFBS, PFHpS, PFOS, PFDS, and PFTrDS, ranging from 0.001 to 0.014 µg/l.

In the **Odra river basin**, only PFOS was measured at 80–82 river network profiles during 2017–2023, with a LOQ of 0.100 µg/l from 2017 to 2021, which was lowered to 0.010 µg/l in 2022. Over the entire monitoring period, only two positive values were recorded (0.210 and 0.400 µg/l in 2018). Annual mean values evaluated for the whole basin ranged from 0.010 to 0.101 µg/l, with a mean of 0.075 µg/l for the entire period.

In the **Morava river basin**, PFOS and PFOA were monitored during 2013–2023 at 44–100 profiles. The LOQ for PFOS was 0.020 µg/l in 2013–2019, 0.010 µg/l in 2020–2022, and 0.6 ng/l from 2023. Throughout the entire evaluated period, values below LOQ predominated. The proportion of positive values in individual years up to 2022 was only 0–2 %. Overall, 99.5 % of values were below 0.020 µg/l, 0.4 % were in the range 0.020–0.100 µg/l, 0.1 % were above 0.100 µg/l, and the maximum recorded value was 3.65 µg/l. Annual mean values calculated for the entire basin ranged from 0.0006 to 0.021 µg/l in individual years, with an overall average of 0.016 µg/l. Since 2023, when the LOQ was lowered to 0.6 ng/l, approximately 10 % of results have exceeded the LOQ.

For PFOA, the LOQ used throughout the entire period was 0.010 µg/l. Over the entire evaluated period, values below the LOQ predominated. In individual years up to 2022, only 0–2 % of values were positive. Overall, 99.6 % of values were below 0.010 µg/l, 0.3 % of values ranged from 0.010–0.100 µg/l, and 0.1 % of values were above 0.100 µg/l, with the maximum recorded value being 1.8 µg/l. Annual mean values, calculated for the entire catchment, ranged from 0.010–0.014 µg/l in individual years, with an overall mean of 0.011 µg/l. In 2024, monitoring of PFAS was initiated at 27 selected profiles in the Morava basin, covering the scope of Directive 2020/2184 on the quality of water intended for human consumption and the proposed amendment to European Parliament and Council Directive 2008/105/EC. The applied LOQs for individual substances ranged from 0.018 to 1.0 ng/l. In addition to PFOS and

PFOA, PFBA, PFPeA, PFHxA, PFHpA, PFNA, PFDA, PFUnDA, PFBS, and PFHxS were also detected above the LOQ, in the range of 0.02–12.6 ng/l.

In the **Elbe river basin**, PFOS and PFOA were monitored annually from 2012 to 2024 at 20–130 profiles. The LOQ for PFOS was 0.020 µg/l in 2012–2015, 0.002 µg/l in 2016–2017, and 1 ng/l from 2018 onwards. Throughout the entire monitoring period, values below the LOQ predominated, accounting for approximately 70 % overall, with 96.5 % of values below 0.020 µg/l, 3.2 % ranging from 0.020 to 0.100 µg/l, 0.3 % exceeding 0.100 µg/l, and the maximum recorded value 0.568 µg/l. The annual mean values calculated for the entire basin ranged from 0.0013 to 0.031 µg/l in individual years, with a mean of 0.0054 µg/l for the entire period.

For PFOA, the LOQ was 0.020 µg/l in 2012–2015, 0.005 µg/l in 2016–2023, and 1 ng/l from 2018 onwards. Throughout the monitored period, values below the LOQ predominated, accounting for about 95 %. Overall, 99.6 % of the values were below 0.020 µg/l, 0.4 % were in the range 0.020–0.100 µg/l, and the maximum recorded value was 0.046 µg/l. Annual mean values (evaluated for the entire basin) ranged from 0.0025 to 0.020 µg/l in individual years, with an overall mean of 0.0063 µg/l. Broader PFAS monitoring in this catchment started in 2025.

In the **Vltava basin**, PFOS and PFOA were monitored on 28–134 profiles during 2012–2024. The LOQ for PFOS was 0.100 µg/l in 2012–2013, 0.005 µg/l in 2014–2021, 0.003 µg/l in 2022, and 0.5 ng/l from 2023 onwards. Throughout the entire monitoring period, values below the LOQ prevailed. Positive values in individual years ranged from 0 % to 26 %. Overall, 87 % of values were below 0.020 µg/l, 12.9 % were between 0.020 and 0.100 µg/l, 0.1 % were above 0.100 µg/l, and the maximum recorded value was 0.289 µg/l. Annual mean values evaluated for the entire basin ranged from 0.0022 to 0.100 µg/l in individual years, with an overall average of 0.017 µg/l. Since 2023, when LOQ was lowered to 0.5 ng/l, approximately 20 % of results have exceeded the LOQ.

For PFOA, the LOQ was 0.100 µg/l in 2012–2013, 0.010 µg/l in 2014–2021, 0.005 µg/l in 2022, and 2 ng/l from 2023 onwards. Throughout the entire monitoring period, values below the LOQ predominated. Positive values in individual years ranged from only 0 % to 22 %. Overall, 87.4 % of values were below 0.010 µg/l, 12.6 % were in the range 0.010–0.100 µg/l, and only a single value exceeded 0.100 µg/l, with the maximum recorded value being 0.111 µg/l. The annual mean values for the entire basin ranged from 0.0022 to 0.100 µg/l in individual years, with an overall mean of 0.020 µg/l. In 2023, PFAS monitoring in line with Directive 2020/2184 on the quality of water intended for human consumption was initiated at 42 selected profiles in the Vltava basin, and from 2024 it was extended to include four additional substances. The applied LOQ for individual substances ranged from 0.5 to 6.0 ng/l. In addition to PFOS and PFOA, PFBA, PFBS, PFHxS, PFHpA, PFHxA, PFOS-H4, and PFTrDA were detected above the LOQ in the range of 1.2–55 ng/l. Further details on the monitoring of these substances in the Vltava basin are provided in [74].

The values detected in surface waters in the Czech Republic can be compared with findings of PFAS compounds in other countries. Between 2004 and 2010, surface water samples from 41 cities across 15 countries were analysed. PFOS and PFOA were present in all samples, with average concentrations ranging from non-detectable (ND) to 0.070 µg/l for PFOS and 0.0002–1.630 µg/l for PFOA. The maximum average PFOS concentration in surface waters in the United Kingdom was 0.019 µg/l. The PFOA concentration in surface waters in Osaka reached 1.630 µg/l. In the other cities included in the study, average PFOA concentrations were generally below 0.100 µg/l. In surface water from the Júcar River, PFAS were detected at concentrations ranging from 0.04 ng/l to 0.0831 µg/l. In Sweden, average concentrations of 26 PFAS were found in samples collected from drinking water source areas at 0.0084 µg/l, in surface waters at 0.112 µg/l, and in groundwater at 0.049 µg/l. In surface waters of the Rhine river basin, from Lake Constance to the North Sea, the concentrations of 40 PFAS were examined to assess the impact of both point and diffuse sources. Among the PFAS, perfluorobutane sulfonic acid (PFBS) predominated with concentrations up to 0.181 µg/l, and perfluorobutanoic acid (PFBA) with concentrations up to 0.335 µg/l. These two compounds accounted for up to 94 % of the total PFAS [24].

Pilot extension of monitoring to additional profiles

To supplement the monitoring profiles of PFAS substances on a broader scale, pilot monitoring was proposed in the Ohře and Odra river basins. In collaboration with the river basin administrators major closing profiles and sites with repeated PFOS detections above the limit of quantification were selected. These profiles are listed in *Tab. 2*. In addition to the sites in the target river basins, the Kopaninský stream on the outskirts of Prague was included, as it is strongly affected by Václav Havel Airport.

A summary of the monitoring sites in the Ohře basin is shown in *Fig. 1*, the sites sampled in the Odra basin are presented in *Fig. 2*, and *Fig. 3* shows the sampling site on the Kopaninský stream.

Fig. 1. Location map of Ohře basin profiles

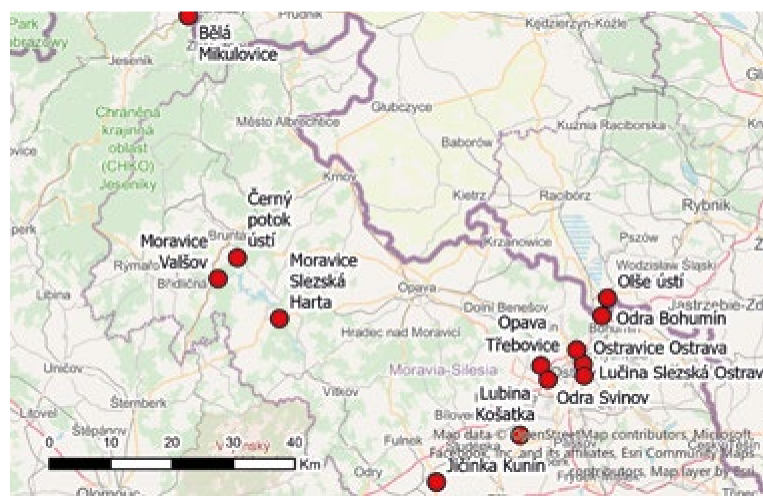

Fig. 2. Location map of Odra basin profiles

Tab. 2. Selected sampling profiles

Watercourse	Profile	Profile code	Note on selection
Bílina	Ústí nad Labem	POH_1028	PFOS (surface water): repeated occurrence of PFOS > MS, repeated occurrence of values > 0.05 µg/l
Ohře	Terezín	POH_1001	PFOS (surface water): repeated occurrence of PFOS > MS, maximum value 0.046 µg/l
Ohře	Želina	POH_1008	PFOS (surface water): repeated occurrence of PFOS > MS, PFOS (biota): 6.67–43.2 µg/kg
Bystřice	Ostrov	POH_1024	PFOS (surface water): repeated occurrence of PFOS > MS, maximum value 0.110 µg/l
Transfer from PPV Březenecká to HS Otvice	Chomutov	POH_1283	PFOS (surface water): repeated occurrence of PFOS > MS, maximum value 0.140 µg/l
Rolava	Rybáře	POH_1022	PFOS (surface water): repeated occurrence of PFOS > MS
Reslava	Pomezí – border	POH_1105	PFOS (surface water): repeated occurrence of PFOS > MS, maximum value 0.083 µg/l
Ploučnice	Březiny	POH_1032	PFOS (surface water): repeated occurrence of PFOS > MS, maximum value 0.055 µg/l, PFOS (biota): 0.99–2.99 µg/kg
Chodovský stream	Dvory	POH_1021	PFOS (surface water): repeated occurrence of PFOS > MS
Blšanka	Trnovany	POH_1026	PFOS (surface water): repeated occurrence of PFOS > MS
Chomutovka	Postoloprty	POH_1027	PFOS (surface water): repeated occurrence of PFOS > MS
Mračný stream	Záluží	POH_1080	PFOS (surface water): maximum recorded PFOS value – 0.6 µg/l
Kopaninský pot	Preláta	-	Prague Airport
Odra	Bohumín	POD_1163	Final boundary profile
Odra	below Černý příkop	POD_5569	Mouth of the wastewater from CWWTP Ostrava into the Černý stream
Odra	Svinov	POD_1161	PFOS (biota): 2.86–8.80 µg/kg
Olše	mouth	POD_5407	Mouth of the main watercourse from the Karviná district
Ostravice	Ostrava	POD_1152	PFOS (biota): 0.264–3.360 µg/kg
Lučina	Slezská Ostrava	POD_1154	Havířov WWTP + industry
Jičínka	Kunín	POD_1164	Nový Jičín WWTP
Opava	Třebovice	POD_1146	Mouth of the main watercourse from the Opava and Jeseník districts
Moravice	Valšov	POD_5203	Upstream of the Slezská Harta HS
Černý stream	mouth	POD_3581	Bruntál WWTP
Moravice	Slezská Harta	POD_101	Upstream of Kružberk HS
Bělá	Mikulovice	POD_3596	Česká Ves WWTP (Jeseník)
Lubina	Košatka	POD_1165	Industry, airport, maximum recorded PFOS value – 0.4 µg/l

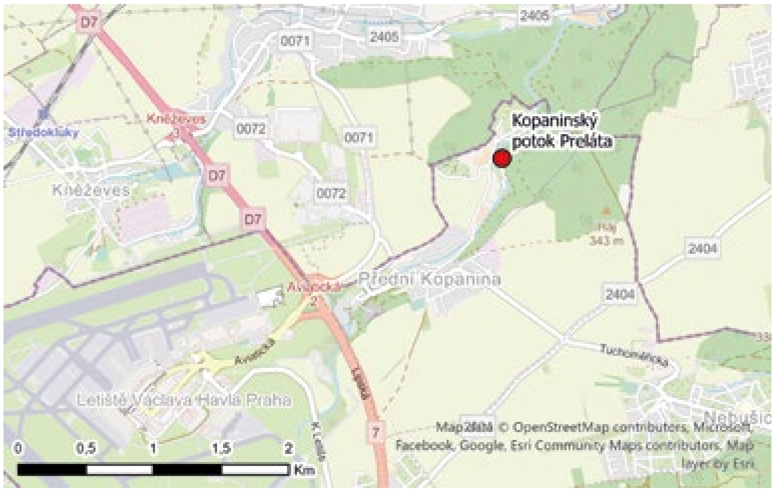

Fig. 3. Location of the sampling profile on the Kopaninský stream

The sampling also includes the measurement of field parameters: air temperature, water temperature, and water electrical conductivity. At profiles where it is possible, the flow is recorded at the nearest gauging station.

ANALYTICAL METHODS USED FOR THE DETERMINATION AND IDENTIFICATION OF PFAS

Target analysis

In developing the method for determining PFAS in surface water, we based our approach on published methods that employed similar instrumentation [67, 68]. A liquid chromatography method with mass spectrometric detection under negative electrospray ionization conditions was selected. Methanolic standard solutions were purchased from Neochema and Altium International, as well as internal standards from Wellington Laboratories, and instrument accessories for PFAS analysis.

Analyses were carried out on an Exion LC/SCIEX liquid chromatograph coupled with a Triple Quad™ 7500 mass spectrometer using negative-mode electrospray ionization, Q_0D optimization, and simple mode for the analysis. For analyte separation, a delay column Phenomenex Luna Omega C18, 100 Å, 50 × 2.1 mm, 1.6 µm, and an analytical column Phenomenex Luna Omega PS C18, 100 Å, 100 × 3.0 mm, 3 µm, were used. For the gradient elution of analytes, mobile phase A (20 mM ammonium acetate in water) and mobile phase B (methanol) were used. The mobile phase flow rate was 0.6 ml/min. The initial concentration of mobile phase A was 90 %, decreasing to 45 % at 0.1 min. From 4.50 min to 4.95 min, the concentration of mobile phase A was 1 %, returning to 90 % at 5.0 min. This gradient was used for PFAS with shorter chains.

Long-chain PFAS such as PFHxDA and PFODA are more hydrophobic than short-chain PFAS and appear to bind to polypropylene containers when the methanol concentration is below 40 %. For these compounds, the method had to be adjusted, and the gradient elution conditions were modified. The initial concentration of mobile phase A was 90 %, decreasing to 35 % at 1.5 min. At 8 min, the concentration of phase A was 5 %. From 8.1 min to 12.0 min, the concentration of mobile phase A was 1 %, rising to 90 % at 12.5 min. Calibration with the internal standard was prepared over the range 1–200 ng/l.

Sample preparation is performed as follows: 1 ml of the water sample is added to a 2 ml glass vial containing 0.65 ml of a mixed methanolic solution of surrogate standards (resulting in a concentration of 50 ng/l for each standard). The final MeOH concentration in the diluted sample is 40 %, and standards, blanks, and control samples are prepared with the same methanol concentration. The volume of sample injected is 100 µ/l.

Optimal chromatographic conditions were tuned for each individual PFAS. For each analyte, two characteristic transitions are monitored, one of which is for the internal standard. *Tab. 3* provides an overview and characteristics of the internal standards assigned to each analyte. The measured MRM transitions are listed in *Tab. 4*. The method is ready for testing with analytical standards.

Tab. 3. Internal standards

Compound	Internal standard	
PFBA	MPFBA	13C4-PFBA
PFBS	M3PFBS	13C3-PFBS
PFPeA	M5PFPeA	13C5-PFPeA
PFHxA	MPFHxA	13C5-PFHxA
PFPeS	M3PFHxS	13C3-PFHxS
HFPO-DA	M3HFPO-DA	13C3-HFPO-DA
DONA	MPFHxA	13C5-PFHxA
PFHpA	M4PFHpA	13C4-PFHpA
PFHxS	M3PFHxS	13C3-PFHxS
PFHpS	M8PFOA	13C8-PFOA
PFOA	M8PFOA	13C8-PFOA
PFOS	M8PFOS	13C8-PFOS
PFNA	M9PFNA	13C8-PFOS
PFNS	M6PFDA	13C9-PFNA
PFDA	M6PFDA	13C6-PFDA
PFDS	M6PFDA	13C6-PFDA
PFUdA	M7PFUdA	13C6-PFDA
PFUdS	M2PFDoA	13C7-UdA
PFDoA	M2PFDoA	13C2PFDoA
PFDoS	M2PFDoA	13C2PFDoA
PFTrDA	M2PFDoA	13C2PFDoA
PFTrDS	M2PFDoA	13C2PFDoA

Tab. 4. Selected diagnostic ions

Compound	MRM transitions [m/z]		EP [V]	CE [V]	CXP [V]
	Q1	Q3			
MPFBA	217	172.0	-10	-15	-11
PFBA	212.9	169.0	-10	-13	-14
PFPeA	263	219.0	-10	-12	-14
M5PFPeA	268	223.0	-10	-14	-11
M3PFBS	302	79.9	-10	-68	-12
PFBS	299	80.0	-10	-65	-2
	299	99.0	-10	-36	-9
PFHxA	313	269.0	-10	-14	-17
	313	119.0	-10	-27	-7
M5PFHxA	318	273	-10	-14	-17
PFPeS	349	80.0	-10	-62	-9
	349	99.0	-10	-43	-18
M3PFHxS	402	79.9	-10	-80	-8
PFHxS	399	80.0	-10	-95	-13
	399	99.0	-10	-41	-8
PFHpA	363	319.0	-10	-15	-10
	363	169.0	-10	-24	-10
	363	119.0	-10	-27	-14
M4PFHpA	367	322.0	-10	-14	-19
PFHpS	449	80.0	-10	-105	-9
	449	99.0	-10	-73	-10
PFOA	413	369.0	-10	-10	-25
	413	169.0	-10	-25	-10
M8PFOA	421	376	-10	-15	-24
PFOS	499	79.9	-10	-103	-13
	499	98.9	-10	-95	-12
M8PFOS	507	80	-10	-103	-13
PFNA	463	419.0	-10	-17	-14
	463	219.0	-10	-25	-11
M9PFNA	472	427	-10	-17	-14
PFNS	549	80.0	-10	-114	-8
	549	99.0	-10	-106	-10
PFDA	513	469.0	-10	-19	-14
	513	269.0	-10	-26	-15
M6PFDA	519	474	-10	-19	-14
PFDS	599	80.0	-10	-132	-8
	599	99.0	-10	-105	-9

Compound	MRM transitions [m/z]		EP [V]	CE [V]	CXP [V]
	Q1	Q3			
PFUdA	563	219.0	-10	-28	-14
	563	319.0	-10	-27	-18
M7PFUdA	570	525.0	-10	-20	-10
PFUdS	649	80.0	-10	-148	-8
	649	99.0	-10	-129	-10
M2PFDoA	615	570.0	-10	-19	-13
PFDoA	613	569.0	-10	-19	-15
	613	169.0	-10	-36	-11
	613	269.0	-10	-30	-19
PFDoS	699	80.0	-10	-173	-39
	699	98.9	-10	-150	-43
	699	280.0	-10	-73	-25
PFTrDA	663	319.0	-10	-31	-19
	663	219.0	-10	-34	-13
	663	169.0	-10	-35	-16
PFTrDS	749	80.0	-10	-176	-36
	749	99	-10	-165	-45
PFTeDA	713.1	669			
	713.1	168.9			
M2PFTeDA	715.2	670			
C6O4	339	113.0	-10	-17	-44
	339	85.0	-10	-34	-42
DONA	377	251.0	-10	-18	-41
	377	85.0	-10	-34	-3
6:2 FTOH	423	59.0	-10	-48	-15
	423	96.1	-10	-106	-9
8:2 FTOH	523	59.1	-10	-46	-3
	523	116.0	-10	-54	-11
HEPO-DA	285	169.2	-10	-11	-6
	285	185.1	-10	-31	-10
PFODA	913	868.9	-10	-25	-50
	913	169.0	-10	-49	-44
M6PFDA	519	474.0	-10	-15	-26
M2PFDA	515	470.1	-10	-15	-8
M2PFDoA	615	570.0	-10	-18	-38
MPFBA	217	172.0	-10	-15	-11
PFBA	212.9	169.0	-10	-13	-14
PFPeA	263	219.0	-10	-12	-14

Compound	MRM transitions [m/z]		EP [V]	CE [V]	CXP [V]
	Q1	Q3			
M5PFPeA	268	223.0	-10	-14	-11
M3PFBS	302	79.9	-10	-68	-12
PFBS	299	80.0	-10	-65	-2
	299	99.0	-10	-36	-9
PFHxA	313	269.0	-10	-14	-17
	313	119.0	-10	-27	-7
M5PFHxA	318	273	-10	-14	-17
PFPeS	349	80.0	-10	-62	-9
	349	99.0	-10	-43	-18
M3PFHxS	402	79.9	-10	-80	-8

Explanatory notes: Q1 – precursor ion, Q3 – product ion, EP – entrance potential, CE – collision energy, CXP – collision cell exit potential

Non-target analysis

For the development of a non-targeted analysis method focused on PFAS, high-resolution liquid chromatography coupled with mass spectrometry and electrospray ionization in negative mode was chosen.

Analyses were performed on an Agilent 1290 Infinity II liquid chromatograph coupled with a SCIEX X500R QTOF mass spectrometer with electrospray ionization in negative mode. In the first phase, a universal method for non-targeted analysis using ammonium formate as the mobile phase was tested. For PFAS, ammonium acetate was ultimately chosen as the mobile phase. For the separation of analytes, an Arion Plus C18 analytical column (100 × 2.1 mm, 3 µm) was used. Mobile phase A is 5 mM ammonium acetate, and mobile phase B is methanol. The gradient starts at 95 % A for 0.5 min and decreases to 5 % A by 14 min, where it is held for 4 min. At 18.1 min, the concentration of A is raised back to 95 %. From 18.1 min to 22 min, the concentration of A is maintained at 95 %. The column temperature is 30 °C, and the mobile phase flow rate is 0.2 ml/min. The injection volume is 100 µl. Compounds are analysed using electrospray ionisation in negative mode (ESI^-) combining a full scan over the mass range 70–1 200 Da with data-independent acquisition. The spray voltage is –4,500 V, the collision energy –35 V, and the declustering potential –80 V for all compounds. Compound identification is performed using a spectral library.

DISCUSSION AND CONCLUSIONS

Per- and polyfluoroalkyl substances (PFAS) are currently receiving considerable attention. These substances, due to their chemical properties, widespread use across various industrial sectors, environmental persistence, long-term bioaccumulation potential, and the associated risks to human health, raise significant concern. The article summarizes the legislative requirements for monitoring PFAS in the EU and the Czech Republic, including the lists of substances according to European Parliament and Council Directive 2020/2184 and the proposed amendment to Directive 2008/105/EC. Based on data provided by the individual River Basin Authorities, an analysis of the current status of PFAS monitoring in surface waters in the Czech Republic was carried out. The determination of these substances is analytically demanding and requires the implementation of new methodologies, including instrumental equipment. In the individual river basins, these substances are monitored to varying extents and with differing sensitivity. Until 2022, only PFOS, as well as PFOA (except for the Odra and Ohře basins) were systematically monitored in surface waters in the Czech Republic. However, due to the different LOQ used in individual river basins in previous years, when most results were lower than the stated LOQ, the nature of the data does not allow for an objective assessment of the situation throughout the Czech Republic. With the expansion of analytical capabilities, methods are gradually being introduced that enable the determination of individual compounds with higher sensitivity and, in particular, a wider range of PFAS substances monitored. Since 2023, monitoring of PFAS has also started in individual river basins in accordance with the requirements of Directive 2020/2184 on the quality of water intended for human consumption and, where applicable, in accordance with the proposed amendment to Directive 2008/105/EC of the European Parliament and of the Council, including the pilot monitoring by TGM WRI described in the article. Following the final approval of the amendment to Directive 2008/105/EC, there will be a need to transpose the new environmental quality standards for PFAS into Government Regulation No. 401/2015 Coll. According to the latest status of the discussions (in September 2025), the transposition deadline is expected to be 21 December 2027. By the same date, Member States shall establish a supplementary monitoring program for PFAS (including other newly identified priority substances) and, by 22 December 2030, a preliminary programme of measures concerning these substances.

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From a drop to energy: assessing the hydropower potential of watercourses using results from the "*Pico-Hydropower*" project

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Keywords: hydropower — small water courses — hydropower potential — head — water flow

ABSTRACT

The growing demand for decentralized renewable energy sources has sparked renewed interest in harnessing the hydropower potential of small watercourses. This paper presents a two-stage methodology developed within the *Pico-Hydropower project* (TA CR, No. TK04030223), aimed at identifying and evaluating suitable locations for micro-hydropower installations in the Czech Republic. The first stage involves a nationwide spatial assessment of theoretical hydropower potential (HPP) across all fourth-order catchments, based on a combination of digital elevation models (DMR 5G), interpolated values of mean annual flow (Q_a), and calculated average channel head (H). The resulting geodatabase enables prioritization of catchments with above-average potential and serves as input for more detailed analyses.

In the second stage, a specialized software tool called SCR (Sklony_ČR) was developed to identify specific river reaches with usable head and flow. The tool integrates topographic and hydrological data with user-defined technical parameters (e.g., minimum head, flow rate, or desired power output) and allows for rapid screening of suitable locations without the need for extensive field surveys. The methodology was validated through pilot testing in the Otava catchment, confirming its practical applicability for regional energy planning, project development, and academic research.

The results show that the highest hydropower potential is concentrated in the northern and northeastern regions of the Czech Republic, particularly in the catchments of the Morava, Jizera, Úpa, Olše, and Lužická Nisa rivers. The combination of spatial modelling and interactive analysis offers a scalable and user-friendly approach to utilizing the previously overlooked potential of small streams, which can significantly contribute to the sustainable development of decentralized hydropower in mountainous and rural areas. In the next phases of the project, the methodology will be verified through demonstration studies, including legal and environmental assessments of selected locations.

INTRODUCTION

The use of renewable energy sources constitutes one of the main directions of current European and national energy policy [1, 2]. While most past investment has focused on large, centralised sources, interest is growing in decentralised, low-cost, and spatially dispersed solutions that enhance the energy self-sufficiency of local communities. This approach is also being applied in hydropower, particularly in the form of micro- and pico-hydropower plants that are capable of efficiently utilising even low hydropower potential on small watercourses.

In connection with ongoing climate change, the characteristics of precipitation and runoff regimes in the Czech Republic are also changing. Although total annual precipitation does not change significantly in the long term, there are substantial changes in its temporal and spatial distribution [3], as well as an increase in the intensity of short-term precipitation events, which are more frequent and extreme than in the past [4]. The proportion of intense precipitation events is increasing, and the interval between drought episodes and flash floods is shortening. These changes are reflected in the variability of flows in small watercourses and affect their dynamics, stability, and potential for energy utilisation.

Small watercourses (SWC) constitute a significant part of the river network in the Czech Republic, and their distribution also covers areas where other renewable energy sources – such as wind or photovoltaic energy – are not sufficiently effective or feasible. Although their flows and heads often do not allow for direct energy utilisation in the sense of conventional hydropower, the overall SWC hydropower potential can be significant in the context of decentralised energy systems. For its effective use, however, it is essential to have appropriate tools for the systematic identification of suitable locations and for the preliminary technical and energy assessment of their parameters.

The *Pico-Hydropower project* (TA CR, No. TK04030223) responds to the challenge of efficiently utilising SWC by developing a methodology for determining their hydropower potential. This article builds on a previous article in *VTEI* [5], in which a methodology for interpolating flows in catchments without direct measurements was addressed, forming a key input for potential calculations. In the previous phase of the project, the theoretical hydropower potential (HPP) of all fourth-order catchments in the Czech Republic was calculated using a combination of a digital elevation model and interpolated values of mean annual flow (Q_a). The result is a spatial layer that allows for the prioritisation of catchments with above-average potential, serving as an initial filter for more detailed analyses at the level of specific stream sections [6].

Based on accuracy testing of different types of digital elevation models (DMR 4G, DMR 5G, and their derivatives) [7], a specialised tool, SCR (Sklony_ČR), was subsequently developed within the project, enabling the interactive selection of specific river reaches with usable potential. This tool combines spatial data on heads and flows with user-defined technical parameters (e.g., desired output or minimum head) and allows for the rapid identification of suitable locations for micro-hydropower utilisation without the need for extensive field surveys.

The aim of this article is to present a methodology for locating suitable river reaches of SWC using a spatial HPP database for fourth-order catchments and the SCR tool. It also demonstrates how hydrological catchment analysis can be linked with the technical design of specific sites for the installation of micro-hydropower sources.

METHODOLOGY

The first step in assessing the exploitable hydropower potential of watercourses was the spatial delineation and quantitative evaluation of all fourth-order catchments in the Czech Republic. This catchment level was chosen as an optimal compromise between hydrological homogeneity and spatial detail, and it also aligns with the established catchment classification structure used in management databases (e.g., DIBAVOD, CEVT, internal TGM WRI database).

Data inputs

The following primary datasets were used for the calculations:

— Digital elevation model DMR 5G (ČÚZK): a raster with a horizontal resolution of 5 m and a Z accuracy ≤ 0.2 m in open terrain. It is used to determine stream gradients.

— Vector network of watercourses – coarse segments from the DIBAVOD database: represents the main axes of watercourses. The HLGP_ID identifier was supplemented to ensure that the river reaches are consistent with the fourth-order catchment layer.

— Fourth-order catchment polygons: spatial units from the internal TGM WRI database, unified with watercourse data.

— Specific runoff map (q_a) in units [$l \cdot s^{-1} \cdot km^{-2}$]: an interpolated layer created using a geostatistical kriging method with external drift [8] based on selected CHMI profiles with long-term flow records. The layer was calibrated against the overall water balance and verified in the pilot Otava catchment area [5].

Although the main focus of the project was on SWC, the basic hydrological characteristics were systematically determined for all fourth-order catchments in the Czech Republic. For each catchment, the average stream head and the mean annual flow Q_a (as an indicator of long-term water availability) were calculated, and these values were subsequently used to derive the exploitable HPP. This approach enabled not only a comprehensive assessment of all fourth-order catchments but also a subsequent detailed comparison with results for selected SWC.

Methodology for determining basic parameters (H, Q_a, HPP)

The following text describes the procedure for determining the exploitable HPP of watercourses in the Czech Republic. The basis is a spatial division into

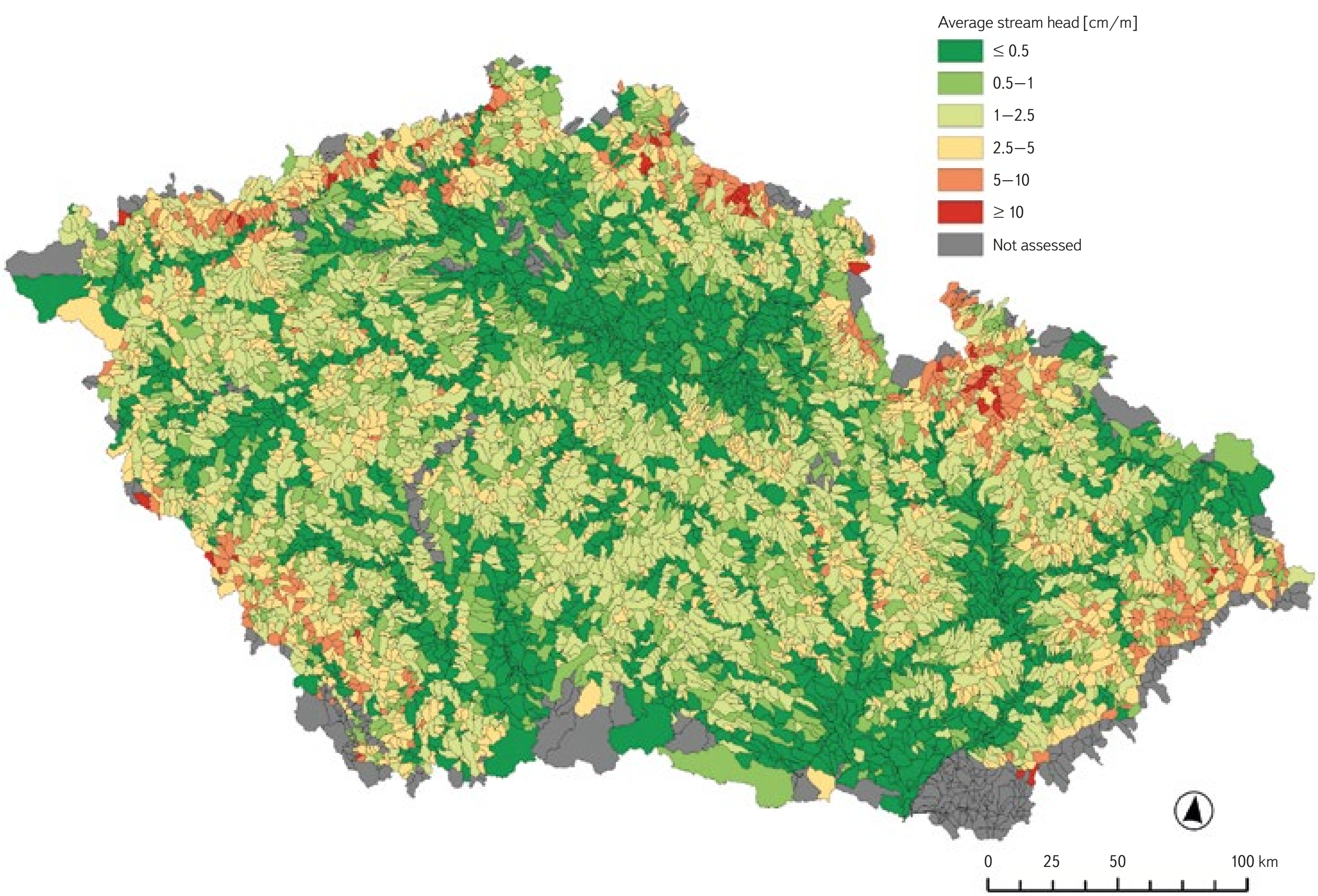

Fig. 1. Mean head of rivers in the Czech Republic (H) – fourth-order catchment scale

fourth-order catchments and the use of a combination of geospatial datasets, a digital elevation model, and hydrological data. The steps described led to the creation of a unified database containing, for each catchment, values of the average stream head (H), mean annual flow (Q_a), and derived hydropower potential (HPP – P), which is the outcome of the project and is available in [7].

a) Average head of the main stream (H)

The value of H was derived from the elevation difference between the start and end of the so-called main stream, defined as the longest connected section of the stream within a given fourth-order catchment. In the database, the main stream line is divided into reaches "from tributary to tributary," or in the headwater section "from the source to first confluence." The start and end points of each segment within a catchment were determined by intersecting the main stream line with the drainage divide. The elevation values of these points were then extracted from the DMR 5G digital elevation model raster using spatial analysis tools. The head was expressed either in metres (total difference) or as the average longitudinal slope in $cm \cdot m^{-1}$, or as a percentage (*Fig. 1*).

b) Mean annual flow (Q_a)

The mean annual flow Q_a was determined for all fourth-order catchments in the Czech Republic. The primary source was a map of specific runoff isolines q_a [$l \cdot s^{-1} \cdot km^{-2}$] [9, 10]. This map was first vectorised and then reclassified using linear interpolation, with the aim of refining the intervals between individual q_a values compared to the original printed map, thereby obtaining a more detailed spatial distribution. Reclassification was carried out in several intervals: in the range 1.16–9 $l \cdot s^{-1} \cdot km^{-2}$ a step of 0.5 was used; in the interval 9–20 $l \cdot s^{-1} \cdot km^{-2}$ a step of 1; and in the interval 20–30.5 $l \cdot s^{-1} \cdot km^{-2}$ a step of 2. Practically, this means that, for example, after the minimum value of 1.16 the next value was 1.5, followed by 2.0, 2.5, … up to 9.0 $l \cdot s^{-1} \cdot km^{-2}$ Most of the Czech Republic falls into this lowest category, whereas the interval 9–20 is characteristic mainly of mountainous areas, and values of 20–30.5 occur only sporadically (e.g., in the Krkonoše Mountains).

The values of q_a were assigned to individual fourth-order catchments based on the intersection of each catchment polygon with the vectorised map of isolines. In cases where a catchment extended across several q_a intervals, the resulting specific runoff was calculated as an area-weighted mean. Subsequently, the mean annual flow Q_a [$l \cdot s^{-1}$] was computed for each catchment according to the following equation:

$$Q_a = q_a \cdot A$$

where:

A is the catchment area [km^2]

If a catchment was split into multiple parts, the resulting flow was determined as the sum of the partial runoff values.

The resulting Q_a values were further calibrated using data from 137 limnigraph stations operated by the Czech Hydrometeorological Institute (CHMI).

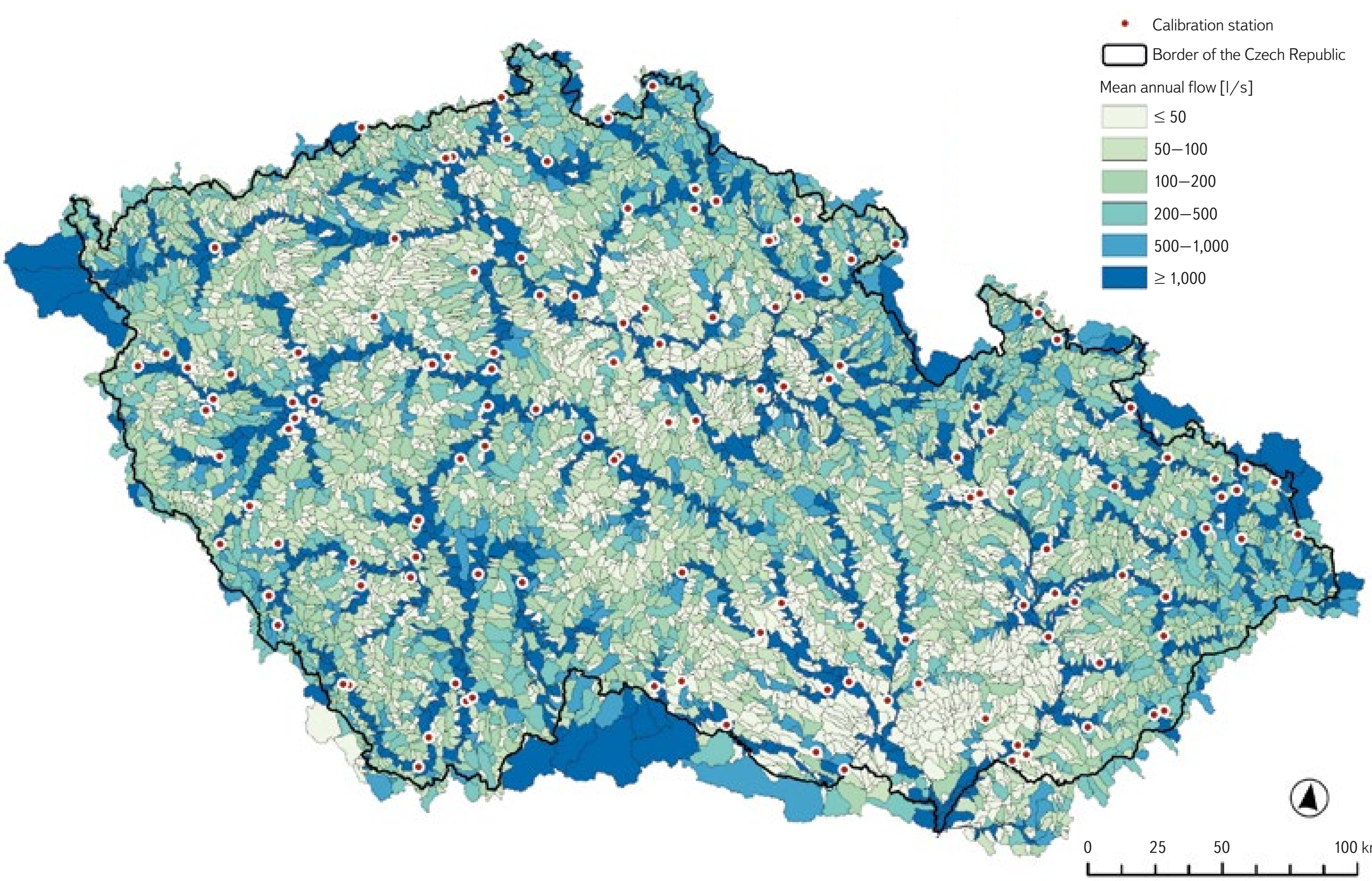

Fig. 2. Mean annual streamflow (Q_a) – fourth-order catchment scale

The stations were selected so as to avoid excessive spatial density of profiles and to ensure that each station represented a sufficiently large upstream catchment area. This approach ensured uniform coverage of the Czech Republic and, at the same time, reduced unnecessary workload associated with very small catchments.

Calibration consisted in comparing the calculated values of Q_a with the measured flows at the gauging-station profiles and subsequently adjusting them. The differences were apportioned across the individual fourth-order catchments proportionally to the magnitude of the originally derived runoff values from the isoline map. In this way, systematic biases were removed and the reliability of the Q_a estimates improved, as shown in *Fig. 2*.

c) Hydropower potential (P)

To estimate the theoretical hydropower potential P [kW], a simplified working equation was used:

$$P = 6 \cdot Q_a \cdot H$$

where:

H	is	elevation difference [m]
The coefficient 6		accounts for unit conversion and gravitational constant
Q_a		represents mean annual flow [$m^3 \cdot s^{-1}$]

At this stage of the calculation, turbine efficiency is not considered, so the resulting value represents the gross theoretical power, primarily useful for comparing the relative potential between catchments.

This simplified relationship is based on the general equation derived from Bernoulli's law for the potential energy of a water column:

$$P = \rho \cdot g \cdot Q \cdot H \cdot \eta$$

where:

ρ	is	water density (1,000 $kg \cdot m^{-3}$)
g		acceleration due to gravity (9.81 $m \cdot s^{-2}$)
Q		mean annual flow [$m^3 \cdot s^{-1}$]
H		elevation difference [m]
η		efficiency (not applied at this stage of the calculation)

The resulting spatial layer, containing the attributes of mean head (H), mean annual flow (Q_a), and derived hydropower potential (HPP), enables a uniform and comparable assessment of all fourth-order catchments in the Czech Republic (*Fig. 3*). This layer serves as the basis for subsequent analyses and forms the primary input for the next phases of hydropower potential assessment.

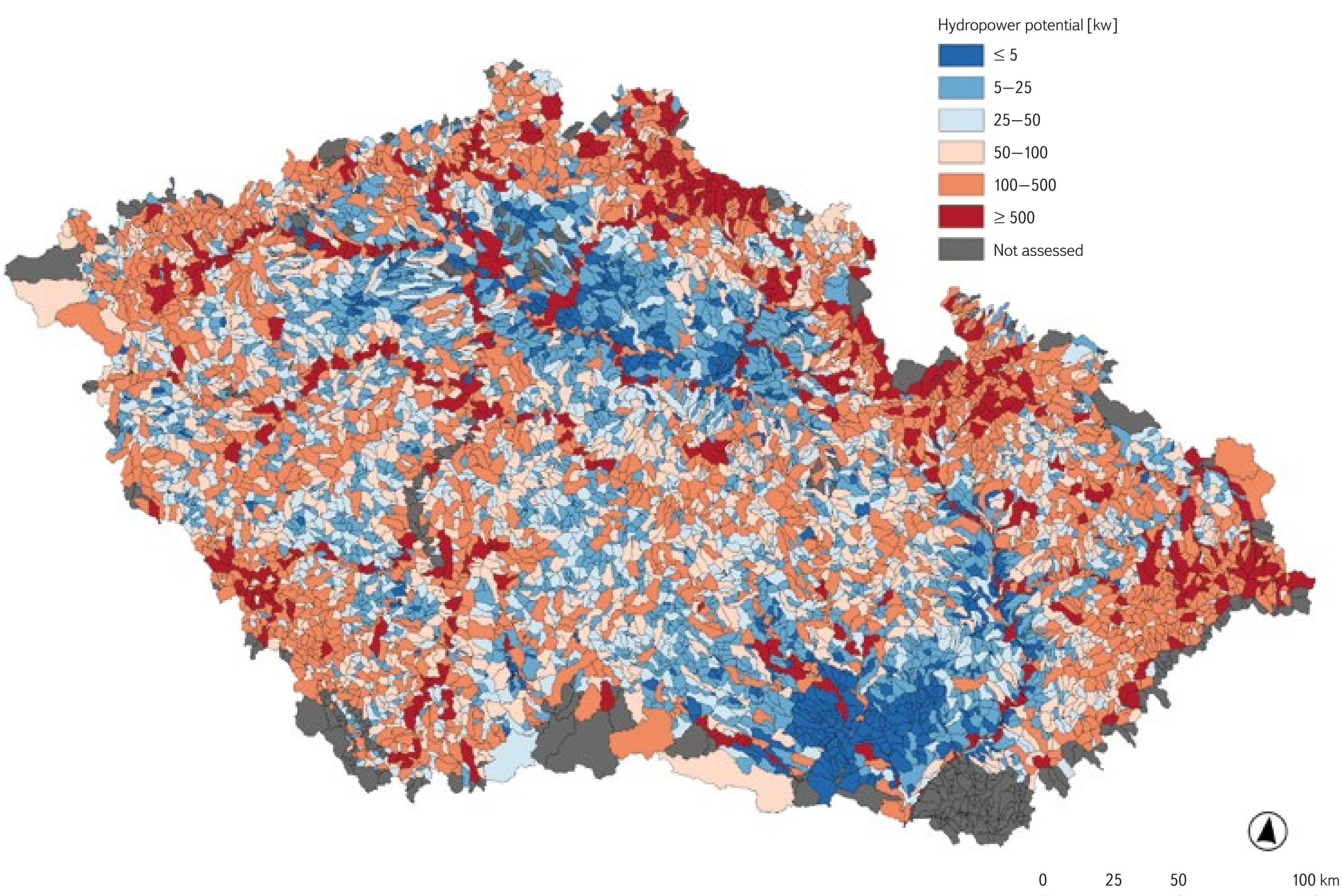

Fig. 3. Estimation of theoretical hydropower potential (P) – fourth-order catchment scale

Identification of subsections using the SCR tool (Sklony_ČR)

While the calculation of hydropower potential for fourth-order catchments allows for the spatial identification of areas with a higher probability of suitable locations, more detailed assessment of specific stream sections is necessary for subsequent use. For this purpose, the SCR tool (Sklony_ČR) was developed within the project – a specialized software tool for the localization and assessment of the hydropower potential of stream sections.

This application is designed as a standalone executable (*.exe) and was developed in the C++ programming language. It is built on a geodatabase generated from the digital elevation model of the Czech Republic, interpolated flow characteristics, and topologically connected stream lines. The tool allows users to search for and filter specific stream sections in the user interface based on defined technical parameters, and subsequently to visualize and analyze them according to the specified criteria.

The operation of the SCR tool is based on a pre-processed geodatabase of sections with usable head, created using a semi-automatic detection method from DMR 5G. This database contains the following types of data:

A. *Slope lines (so-called gradient segments)*
These are vector segments (primary stream sections) traced along the stream axis, created by segmenting the main line based on significant changes in slope. The segments have a defined start, end, length, elevation difference (ΔH), and calculated average slope. Refinement was performed using an algorithm that detects inflection points in the elevation profile of the line derived from DMR 5G.

B. *Flow characteristics (Q_a)*
Each segment was assigned an estimated mean annual flow (Q_a) based on spatial interpolation from the specific runoff map (see section Methodology for determining basic parameters).

C. *Identifiers and technical attributes*
Each segment carries a unique ID (UTOKH_ID), a reference to the corresponding catchment (IDVT), and the stream segment ID (HLGP_ID).

Additionally, the database contains calculated values for:

- segment length (m),
- elevation difference – minimum head (m),
- minimum energy potential – estimated power (kW).

User interface and search algorithm

For the presentation of the SCR user interface [11], the Spůlka (HLPG_ID 108020180) was selected. The application is designed as a guided workflow for selecting river reaches, reflecting the decision-making logic applied in the preliminary assessment of hydropower potential. In the first stage, the user defines the area of interest by selecting a fourth-order catchment or a specific primary stream section.

User-defined technical criteria are subsequently applied to the selected river reach. Filters include minimum segment length (50, 100, 250, and 500 m), minimum elevation difference (1–5 m in 1 m steps), minimum flow value Q_a (0.1–0.5 $m^3 \cdot s^{-1}$ in 0.1 $m^3 \cdot s^{-1}$ steps), and optionally a direct requirement for the resulting power (1–5 kW in 1 kW steps). The combination of these parameters allows for the pre-exclusion of segments with insufficient conditions and streamlines the search for suitable candidate sites.

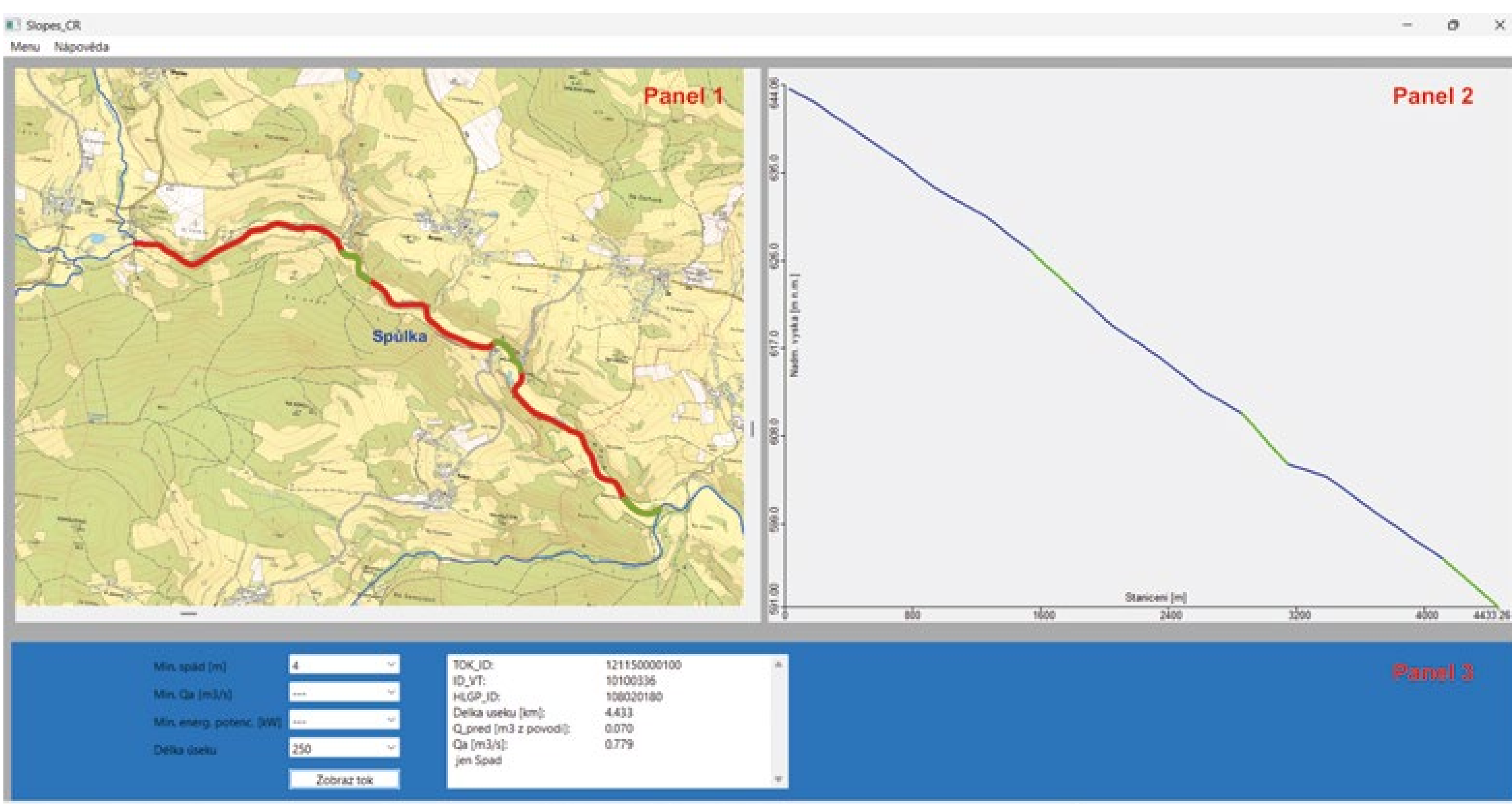

Fig. 4. Identification of river reaches according to the defined parameters (panel 1); longitudinal profile of the selected river with delineated reaches (panel 2); and input parameters with tabular values of the selected reach (panel 3)

The results are made available to the user as both a spatial visualization and a tabular output, as shown in *Fig. 4*. In the map window, suitable segments are highlighted in different colours and can be clicked to access detailed information. It is also possible to display an interactive longitudinal stream profile, where the segments are clearly marked, including their parameters and spatial location. A table with key attributes (length, head, Q_a) is also available as a text. In this way, the application supports rapid identification of stream reaches that meet the specified parameters, requiring minimal prior knowledge from the user. The outputs serve as a basis for subsequent project preparation steps or for comparative analyses at the regional level.

RESULTS

The database of hydropower potential at the level of fourth-order catchments provides a unified overview of the distribution of HPP in small watercourses and allows for rapid identification of regions with higher values for more detailed subsequent assessment. Thanks to visualization in maps and tables, preliminary analysis can be carried out without the need for extensive field surveys. The database is complemented by the Sklony_ČR application, which allows detailed analysis of individual river reaches based on user-defined technical parameters (e.g., head, flow, power). Results are presented as maps and tables with longitudinal profiles of the streams, facilitating the identification of sites with actual energy potential. The combination of the database and the application thus provides a comprehensive tool – from broad-scale assessment to detailed localization of suitable reaches.

For demonstration purposes, a procedure was carried out where fourth-order catchments with a mean annual flow below $1\ m^3 \cdot s^{-1}$ were excluded from the analysis. The remaining catchments were subsequently aggregated to the level of third-order catchments, and their hydropower potential values were summed. Simultaneously, the resulting values were normalized by catchment area, allowing comparison of individual units independently of their size. This procedure provided an overview not only of the absolute total potential but also of its relative intensity per unit area.

The results showed that the highest hydropower potential is concentrated primarily in the northern and northeastern parts of the Czech Republic. Notable contributions come from the Morava catchment to Šumperk, the Kamenice and Jizera, the Úpa and Olše catchments, as well as smaller catchments such as the Lužická Nisa, Smědá, and Vidnavka with Bělá. Higher values were also identified in the mountainous and foothill areas of the Krkonoše, Jizera Mountains, Jeseníky, and Beskydy, where the combination of higher heads and more stable flows creates favourable conditions for the development of micro-hydropower. An overview of the most significant catchments is presented through a map output and a graph, showing the spatial distribution of potential across the Czech Republic. The basic characteristics are summarised in *Tab. 1*..

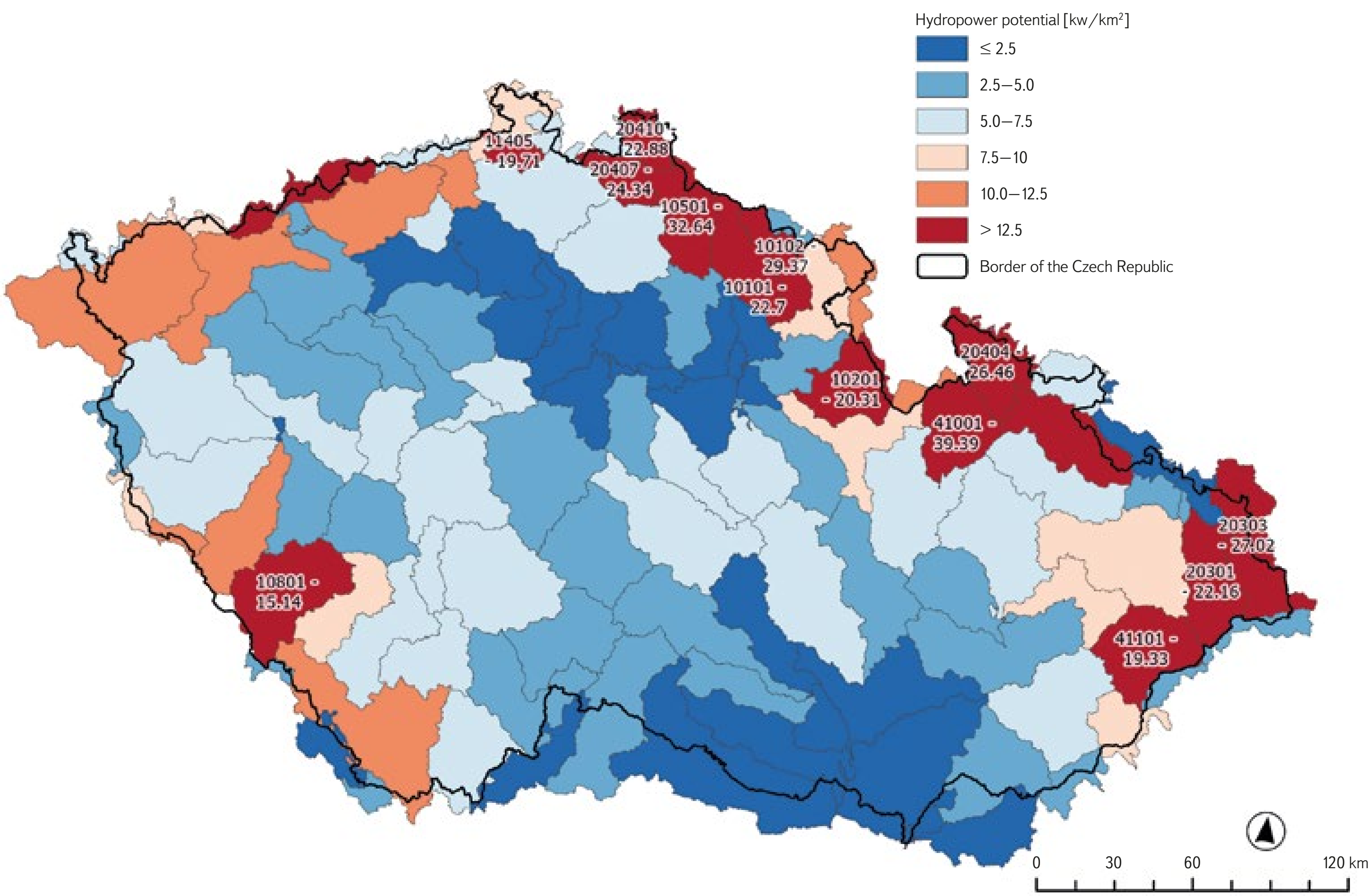

Fig. 5. Hydropower potential of third-order catchments recalculated per unit area (km²)

Tab. 1. Third-order catchments with the highest hydropower potential

Third-order catchment code	Catchment name	Third-order catchment area [km²]	SWC catchment area [km²]	Total HPP [kW]	Number of fourth-order catchments	HPP [$kW \cdot km^{-2}$]
41001	Morava catchment to Šumperk	818.67	635.19	25.02	69.00	39.39
10501	Kamenice and Jizera catchments to the confluence	782.09	531.40	17.35	49.00	32.64
10102	Úpa catchment	512.89	366.05	10.75	45.00	29.37
20303	Olše catchment	1,112.65	484.61	13.09	45.00	27.02
20404	Vidnavka and Bělá catchments	773.75	657.20	17.39	86.00	26.46
20407	Lužická Nisa catchment	377.09	240.48	5.85	27.00	24.34
20410	Smědá catchment	324.25	258.22	5.91	30.00	22.88
10101	Elbe catchment to Jaroměř	711.72	579.40	13.15	68.00	22.70
20301	Ostravice catchment	826.74	590.44	13.08	59.00	22.16
10201	Divoká Orlice catchment	777.78	489.17	9.93	63.00	20.31
11405	Kamenice catchment	220.06	193.54	3.81	21.00	19.71
41101	Rožnovská and Vsetínská Bečva catchments to the confluence	988.39	793.37	15.33	87.00	19.33
10801	Otava catchment	1,289.08	1,054.55	15.97	107.00	15.14
10801	Otava catchment	1,289.08	1,054.55	15.97	107.00	15.14

The created database and the SCR (Sklony_ČR) application find use not only in the assessment of hydropower potential but also in other areas. For public authorities and local governments, they can serve as a basis for energy strategies, strategic documents, and spatial planning. Watercourse managers can use them for planning the management of water resources and for evaluating the impacts of climate change. Investors and project designers are provided with a tool for the rapid selection of suitable sites and for streamlining project preparation, thereby reducing survey costs. The academic sector can use them for modelling, research, and teaching. Thanks to these possibilities, both outputs represent a versatile resource for integrating energy, water management, and environmental planning.

DISCUSSION

One of the key advantages of the presented approach is its two-tiered structure, which allows linking a nationwide mapped assessment of the hydropower potential of fourth-order catchments with the local identification of specific river reaches based on user-defined technical parameters [12, 13].

This approach effectively combines a high level of standardisation and clarity in the mapping phase with the possibility of detailed assessment of specific sites using the SCR application. Users can readily identify catchments with above-average HPP from the map outputs (e.g., specialised N_{map}) and then focus, via the software tool, on pinpointing suitable reaches with particular head, flow, and power characteristics. This eliminates the need for manual inspection of an entire watercourse or cartographic analysis within a GIS environment.

The proposed approach has a high degree of practical applicability for a variety of target groups. For public authorities (municipalities, regions, and watercourse managers), it provides an accessible basis for strategic planning of renewable energy utilisation and can be applied in the preparation of spatial-energy concepts. Designers and investors can use the software tool for a rapid assessment of sites prior to the preparation of a technical study, thereby significantly shortening the project's preparatory phase. The tool is usable without advanced GIS expertise, which extends its applicability to smaller organisations or municipalities lacking specialised support. Its practical utility was confirmed during pilot tests in the Otava catchment, where suitable sites were successfully identified.

It is, however, important to emphasise that the approach carries certain methodological and technical limitations. One of the key constraints is the uncertainty in the estimated flows, which are derived from the interpolation of the specific runoff isoline map [10] and calibrated against measured profiles. In locations without available measurements, high accuracy of flow data cannot be guaranteed [14], which may affect the reliability of the estimated power output [15]. At the current stage of the study, ecological and property-related aspects, which are critical for realistically assessing a site's suitability for a small hydropower installation [16], were also not included. These aspects (e.g., protection zones, migration barriers, conflicts with spatial planning) should be evaluated in subsequent steps of project preparation.

Nevertheless, it can be concluded that the combination of robust map-based analysis and a targeted software tool has produced a practical and highly scalable approach, which expands the possibilities of utilising hydropower potential in small watercourses and contributes to the modernisation of planning for small renewable energy sources in the Czech Republic. A further outcome supporting practical implementation will be delivered in the form of a validated technological approach (Z_{tech}), where several demonstration studies will be tested. In several fourth-order catchments, a pilot assessment will be carried out for the construction of the smallest-scale hydropower plant, complemented by a review of land ownership issues and an evaluation of environmental aspects, with particular emphasis on stream connectivity. The subsequent outcome will also include a preliminary assessment of the economic feasibility of selected options, allowing a more comprehensive evaluation of the suitability of sites for the installation of small hydropower stations. This output will serve as an example of the application of the proposed methodology under real conditions and as a basis for verifying the feasibility of individual options.

CONCLUSION

The presented approach for assessing the hydropower potential of small watercourses in the Czech Republic combines a nationwide spatial evaluation with a detailed analysis of specific river reaches using the SCR tool. This two-tiered methodology enables the efficient identification of sites with exploitable energy potential even without direct flow measurements, thereby significantly shortening the initial phase of project preparation. The applicability of this approach has been validated using data from across the Czech Republic as well as in the pilot area of the Otava catchment.

The proposed tool and methodology provide a practical basis for a territorial screening of sites suitable for the implementation of micro-hydropower installations, particularly in areas where other renewable energy sources are not technically or economically feasible. This approach will be further developed within a Z_{tech} type outcome – a validated technological process – which will focus on assessing the real-world feasibility of constructing micro-hydropower facilities at selected sites and on modelling operational regimes, including water storage and distribution.

This article does not discuss other specific circumstances related to the actual implementation of small hydropower stations, such as construction constraints, legislative procedures, economic costs, and operational risks. These factors have a crucial impact on the ultimate feasibility of projects and should therefore be considered in subsequent phases of project preparation. The approach presented here is primarily focused on the mapping and analytical assessment of potential, serving as an initial step in the systematic identification of suitable sites.

In summary, it can be stated that the combination of spatial modelling, available hydrological data, and a simple tool for technical assessment can make a significant contribution to identifying the hitherto overlooked potential of small watercourses and support the sustainable development of decentralised renewable energy in the Czech Republic.

Acknowledgements

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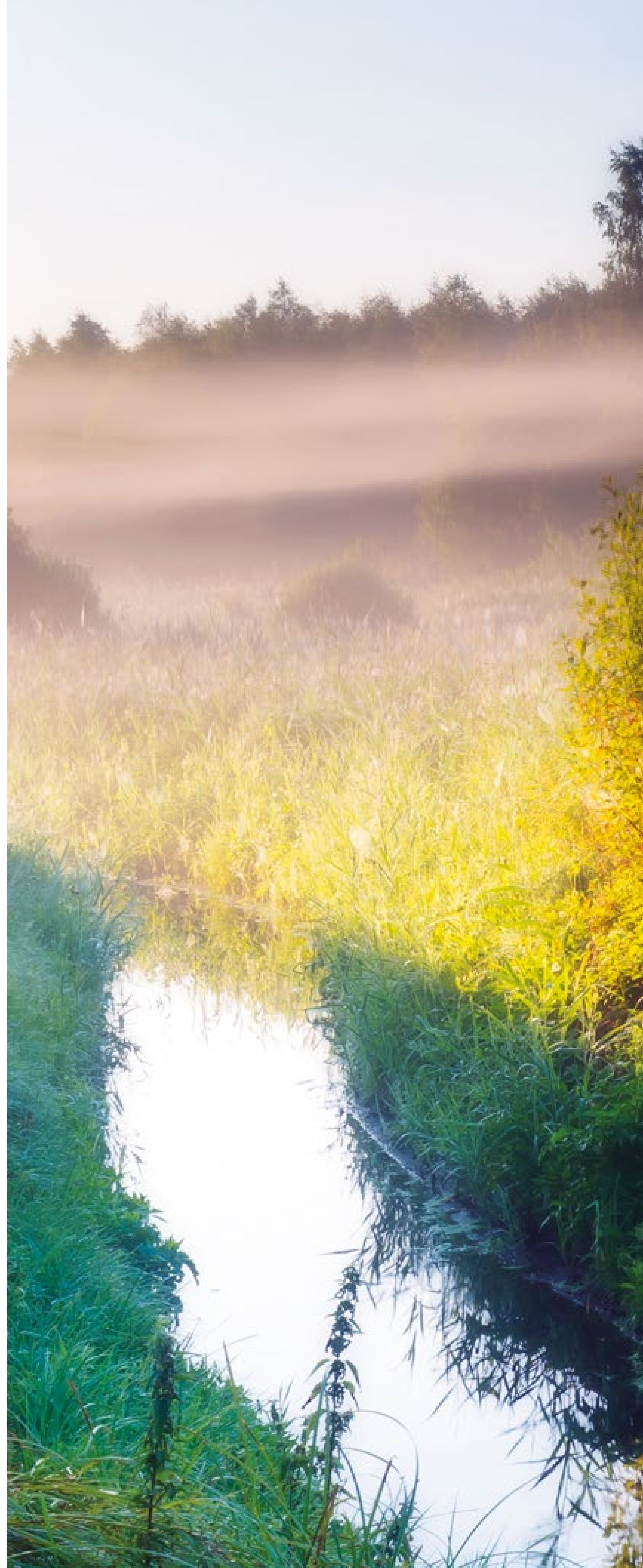


Photo: 123RF.com

Some aspects of catchment protection upstream of future reservoirs

HELENA NOVÁKOVÁ, MILENA FOREJTNÍKOVÁ, MARTIN CALETKA, KATEŘINA SEDLÁČKOVÁ

Keywords: protected areas of natural water accumulation — catchment — water reservoir — modified critical points — erosion — vulnerable zone — comprehensive land consolidation

ABSTRACT

Protected areas of natural water accumulation have been long monitored and protected. So far, little attention has been paid to the catchment area which will be the future source of water for these water reservoirs from the point of view of influencing their quality. This article focuses on certain diffuse (non-point) processes that may lead to pollution and thus to limited use of accumulated water. It describes the methodology for identifying critical points in the vicinity of the future reservoir, where an excessive amount of sediment loads will enter the aquatic environment during torrential rainfall events. This will lead to sedimentation of the reservoir as well as to the input of dissolved pollutants. The methodology was applied to all 61 selected sites; the results are clearly presented in *Tab. 1* and further discussed. As another non-point aspect, the representation of so-called Nitrate Vulnerable Zones within the reservoir catchment areas is evaluated. Although these areas are assessed in terms of excessive nitrate levels in water, other undesirable compounds used in agriculture may also occur there. As a third aspect, the article describes the status of the land consolidation process in the monitored catchments and discusses their contribution to catchment protection. In conclusion, it is stated that it would be necessary to enshrine into legislation the protection of LAPV catchments, especially for those reservoirs intended for drinking water supply.

INTRODUCTION

When assessing the purposefulness and efficiency of constructing a new reservoir, many parameters are important on the one hand – those that can be considered basic, technical, and can be clearly described and quantified. These include the type of reservoir, its capacity and inundated area, hydrological conditions, and so on.

On the other hand, there are numerous parameters that can be described as socio-economic. These include, for example, the attitudes of local people who will be affected by the construction, and the interests of various specialists, each of whom has defined different objectives they wish to achieve through the construction (or non-construction) of the reservoir. Anyone seeking to emphasise their own position and goals selects arguments that support them and downplays or ignores those that do not serve their purposes.

The *Water Centre I* project focused on the study of 61 sites from the 2020 Master Plan of Areas Protected for Surface Water Accumulation [1]. This selection took into account hydrological conditions, that is, areas that will need to be addressed as a priority in terms of water supply [2].

It is important to note that considerations regarding a future reservoir do not affect only the areas impacted by the dam construction itself and the area of the future floodplain. The reservoir brings problems as well as social and economic impacts both downstream and upstream of the affected watercourse: it improves overall conditions in the catchment (and the wider area) below the reservoir; however, it creates pressure on land-use possibilities above it. This aspect has so far received insufficient attention in the case of the protected areas of natural water accumulation (hereafter LAPVs) – most protective measures relate only to the area of the future dam and the anticipated floodplain. Within this scope, they were also adopted and recorded as a Territorial Reserve [3] in the Spatial Development Principles (hereafter SDP) of the regions. *Fig. 1* shows the area of Terezín LAPV from the SDP of the South Moravian Region [4]. If requirements regarding land management and use in the catchment above the future reservoir are mentioned, they are general, non-specific, and their impacts on the lives of affected residents, on infrastructure, agriculture, and local businesses are not monitored. Meanwhile, the protection of the relevant catchment should be a permanent part of LAPV protection, and for sites of type A (drinking water) it should focus particularly on safeguarding water quality.

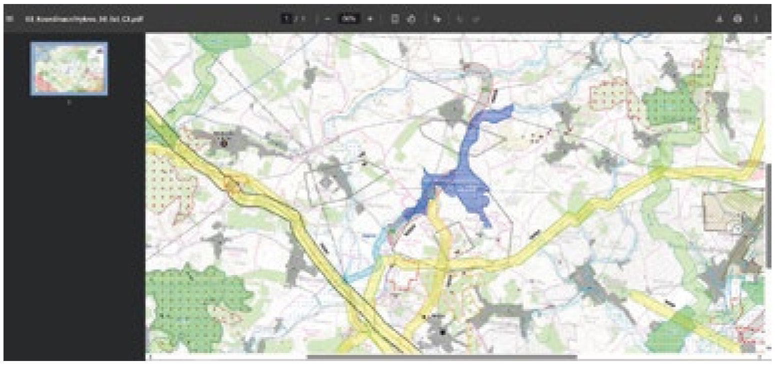

Fig. 1. Example of spatial development principles of the South Moravian Region [4]: LAPV Terezín – blue hatching

Therefore, in the project we focus primarily on identifying, describing, and listing the various aspects and impacts of the proposed construction of hydraulic structures on individuals and entire communities, as well as on different types of economic activity in the affected area. For this article, we have selected three phenomena that are related to the natural configuration of the landscape and its spatial use and transformation. The aim of this analysis is to compile the basis for comparing the proposed reservoirs in terms of individual aspects and their combinations, considering both the advantages and the issues that their construction may cause.

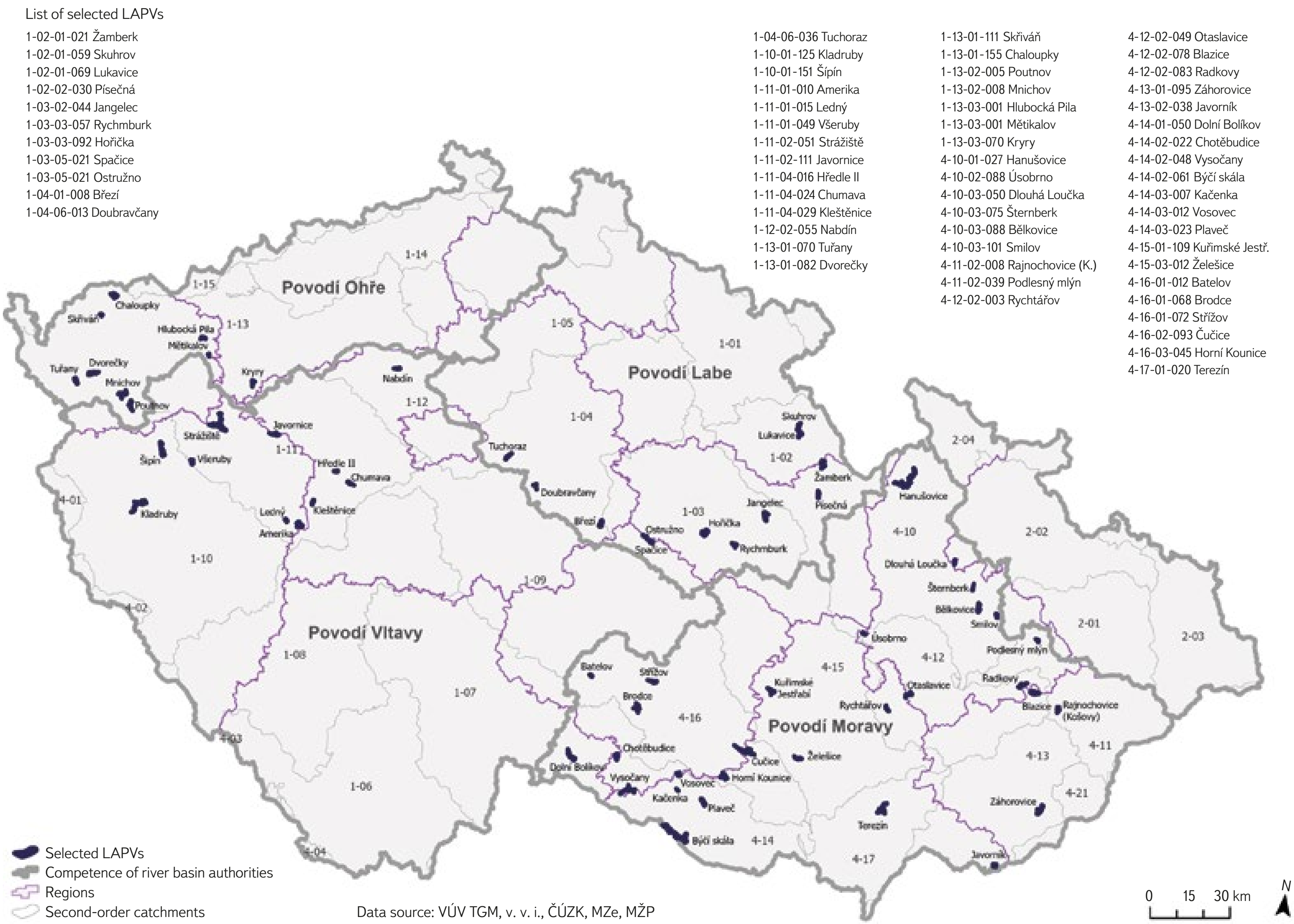

Fig. 2. Location of protected areas of natural water accumulation selected for the project

METHODOLOGY

In the first step, a spatial analysis was carried out for the relevant LAPV catchments or sub-catchments for each site. For these areas, the overlap with designated vulnerable zones and with areas under additional protection of hydrological importance was displayed, together with a list of affected water bodies, their current status, and the measures expected for them under the sub-basin plans. The source of some of this information was the relevant sub-basin plans [5–13].

Within the cadastral areas of municipalities belonging to the catchments of the individual sites, the status of the preparation and implementation of comprehensive land consolidation (hereinafter CLC) is monitored.

All the information obtained and processed for each site is stored in a database maintained in Excel and is used in other project outputs.

A total of 61 LAPV sites selected for the Technology Agency of the Czech Republic project No. SS02030027 *Water Systems and Water Management in the Czech Republic under Climate Change Conditions (Water Centre)*, guaranteed by the Ministry of the Environment, were included in the analysis. The sites are clearly shown in the following map (*Fig. 2*).

Modified critical points

The main part of the analysis focused on assessing the immediate surroundings of future water bodies in terms of the risk of runoff erosion during torrential rainfall. The method of critical points was used, based on a morphometric and hydrological analysis of the digital terrain model (DTM) in ESRI ArcGIS for Desktop, or the more recent ArcGIS Pro [14]. Beside the ESRI environment, there are also other freely available software tools that enable similar DTM analyses. A significant example is SAGA GIS (System for Automated Geoscientific Analyses), which, in addition to DTM analysis, is also used for modelling surface runoff and erosion–sedimentation processes [15]. Another commonly used robust platform is GRASS GIS (Geographic Resources Analysis Support System), which also offers a range of advanced tools for DTM analyses and surface runoff simulations [16]. Based on the results of a case study [17], it can be stated that both open-source tools are becoming increasingly robust platforms for morphometric and hydrological DTM or digital surface model (DSM) analyses, whether considering the relatively simple determination of flow direction and flow accumulation or more sophisticated analyses.

Critical points are identified at locations where the flow path lines of concentrated runoff, generated on the basis of a DTM, enter the built-up areas of municipalities. The modified procedure replaces the settlement boundary with a line of inundation of the water reservoir. Given the nature of flash floods (for which the methodology is designed) and their predominantly local impacts, only critical points with a contributing area not exceeding 10 km^2 are considered. For each contributing area, the physical-geographical characteristics are calculated:

Pp,r – Relative size (with respect to the maximum of 10 km^2) [-]
Ip – Average slope [%]
ORP – Proportion of arable land [%]
CNII – CNII value [-]
Hm,r – Relative value of the one-day precipitation total with a 100-year return period [-]

The combination of physical-geographical conditions, land-use types, regional differences in land cover, and the potential occurrence of extreme precipitation (in relation to synoptic conditions) for specific contributing areas is expressed by the indicator of critical conditions for the emergence of adverse effects of flash-flood events F [-]. It is proposed in the form supplemented with the weights of the relevant variables.

$$F = P_{p,r} \cdot H_{m,r} \cdot (a_1 \cdot I_p + a_2 \cdot ORP + a_3 \cdot CNII)$$

where:

a is the weight vector [$a_1 = 1.48876$; $a_2 = 3.09204$; $a_3 = 0.467171$]

Four criteria are used in the final selection of critical points (CPs). These differ for contributing areas of a predominantly agricultural character with more than 40 % arable land (referred to as variant A) and for areas where the proportion of arable land is below 40 % (variant B). Thus, the delineation also includes areas that are not primarily agricultural in character, but where investigations carried out in model catchments have nevertheless recorded damage caused by the transport of debris.

Variant A – combined criteria apply:

K1	size of the contributing area	0.3–10.0 km^2
K2	average slope of the contributing area	≥ 3.5 %
K3	proportion of arable land in the catchment	≥ 40 %
K4	F – indicator of critical conditions	≥ 1.85

Variant B – combined criteria apply:

K1	size of the contributing area	1.0–10.0 km^2
K2	average slope of the contributing area	≥ 5 %
K3	proportion of arable land in the catchment	< 40 %
K4	F – indicator of critical conditions	≥ 1.85

The main output of the CP identification process is a spatial location of the selected CPs (*Fig. 3*) and a table of LAPV with the selected CPs. For each selected CP, the designation and the values of the area (km^2), proportion of arable land (%), and average slope of the contributing area (%) are provided. The identification of CPs is the first step toward determining measures in the catchment aimed at mitigating or eliminating potential infilling of the reservoir area with sediment transported during intense rainfall events.

The basic data sources for the CP analysis were the datasets of the Digital Terrain Model of the Czech Republic, fourth generation (DMR 4G) [18] and fifth generation (DMR 5G) [19]. These are point clouds from airborne laser scanning of the Earth's surface. Irregular triangular networks (TINs) were created from the point layers and subsequently a raster digital terrain model (DTM) with a resolution of 5 m. The DTM was subsequently modified using the so-called

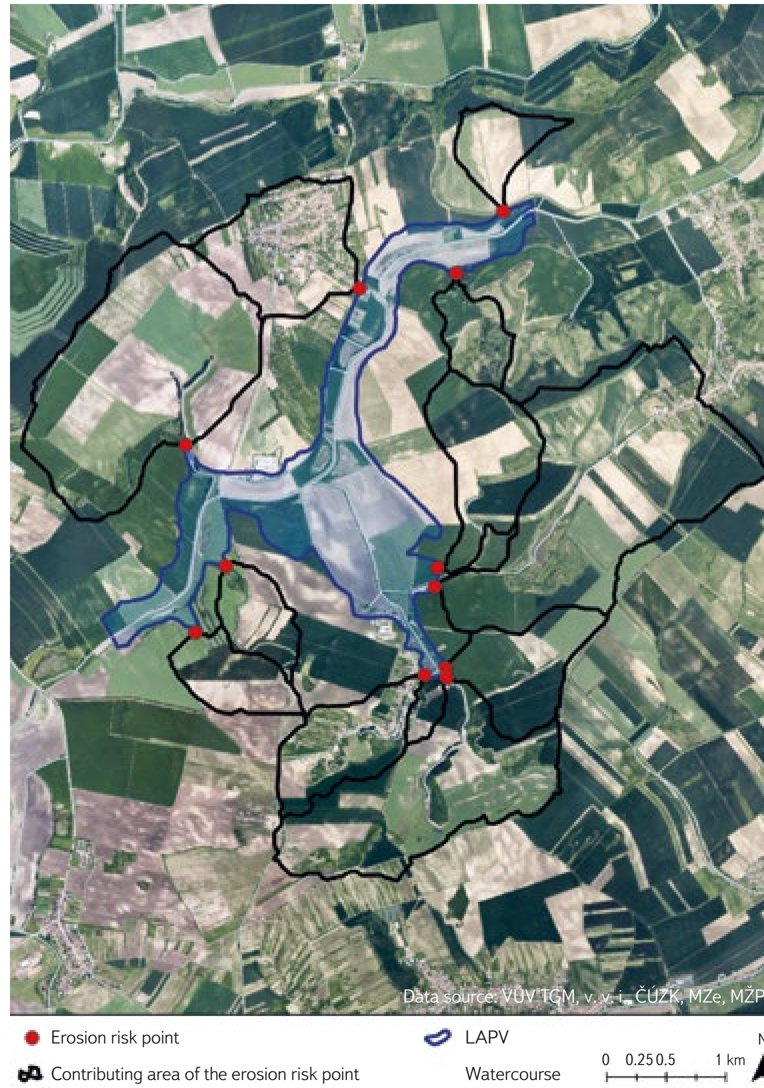

Fig. 3. Location of identified modified critical points for Terezín protected area of natural water accumulation

"burning" method [20, 21] for features that may not be captured in the original DTM but can have a crucial influence on the direction and accumulation of surface runoff, and thus on the description of the real character of its formation and, ultimately, on the correct delineation of the contributing areas of the CPs. Specifically, layers from the planimetric section of the ZABAGED® database were used – watercourses, culverts, and bridges.

Vulnerable zones

Erosion wash-off in the reservoir catchment not only carries the risk of sedimentation in the reservoir but also the introduction of pollutants, particularly from diffuse sources of contamination, thereby causing undesirable deterioration of water quality in the reservoir. In the Master Plan of Areas Protected for Surface Water Accumulation [1], the sites are divided according to their importance into two categories:

Category A comprises areas whose water-management importance lies primarily in their ability to create or supplement sources for drinking water supply, and possibly to fulfil other functions as well.

Category B comprises areas that, due to their location and characteristics, are suitable for accumulation for the purposes of flood protection, meeting water abstraction

Fig. 4. Intersection with declared vulnerable zones for the catchment area upstream of Terezín protected area of natural water accumulation

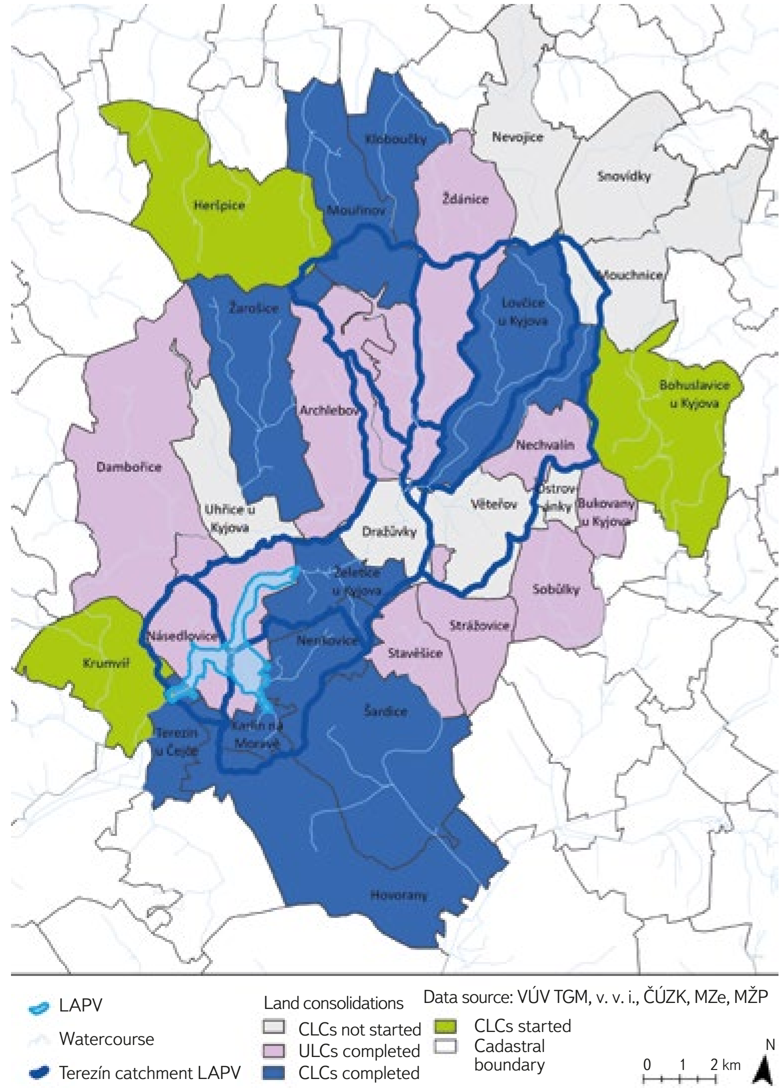

Fig. 5. Status of comprehensive land consolidation in the catchment of Terezín protected area of natural water accumulation

demands, and enhancing flows (ensuring ecological flows in watercourses).

The factors threatening water quality in reservoirs include the input of pollution from agricultural sources. In view of these considerations, and in connection with the potential use of some LAPV as sources of drinking water, the percentage of vulnerable zones in the catchment – or in the sub-catchment of the protected LAPV – and the determined vulnerability of the inundated LAPV areas were included as an additional criterion.

The identification of vulnerable zones is based on the Nitrates Directive [22], which aims to reduce water pollution caused by nitrates from agricultural sources and to prevent further such pollution.

In the Czech Republic, the Nitrates Directive is transposed by Section 33 of Act No. 254/2001 Coll., on Waters [23], and defines vulnerable zones as sites where surface water and groundwater – particularly those used or intended as sources of drinking water – have nitrate concentrations exceeding 50 mg/l or may reach this value, or where surface waters are experiencing, or may experience, undesirable deterioration of water quality due to high nitrate concentrations from agricultural sources. Vulnerable zones are established by government regulation. At the start of the project, Government Regulation No. 277/2020 Coll., on the designation of vulnerable zones and the action programme, was in force [24]. During the project, the fifth revision of vulnerable zones was carried out, and measures of the sixth action programme were established [25]. The revision was promulgated by Government Regulation No. 193/2024 Coll., effective from 1 July 2024 [26]. Vulnerable zones are delineated by cadastral units of the Czech Republic [27]. For the purposes of the project, a dataset containing the list of cadastral units designated as vulnerable zones as of 1 July 2020 was used [28]. As an example, *Fig. 4* shows the intersection with the declared vulnerable zones for the catchment above Terezín LAPV.

The Czech Republic issues a joint action programme for all designated vulnerable zones.

The method of maintaining records on the status of surface and groundwater is established by Decree No. 252/2013 Coll., on the scope of data in records of the status of surface and groundwater and on the manner of processing, storing, and transmitting these data to public administration information systems [29].

Comprehensive land consolidation

Land consolidation is one form of landscape planning and should ensure the use and protection of the landscape through biotechnical, organisational, and legal measures. It establishes the definitive form of landscape-shaping measures, with partial objectives including, for example, the simplification of land records or allocation procedures. Comprehensive land consolidations (CLC) address not only ownership rights of the lands involved but also include erosion control and water-management measures, the design of road networks, and measures to improve nature conservation and ecological stability of the landscape. They are usually carried out for entire cadastral areas (in contrast to uniform land consolidation – ULC, which typically takes place on smaller areas and among fewer landowners) [30].

Given that CLCs also include erosion control and water-management measures, the construction of a new reservoir may alter their function. Therefore, not only all cadastral areas affected by the potential inundation were considered, but it was also important to focus on cadastral areas within the catchment influenced by the reservoir, as its construction will also change runoff conditions in the surrounding smaller catchments. By overlaying the layer of cadastral maps with the areas of affected catchments in GIS, the affected cadastral areas were identified, and the status of CLCs in each cadastral area was checked on the Land Office portal [31]. An example of the method for Terezín LAPV is shown in *Fig. 5*.

RESULTS

A total of 61 protected areas of natural water accumulation (LAPV – Sites for Surface Water Accumulation) were evaluated. Below, *Tab. 1* summarises the results of the analyses of the selection of modified critical points and the vulnerability of areas with respect to the Nitrates Directive for the selected LAPV.

Focusing on the results of the modified CP analysis, two sites – Nabdín and Hředle II – can be considered non-risk areas. No modified CPs were identified in their catchments. At the other end of the spectrum, i.e., among sites with a high number of selected M-CPs (>10 M-CPs), are Kladruby (10 M-CPs), Trkmanka (11 M-CPs), Vysočany (11 M-CPs), Strážiště (13 M-CPs), and Hanušovice (17 M-CPs). The second value derived from the analysis is the total area of the catchments – the contributing areas of the M-CPs. This specifies the area where measures will be necessary to mitigate or eliminate erosion processes. The sites with the largest total M-CP catchment areas are Poutnov (25.84 km^2, 6 M-CPs), Čučice (28.09 km^2, 8 M-CPs), Vysočany (28.59 km^2, 11 M-CPs), and Hanušovice (51.30 km^2, 17 M-CPs).

Tab. 1 also includes data on the percentage of vulnerable zone relative to the total area of the LAPV catchment (or sub-catchment) and a list of cadastral units designated as vulnerable zones located within the inundation zone of the LAPV.

The database also includes the results of the analyses of CLCs carried out in the catchments for all 61 LAPV. However, the article does not present the full overview, particularly due to the temporal variability of these data. The entire

Tab. 1. Summary of analysis results for selected protected areas of natural water accumulation

Designation according to the 2020 Master Plan	Hydrological order number	LAPV name	Watercourse	Category	Inundation area [km^2]	Number of selected M-CPs	Catchment area of M-CPs [km^2]	Number of selected M-CPs
14	1-02-01-021	Žamberk	Rokytenka	B	1.90	2	6.70	1 %; The floodplain area is not designated as vulnerable.
Annex No. 4	1-02-01-059	Skuhrov	Bělá	A	0.97	2	2.44	24 %; 773476 Malý Uhřínov; 749109 Skuhrov nad Bělou
7	1-02-01-069	Lukavice	Kněžná	B	0.70	3	12.24	98 %; 773476 Malý Uhřínov, 682535 Prorubky, 688851 Lukavice u Rychnova nad Kněžnou
10	1-02-02-030	Písečná	Potočnice	B	0.63	4	11.04	The area is not designated as vulnerable.
6	1-03-02-044	Jangelec	Loučná	B	1.93	2	3.51	94 %; 617504 Pekla, 648752 Hrušová, 767263 Tisová u Vysokého Mýta, 788228 Vysoké Mýto
11	1-03-03-057	Rychmburk	Krounka	B	0.79	5	2.29	59 %; 695947 Miřetín, 719226 Perálec, 640034 Hněvětice, 734241 Předhradí u Skutče
5	1-03-03-092	Hořička	Ležák	B	2.69	4	13.45	32 %; The floodplain area is not designated as vulnerable.
12	1-03-05-021	Spačice	Doubrava	B	0.45	3	5.03	68 %; 672190 Úhrov, 781924 Heřmanice u Vilémova
8	1-03-05-021	Ostružno	Doubrava	B	0.50	5	5.17	70 %; 658553 Jeřišno, 658570 Vestecká Lhotka
2	1-04-01-008	Březí	Klejnárka	B	0.72	3	4.27	89 %; 738310 Radostice u Brna, 757438 Střelice u Brna, 712612 Ořechov
3	1-04-06-013	Doubravčany	Výrovka	B	0.54	1	3.23	98 %; 643190 Bohouňovice II, 791091 Vršice, 600920 Hryzely, 600911 Barchovice, 791075 Nesměň u Zásmuk
13	1-04-06-036	Tuchoraz	Šembera	B	0.88	2	4.02	83 %; 631205 Doubravčice, 771384 Tuchoraz, 767182 Vrátkov
70	1-10-01-125	Kladruby	Úhlavka	A	3.06	10	22.71	46 %; 792888 Telice, 792896 Zhoř u Stříbra, 733717 Prostiboř, 612677 Tuněchody u Stříbra
82	1-10-01-151	Šipín	Úterský Stream	A	2.11	5	10.97	35 %; 775614 Olešovice, 716031 Krsov
59	1-11-01-010	Amerika	Klabava	A	2.06	1	1.46	The area is not designated as vulnerable.

Designation according to the 2020 Master Plan	Hydrological order number	LAPV name	Watercourse	Category	Inundation area [km²]	Number of selected M-CPs	Catchment area of M-CPs [km²]	Number of selected M-CPs
Annex No. 4	1-11-01-015	Ledný	Ledný Stream	B	0.48	2	7.75	The area is not designated as vulnerable.
85	1-11-01-049	Všeruby	Třemošná	B	0.68	3	1.22	1 %; The floodplain area is not designated as vulnerable.
80	1-11-02-051	Strážiště	Střela	A	3.80	13	16.94	33 %; 763756 Štichovice, 697133 Černá Hať, 763748 Křečov, 691461 Česká Doubravice, 691496 Manětín, 697168 Strážiště u Mladotic, 691526 Vysočany u Manětína, 691453 Brdo u Manětína, 697150 Mladotice
69	1-11-02-111	Javornice	Javornice	B	1.03	7	12.86	96 %; 614874 Břežany u Rakovníka, 762601 Milíčov, 654574 Slatina u Chříče, 672068 Kožlany, 632996 Hedčany
66	1-11-04-016	Hředle II	Stroupínský Stream	B	0.66	0	0.00	18 %; The floodplain area is not designated as vulnerable.
68	1-11-04-024	Chumava	Chumava	B	0.90	3	3.87	88 %; 683205 Libomyšl, 704202 Neumětely
72	1-11-04-029	Kleštěnice	Jalový Stream	B	0.62	1	1.82	11%; The floodplain area is not designated as vulnerable.
76	1-12-02-055	Nabdín	Bakovský Stream	B	0.89	0	0.00	11 %; The floodplain area is not designated as vulnerable.
58	1-13-01-070	Tuřany	Šitbořský Stream	B	1.43	1	1.04	The area is not designated as vulnerable.
50	1-13-01-082	Dvorečky	Libava	A	1.52	1	2.71	The area is not designated as vulnerable.
56	1-13-01-111	Skřiváň	Skřiváň	B	0.36	1	2.20	The area is not designated as vulnerable.
52	1-13-01-155	Chaloupky	Rolava	A	1.93	2	11.67	The area is not designated as vulnerable.
55	1-13-02-005	Poutnov	Teplá	A	1.23	6	25.84	1 %; The floodplain area is not designated as vulnerable.
Annex No. 4	1-13-02-008	Mnichov	Pramenský Stream	A	1.82	2	4.29	The area is not designated as vulnerable
51	1-13-03-001	Hlubocká Pila	Liboc	A	0.78	2	6.20	The area is not designated as vulnerable.
54	1-13-03-001	Mětikalov	Liboc	B	0.32	3	11.30	The area is not designated as vulnerable.
53	1-13-03-070	Kryry	Podvinecký Stream	B	0.73	5	21.99	36 %; The floodplain area is not designated as vulnerable.
24	4-10-01-027	Hanušovice	Morava	A	5.34	17	51.30	0 %, The floodplain area is not designated as vulnerable
40	4-10-02-088	Úsobrno	Úsobrnský Stream	B	0.38	1	2.23	1 %; The floodplain area is not designated as vulnerable.
22	4-10-03-050	Dlouhá Loučka	Huntava	A	0.38	1	1.55	7 %; 626465 Křivá, 626457 Horní Dlouhá Loučka
38	4-10-03-075	Šternberk	Sitka	B	0.65	3	5.98	The area is not designated as vulnerable.
17	4-10-03-088	Bělkovice	Trusovický Stream	A	1.26	4	8.08	The area is not designated as vulnerable.
36	4-10-03-101	Smilov	Lichnička	A	0.36	1	2.74	The area is not designated as vulnerable.
34	4-11-02-008	Rajnochovice (Košovy)	Juhyně	A	0.91	5	15.12	The area is not designated as vulnerable.
32	4-11-02-039	Podlesný mlýn	Velíčka	B	0.30	2	8.45	2 %; The floodplain area is not designated as vulnerable.
35	4-12-02-003	Rychtářov	Velká Haná	B	0.53	2	2.52	6 %; 744425 Rychtářov
30	4-12-02-049	Otaslavice	Brodečka	B	1.02	3	5.42	6 %; The floodplain area is not designated as vulnerable.

Designation according to the 2020 Master Plan	Hydrological order number	LAPV name	Watercourse	Category	Inundation area [km²]	Number of selected M-CPs	Catchment area of M-CPs [km²]	Number of selected M-CPs
18	4-12-02-078	Blazice	Libosvárka	B	2.10	2	6.02	The area is not designated as vulnerable.
33	4-12-02-083	Radkovy	Dolnonětčický Stream	B	1.17	3	2.40	The area is not designated as vulnerable.
Annex No. 4	4-13-01-095	Záhorovice	Kladenka	B	1.20	3	3.49	0,5 %; 704415 Nezdenice
Annex No. 4	4-13-02-038	Javorník	Hrubý Stream	A	0.62	3	6.15	The area is not designated as vulnerable.
23	4-14-01-050	Dolní Bolíkov	Bolíkovský Stream	B	1.54	5	17.10	16 %; 718718 Lidéřovice, 617865 Cizkrajov, 684325 Lipolec, 623113 Dolní Bolíkov-Nová Ves, 617873 Dolní Bolíkov
27	4-14-02-022	Chotěbudice	Želetavka	B	0.61	7	15.47	100 %; 686816 Lomy u Jemnice, 652946 Chotěbudice, 615218 Budeč, 780391 Vesce u Dačic, 644030 Horní Slatina
43	4-14-02-048	Vysočany	Želetavka	A	1.46	11	28.59	98 %; 688045 Lubnice, 625736 Malý Dešov, 670596 Kostníky, 787850 Vysočany u Znojma, 725285 Police u Jemnice, 791571 Zblovice
Annex No. 4	4-14-02-061	Býčí skála	Dyje	B	4.68	4	11.56	100 %; 669121 Popice u Znojma, 793426 Znojmo-Hradiště, 638056 Havraníky, 688991 Lukov nad Dyjí, 640000 Hnanice, 642606 Čížov, 724114 Podmolí
28	4-14-03-007	Kačenka	Jevišovka	B	0.21	1	1.57	100 %; 718319 Pavlice, 636215 Grešlové Mýto, 608491 Boskovštejn
42	4-14-03-012	Vosovec	Nedveka	B	0.63	3	20.77	100 %; 630187 Dolní Smrčné, 758060 Přímělkov, 758078 Střížov, 717614 Panská Lhota
31	4-14-03-023	Plaveč	Jevišovka	B	0.80	2	3.76	100 %; 743305 Rudlice, 781282 Vevčice, 721557 Plaveč
29	4-15-01-109	Kuřimské Jestřabí	Libochovka	B	0.88	5	4.91	29 %; 677698 Kuřimské Jestřabí, 629669 Dolní Loučky, 624853 Deblín, 745570 Řikonín
44	4-15-03-012	Želešice	Bobrava	B	0.80	3	2.29	61 %; 738310 Radostice u Brna, 757438 Střelice u Brna, 712612 Ořechov
16	4-16-01-012	Batelov	Hraniční Stream	A	0.40	1	0.53	100 %; 628875 - Dolní Cerekev, 740497 - Rohozná u Jihlavy, 601144 - Batelov
20	4-16-01-068	Brodce	Brtnice	A	0.90	5	7.02	100 %; 666998 Brodce, 612979 Brtnička, 612961 Jestřebí u Brtnice, 711471 Opatov na Moravě
37	4-16-01-072	Střížov	Brtnice	A	0.50	2	3.84	100 %; 630187 Dolní Smrčné, 758060 Přímělkov, 758078 Střížov, 717614 Panská Lhota
21	4-16-02-093	Čučice	Oslava	A	2.55	8	28.09	66 %; 705659 Nová Ves u Oslavan
25	4-16-03-045	Horní Kounice	Rokytná	B	0.97	3	10.04	100 %; 741876 Šemíkovice, 643106 Horní Kounice, 741868 Rouchovany, 740161 Rešice
39	4-17-01-020	Terezín	Trkmanka	B	3.16	11	13.29	58 %; 675211 Krumvíř, 766542 Terezín u Čejče, 663263 Karlín na Moravě, 796018 Želetice u Kyjova, 703362 Nenkovice, 701653 Násedlovice

* The data express the percentage of the catchment (sub-catchment) area designated as vulnerable; cadastral areas designated as vulnerable that lie within LAPV floodplain.

process is still ongoing, and unfortunately proceeding very slowly. In practice, the term "completed" means that the project has been finished and the property settlements have been carried out. Implementation of the so-called Joint Facilities Plan, which is most closely related to the water-management function of the landscape, has often been postponed to a later date. The differences in the progress of land consolidations across cadastral areas within LAPV catchments are currently significant. For example, in the LAPV Strážiště catchment, on the Střela river, which includes the largest number of cadastral units (98), only 14 of them have completed land consolidations due to the predominantly forested character of the area. For Kryry Reservoir, which is closest to implementation, 13 out of a total of 23 cadastral units have been completed, and six are in progress.

Fig. 6. Terezín protected area of natural water accumulation – current state

DISCUSSION

As a case study, Terezín LAPV on the Trkmanka has already been presented several times in this article. It is a reservoir located in the gently undulating landscape of southern Moravia, with its catchment beginning in the north as far as Ždánický Forest. The reservoir itself, however, lies in open agricultural land, and almost the entire surrounding area constitutes the contributing areas of the M-CPs. The character of these areas is shown in *Fig. 6*. The soils are often overly dry and degraded, lacking the capacity to retain water, and are therefore particularly susceptible to erosion during flash floods as well as to wind erosion. If a decision is made to construct the reservoir, additional erosion-control measures will be necessary to prevent rapid sedimentation. The presented calculation method will assist the designer both in planning the measures and in verifying their effectiveness.

Vulnerable zones are clearly related to agricultural land management. Therefore, the rights and obligations within them are determined primarily by the Ministry of Agriculture, even though the impacts also affect the aquatic environment. The extent of these areas is regularly updated, with the basis for these updates being the results of groundwater monitoring. Excessive amounts of nitrates from groundwater subsequently enter surface waters through springs and drainage, where they become part of other natural processes. However, for surface waters in future reservoirs, the potential presence of pesticide substances and their metabolites may pose a greater problem, with elevated nitrate levels serving as an indicator that undesirable substances from crop production are entering the waters. The issue of pesticides, their monitoring, and their environmental impacts is still a developing field; the active substances and products used change from year to year. In view of the above, it would be appropriate to focus attention on vulnerable zones, prioritising those in the catchments of Group A LAPV, assumed to be potential sources of drinking water. It has been shown that some of these pollutants persist in waters long after their use has been banned.

Comprehensive land consolidations take place continuously over long periods. During their implementation, the requirements for their execution have gradually evolved. Initially, their primary objectives were property settlements with landowners and the consolidation of plots of land. Emphasis on erosion-control measures developed gradually, and after periods of drought, the need for water retention in the landscape is now highlighted. CLC can thus be an ideal tool for mitigating or eliminating the phenomena identified during the search for M-CPs. Their disadvantage, on the other hand, lies in the high administrative, time, and financial demands during the design, consultation, and implementation phases. Their execution then affects the use and functionality of the landscape for many years.

When constructing a larger hydraulic structure, it is always necessary to consider changes in the affected catchments, which may influence existing or future CLCs. Therefore, the entire relevant LAPV catchment should always be identified and taken into account in spatial planning documents. CLCs should then be completed and evaluated across the whole catchment, together with any necessary erosion-control interventions.

Water-management authorities should also place greater emphasis on the protection of the relevant catchments in their decision-making. However, this would require additional legislative tools, for example in the form of a protection zone for a future water source. One of the existing options is also the increased use of prohibitions or restrictions on activities in designated protected areas of natural water accumulation, or alternatively, the extension of these areas to cover entire LAPV catchments [32].

CONCLUSION

For a long time, sites designated for future surface water accumulation have been protected within spatial planning; however, targeted protection of the catchments of these reservoirs is lacking. Investigations carried out within the project showed that general environmental protection may not be sufficient in these cases. The better condition of some sites is attributed more to natural conditions and the development of the landscape over the years than to targeted measures. This applies particularly to points that are critical for concentrated runoff and the transport of washed-off material into watercourses during heavy rainfall events. The article further documents the impact of diffuse, predominantly agricultural activities in the affected catchments. These are long-term negative effects with lasting consequences, even in the event of targeted interventions. It is therefore necessary to introduce legislative protection of the relevant catchments now, particularly in cases where the future reservoir is intended to serve as a source of drinking water.

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Photo: J. Hrdinka

The beginnings of timber floating in the region of Novohradské hory

JAROMÍR FLORIAN

Keywords: timber floating — timber rafting — Novohradské hory (Gratzen Mountains) — South Bohemia

ABSTRACT

In the last quarter of the 18th century, a unique system for timber floating was built in the region of Nové Hrady. Its creation is linked to the name of the then owner of the Nové Hrady Estate, Johann Nepomuk Buquoy, while the project and its implementation were designed and overseen by engineer Johann Franz Riemer. The uniqueness of the system lay in the fact that it allowed the floating of both loose timber (logs) and bound timber (rafts), even on the narrow and low-capacity streams of the Novohradské hory (Gratzen Mountains). The basis of the navigation system was formed by modified (navigable) watercourses, on which there were reservoirs (ponds) ensuring the necessary amount of water for floating timber. The beginnings of the construction of the navigation system date back to the second half of the 1770s. Materials preserved in the archival records of the Nové Hrady Estate provide insight into the beginnings of the waterway construction in 1780–1784. In 1783, the first part of the construction of the navigation system was completed. From that year on, logs were transported to České Budějovice and the first rafts to Prague. In the section to České Budějovice, the waterway included the Pohořský stream, which connects to the Černá and Malše rivers. After 1783, the expansion of the navigation system continued to the upper reaches of the Černá river and its tributaries. The navigation system was completed at the turn of the 18th and 19th centuries by making smaller tributaries of the Černá river navigable and with the construction of reservoirs on those streams. The navigation system was maintained and operated until the first half of the 1940s.

INTRODUCTION

From the late 1770s to the turn of the 18th and 19th centuries, a unique navigation system was constructed in the Novohradské hory (Gratzen Mountains) and their foothills, enabling the transport of both loose timber and bound timber. The key part of the system was located on the Nové Hrady Estate, which had been owned since 1621 by the Buquoy family, of French origin [1]. To transport the abundant timber from the forest districts of the Gratzen Mountains, the Černá river and its tributaries were used. From Kaplice, the logs were driven further to České Budějovice along the Malše river (*Fig. 1*).

Based on a set of surviving and hitherto systematically unprocessed sources from the Nové Hrady Estate archive, this study attempts to map in greater detail the construction and operation of the navigation system in the last quarter of the 18th century, with a primary focus on the years 1780–1784. The study concentrates on the more general aspects of the system's construction and development and builds on insights presented in the existing professional literature, which has mainly addressed the system during its peak and later periods of operation.

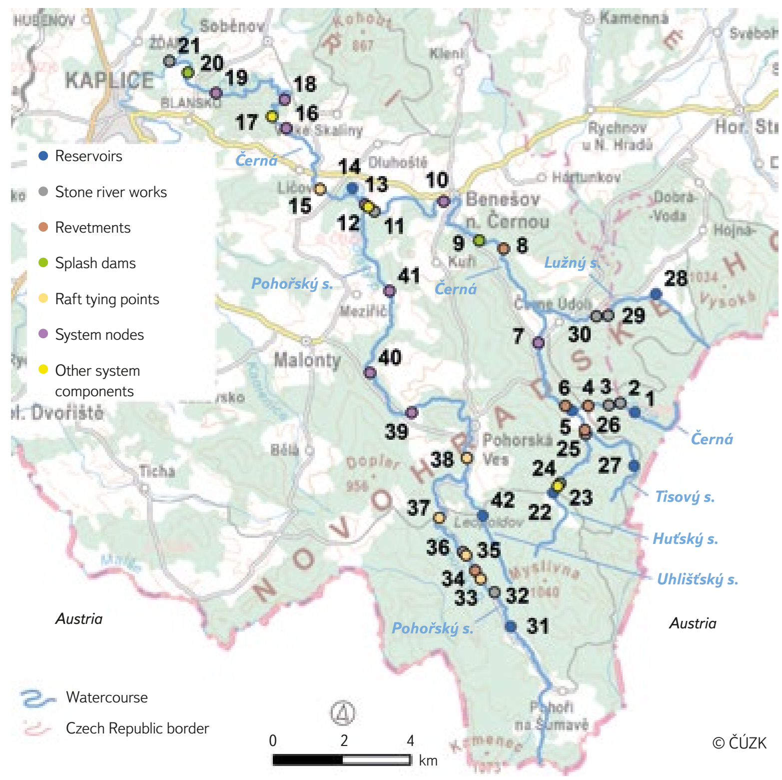

Fig. 1. Map of key parts of the navigation system

Purpose of the navigation system and the context of its creation

As a result of the so-called "wood crisis" – caused by the massive exploitation of forests in response to growing demand for wood as fuel, industrial, and construction material – around the mid-18th century, the demand for firewood and construction timber increased sharply, especially in large towns. This created an opportunity for owners of large forest estates to monetise previously almost untouched timber resources. The waterway represented the cheapest and, at the time, practically the only means of transporting timber. From a technical perspective, there were two methods of floating timber along waterways. The first was the log driving (Holztrift, Holzschwemme). This method was used to transport firewood (Brennholz) and later also pulping timber (Schleifholz) intended for cellulose production. The second method was timber rafting (Holzfloßung), used for floating long logs. Individual logs were joined into rafts (Flöße), which were then bound together into large rafts called 'pramms' (Prahm) many tens of metres long. This method was used to transport construction timber. These large rafts could also carry additional cargo, such as logs, various wooden products (shingles, wooden rods, planks), or other goods – for South Bohemian rivers, this included salt from the Alpine regions. This practice increased the profitability of timber rafting. Historical records indicate that as early as the first half of the 1780s, efforts were made to increase the profitability of the Buquoy navigation system. Later on, this was apparently common practice: at the end of the 19th and the beginning of the 20th century, rafts carried firewood, timber for mines (Grubenholz), and railway sleepers (Schwellen) [2–4].

The beginnings of efforts to transport timber from the forests of the Gratzen Mountains date back to the mid-18th century. In 1748, František Karel Berner proposed log driving using reservoirs. The first attempt to float timber from the Gratzen Mountains forests was made by entrepreneurs Goldberg and de Sommer in the mid-18th century [5, 6]. They drove logs intended for the manufacture of masts to Hamburg, but the endeavour remained only an experiment; systematic timber floating required the river channels to be made navigable and modified. At the time, the then-owner of the Nové Hrady Estate, Count Franz Leopold Buquoy (1703–1767), was presented with several proposals for large-scale log driving from the Gratzen Mountains. These proposals differed considerably, particularly regarding the financial costs of establishing the system. They also included a proposal by the engineer Johann Franz Riemer from 1761, which involved the construction of reservoirs and the improvement navigation of river channels. Due to unfavourable circumstances – for instance, the famine of 1770–1772 – Riemer's proposal was only implemented in the second half of the 1770s under Count Johann Nepomuk Buquoy (1741–1803) [7].

Geographical delimitation of the navigation system

The core of the system consisted of navigable streams. The principal waterways were the Malše (Maltsch), the Černá (Schwarzaubach) and Pohořský stream (Buchersbach). Gradually incorporated into the system were the Uhlišťský stream (Kohlstätterbach), a tributary of the Pohořský stream, and the tributaries of the Černá – Lužný (Luggaubach), Huťský (Gereutherbach) and Tisový stream (Eibenbach).

A key element of the navigation system was the ponds or reservoirs constructed on each of the navigable streams. Since the streams generally did not provide sufficient water to transport timber, the navigation systems could not function without this component. In sources from the 1780s and 1790s, the ponds are referred to as Reservoire, that is, reservoirs. Some of them originally served as fishponds, but most were created specifically as part of the navigation system. By the end of the 19th and first half of 20th centuries, the reservoirs were referred to exclusively as ponds (Triftteiche). The navigation system also always included one additional pond located off the waterways, below the confluence of the Černá river and Pohořský stream. This pond supplied water for log driving along the lower reaches of the Černá and the Malše. The composition of the ponds was changing over the course of the system's development.

Fig. 2. Uhlišťský pond – one of the reservoirs (photo: M. Bureš, July 2024)

Fig. 3. Remains of a wooden outlet pipe at Huťský pond (photo: M. Bureš, July 2024)

In the first half of the 20th century – during the peak and late phases of the navigation system – the following ponds were in operation: Pohořský (Buchersteich) and Uhlišťský (Kohlstätterteich) on their eponymous streams, Zlatá Ktiš (Goldener Tisch) on the Černá, Mlýnský (Mühlbergteich) on the Lužný stream, and Huťský (Gereutherteich) and Tisový (Eibenteich) on their eponymous streams (*Fig. 2*). Just below the confluence of the Černá and Pohořský stream, the Buquoy family leased the Kancléřský pond (Kanzlerteich) from the Český Krumlov prelature [3].

By releasing water from the ponds (reservoirs), a surge of water was created that enabled the transport of loose or bound timber along the route from the Gratzen Mountains to České Budějovice. Water was discharged through wooden pipes placed at the lowest point of the dam (*Fig. 3*). The amount of water released was regulated by equipping each pond with multiple pipes (two to four, varying by pond) and by the ability to open each pipe only halfway.

Watercourses had to be modified for transport purposes. Making them navigable involved a wide range of measures aimed at creating a smoothly passable waterway. The channels had to be cleared of rocks and sand deposits. Where desirable and technically feasible, the channels were straightened; river bends lengthened the waterway and increased the risk of logs being washed onto the bank and damaged, and they also made timber rafting more difficult. Exposed sections and bends were protected with timber revetments. In the bends of the watercourses, stone linings were constructed (*Fig. 4*). The passability of driven wood was ensured by raft sluices built into the weirs. Where rafts were to be assembled, binding stations with their own weirs (Bindwehre) were established.

In the forests, sites were constructed for storing logs. At the landing sites on the timber transport routes, timber depots (Legstätte) were established; there, splash dams (Rechen, Holzfangrechen) were installed to stop and remove timber from the water (*Fig. 5*) [5, 8]. By the mid-1780s, depots existed along the waterway to České Budějovice: on the Černá river at Ličov and in Ponholz near Blansko by Kaplice, on the Malše at Velešín, and at the southern edge of České Budějovice by the so-called Špitálský weir.

MATERIALS AND METHODS

The construction of such an extensive and well-planned system took many years and generated a substantial body of written documents at the time. To the present day, a collection of documents has survived, albeit with significant gaps, covering the years 1780–1799. It is preserved in the State Regional Archive in Třeboň, within the archives of the Nové Hrady Estate [9]. Due to their fragmentary nature, the development of the navigation system can be followed in a more continuous manner only for the years 1780–1784. This period, however, represents a key stage in the system establishment.

The existing professional literature on the Buquoy navigation system is limited. A more comprehensive treatment of the topic is provided by Michal Bureš and Jan Pařez [5], and partially also by Jan and Erika Andreskovi [6] in the book *Novohradské hory a podhůří (Gratzen Mountains and Foothills)*. Another team of authors, which included the author of this study, reviewed the history of the navigation system with a focus on the transport of logs; archaeologist Michal Bureš assessed the significance of the surviving parts of the system

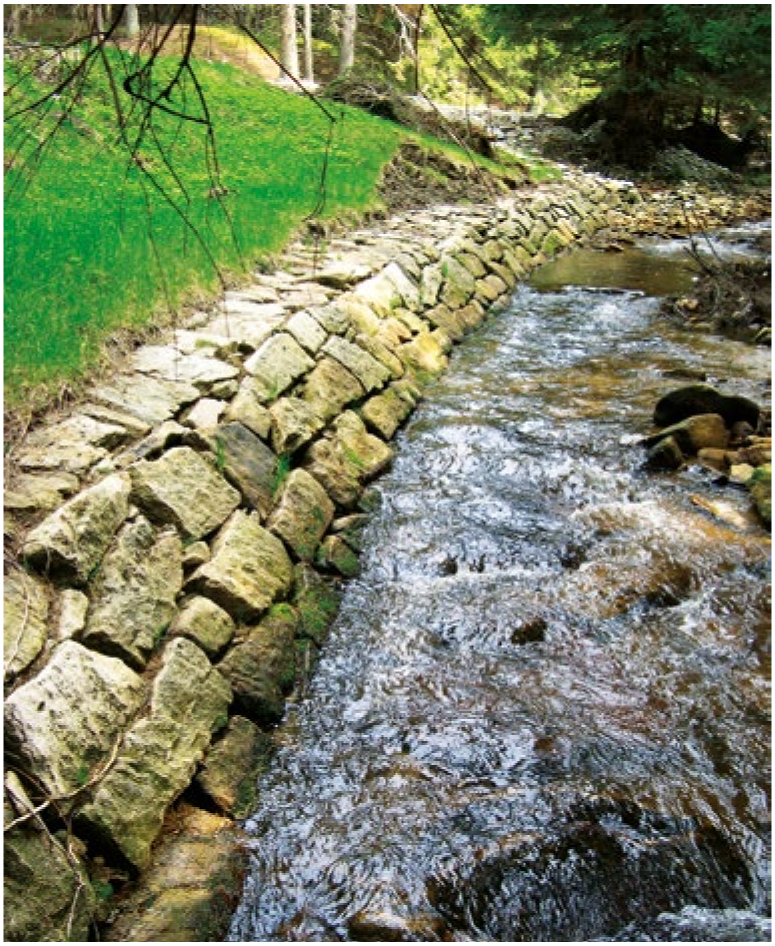

Fig. 4. Bend on the Černá river below Zlatá Ktiš pond, built from dressed stone blocks (photo: M. Bureš, May 2003)

Fig. 5. Simple timber barrier, a so called rechle (from the German Rechen, meaning rake) (source: Roučka, Z. *Předválečnou Šumavou. Život – práce – Krajina*. Plzeň, 2006)

from the perspective of heritage conservation [1]. The present study builds on the research results published in the above-mentioned article. The history of timber floating in the Gratzen Mountains is also addressed by Jarmila Hansová in her study on splash dams [8]. Among smaller, older works, the article by Petr Jelínek [10] is noteworthy. A valuable account of the course of timber floating in the Gratzen Mountains during the 1930s is provided by Josef Klouda in his 1960 article [11].

The primary sources of information on the Buquoy navigation system remain the three publications by the Buquoy chief forest officer Theodor Wagner, published in 1895 [2], 1904 [3], and 1913 [4]. Existing literature therefore presents the system in its peak form at the turn of the 19th and 20th centuries.

The most abundant and information-rich source consists of the so-called construction reports (Bauberichte), submitted at weekly intervals by Johann Franz Riemer or another official supervising the construction of the navigation system. The reports primarily document the clearing of streams, the construction and, where necessary, repair of sluices, weirs, and revetments of streambeds and banks. They also contain information on the progress of floating both loose and bound timber. Through the construction reports, the owner of the estate, Count Johann Nepomuk Buquoy, received up-to-date information on the progress of the construction of the navigation system, while various matters were also submitted to him for decision, such as the 1783 proposal to establish a new reservoir. Many construction reports contain his decisions and instructions, his comments, as well as words of praise. The Count actively intervened in both the building of the system and the floating operation, and he demanded full commitment from his officials.

Occasionally, the construction reports are accompanied by appendices in the form of tabulated statements recording the work carried out over a given period (usually a week). These list the type and number of construction personnel (masons, carpenters, labourers, stone-blasters), the amounts of wages paid, etc. The most complete surviving set of documents relates to the floating of logs and rafts in April and May 1783.

Some other written documents also have considerable informational value – proposals or expert opinions – which touch on a wide range of aspects connected with the construction and operation of the navigation system, from the techniques of log tying to the question of securing a sufficient number of raftsmen, the financing of construction costs, and the organisation of forest management in accordance with the needs of timber floating. The extensive cartographic documentation from the second half of the 18th century, often accompanied by detailed textual annotations, is equally significant. This material is also preserved in the Nové Hrady Estate archive collection.

A significant source of information on the early stages of the navigation system is a typescript copy of an original 1795 report, held in the State Regional Archive in Třeboň within the collection of the Regional Water Management Development and Investment Centre in České Budějovice [7].

All the above-mentioned source material – consisting primarily of dozens of handwritten documents from the final quarter of the 18th century – first had to be read through to gain an overview of the range of topics it covers. From this body of material, information was selected that made it possible to compile a chronological outline of the beginnings of timber floating in the Gratzen Mountains. A number of assertions found in both the professional literature and the sources themselves were verified from a critical perspective (for example, the claim that rafts were first floated to Prague as early as 1783). To extract many of the detailed pieces of information, it was necessary to combine and compare data contained in individual sources – whether written documents or maps. A separate task involved arranging these individual pieces of information in chronological order, as the sources in the archival collection are not organised in a way that allows them to be read as a continuous narrative.

Given that the core of this study (the Results) explicitly rests on the processing and interpretation of primary source material, it would not have been feasible to cite every single piece of information, as this would require a reference after virtually every sentence – and frequently to two or more documents at once. Therefore, wherever sources are cited only in general terms, or where no other reference is provided, the information is drawn from the corpus of materials introduced above (construction reports and other written documents, maps) held in the Nové Hrady Estate archival collection, from which the vast majority of the data originates.

RESULTS

The year 1780

Construction of the navigation system began in 1778, following a thorough examination of Riemer's proposal and the granting of official permission for the works. The Buquoy navigation system predated both of the renowned Šumava timber-floating canals – the Schwarzenberg Canal (under construction from 1789) and the Vchynicko–Tetovský Canal (under construction from 1800). In terms of technical design it was entirely unique, as it made it possible to operate timber rafting even on the low-capacity, narrow watercourses of the Gratzen Mountains.

A more continuous sequence of the fragmentarily preserved sources from the Nové Hrady Estate collection begins in 1780. By that time construction works were already well underway, and the Pohořský stream together with part of the Černá river had been modified to such an extent that from 9 to 13 April it was possible to float 955.5 (cubic) fathoms (*note: the Czech sáh = fathom*) of logs to the depot at Ličov (Litschau) below the confluence of the Černá and Pohořský stream. To gain an idea of how much timber this represents when converted into the cubic metres used today, it is important to bear in mind that these were so-called stacked cubic fathoms, that is, the volume of wood arranged into piles including the spaces between the logs. 955.5 stacked cubic fathoms corresponds to roughly 6,500 stacked m^3. This approximate conversion is based on the cubic fathom defined by the Lower Austrian system of measures, which was in force in Bohemia in the 1780s. Under this system a cubic fathom equalled approximately 6.82 m^3. The volume of the actual timber (expressed in so-called solid m^3) was in fact two thirds to one half smaller. The logs were typically two or three feet long (a foot in the Lower Austrian system of measures corresponds to approximately one third of a metre) [12].

The waterway downstream of Ličov was being heavily modified with a view to extending the stretch navigable by log driving and introducing timber rafting. In all probability, during the summer months of 1780, Uhlišťský pond was constructed on Uhlišťský stream (Theodor Wagner, in a treatise from 1904, gives the year 1775). The contract for the construction of Uhlišťský pond was concluded in the spring (probably April 1780) with a certain Joseph Wagner of Stropnice for the sum of 1,200 gulden. The necessary tools – such as wheelbarrows, pickaxes, iron bars, augers, and hammers – as well as gunpowder for breaking rocks were to be supplied to him by the Buquoy estate administration. In 1780, splash dams were built at Ponholz [8]. From the construction reports we learn, among other things, of the intention to build splash dams at Velešín (April), of the cleaning of the lower course of the Pohořský stream, of modifications to the weirs along the lower reaches of the Černá (October), and of the construction of two sluices at the weirs by the paper mill (Papiermühl) near Blansko by Kaplice (end of 1780).

A relatively large space is devoted in the construction reports to this type of navigation-related construction work. It was carried out directly by the Buquoy estate administration, using its own carpenters (Zimmerleiten) and masons (Maurer), assisted by journeymen (Geßelle) and labourers (Handlanger), as well as stone-blasters (Steinschießer). They were paid for their work at weekly intervals. Part of the work was contracted out by the estate administration, as in the case of the construction of Uhlišťský pond. The Buquoys had sufficient construction timber available from their own estate forests. The construction of the navigation system was ideally to be financed from the proceeds of timber sales. In the early 1780s the Buquoy family traded in timber from forest districts outside the Gratzen Mountains; for 1782 there is an explicit reference to the sale of timber from the forest districts of the Libějovice estate, which the Buquoys also held at that time. Another potential financial source was the revenue from the grain trade, or income flowing into the manorial treasury from feudal rents. If the navigation system was to pay for itself, it had to be completed as quickly as possible.

The year 1781

In the spring of 1781, from 23 to 28 April, logs were floated to Ličov, to the paper mill near Blansko, and to Ponholz. Thus, in that year log driving was extended along the entire Černá river from its confluence with the Pohořský stream. At all three timber depots a total of 1,471.5 fathoms of logs were hauled out. Most of the timber was floated to Ponholz – 1,102 fathoms. The first raft-floating trials probably also took place no later than the autumn of 1781. The surviving construction reports from November inform us only about the floating of logs, to a total volume of almost 1,200 logs, to the (manorial) Lužnice sawmill (Luschnitzer Breth-Saag, Luschnitzer Saag Mühl) situated on the Pohořský stream near Terčí (today Pohorská) Ves. The logs were apparently floated from several locations along the upper course of the Pohořský stream, possibly including the so-called Baron Bridge (Baronwehr) below Pohořský pond, to which the starting point of timber rafting was later shifted [3]. The surviving sources indicate that at least until 1795, rafts were floated from Lužnice sawmill, whereas logs were floated on the upper, steep course of the Pohořský stream [7]. Lužnice sawmill was located near Terčí Ves (*Fig. 6*), which is why the timber depot there is commonly referred to as Terčí Ves depot (Theresiendorfer Legstatt). At Terčí Ves, splash dams were installed to allow logs to be pulled out of water. In the depot, timber could properly dry before being floated further to its destination.

Fig. 6. Location of Lužnice sawmill (Herrschaftliche Luschnitzer Saag Mühl) near Terčí (nowadays Pohorská) Ves (source: *State Regional Archives in Třeboň, Satellite Office Třeboň, archival fond Nové Hrady Estate*, map No. 2 759)

The year 1782

In 1782, logs were probably floated on the Malše river on a large scale for the first time. From 8 to 19 April, 2,115.75 fathoms of timber were floated to the depot in Velešín. From 22 to 28 May, timber was floated to Ličov (214 fathoms) and Ponholz (352 fathoms). For 1782, the first autumn float is also documented, which took place from 4 to 9 November; logs were then transported to Ličov (319.25 fathoms) and Ponholz (258.5 fathoms).

The first reports of trial timber rafting on the Pohořský stream and the Černá date from the spring of 1782, specifically on the stretch from the timber depot at Terčí Ves, where logs were floated individually, to Ponholz. The sources describe a series of four timber rafting trials, which took place from late April to the first half of May. During the fourth rafting, carried out on 13 May, 13,156 Viennese fathoms of timber were successfully floated from Terčí Ves to Ponholz. The raft arrived in Ponholz to great admiration from the onlookers; the route to České Budějovice was open. For 1783, it was planned to float rafts to Prague, and preparations for this were underway. At the beginning of December 1782, leading officials of the Nové Hrady Estate met, with Riemer and Count Buquoy himself in attendance, to discuss preparations for log driving and timber rafting in 1783. They addressed the establishment of a timber depot in České Budějovice, the demand for logs, the organisation of tree felling for log driving and rafts, and the financing of further development of the navigation system. It was resolved to construct a timber depot above Budějovice at the so-called Špitálský weir (Spitalwehr), with the land to be leased rather than purchased. At the same time, during the winter, possibilities for selling timber in Budějovice were to be explored. Even in 1782, construction and transport work continued along the waterway. The cleaning of streambeds and the construction and repair of wooden bank reinforcements also continued.

The year 1783

In the history of the Buquoy navigation system, 1783 holds a prominent position. From 7 to 15 April, the first transport of logs to České Budějovice took place. At the newly constructed timber depot near Špitálský weir, 1,232 fathoms of wood were removed from the water. The timber had been floated from the depot in nearby Velešín. It consisted of wood (or part of it) that had been floated from the Gratzen Mountains to Velešín the previous year, for which buyers apparently could not be found.

The second transport of logs to České Budějovice took place from 23 April to 13 May. It was the first transport of logs to Budějovice directly from the forests of the Gratzen Mountains. On the Pohořský stream, the logs were thrown into the water at several locations on 23 and 24 April. By 13 May, all floated timber had been stacked into piles at the České Budějovice depot. In total, it amounted to 1,933 fathoms, partly of hardwood but predominantly softwood logs. Simultaneously with the transport to České Budějovice, timber was also floated to Ponholz. At the local splash dams, 492 fathoms of logs were floated. The costs of transporting logs to České Budějovice and Ponholz in the period from 23 April to 13 May amounted to 1,575 gulden 44 kreuzer, while the net profit from the transport was 2,697 gulden 1 kreuzer.

From May 1783, we have reports of two timber rafting trials, which also had a purely practical purpose, as they were used to deliver timber for the construction of sluices at the end of the route just before České Budějovice. The first trial timber rafting took place from 6 to 8 May 1783. The transport ran from Terčí Ves to the mill weir in Plav. The timber rafting coincided in time with the log driving. Both operations were uncoordinated at the time, and, as Riemer notes in his report of 11 May 1783, the rafts floated from Doudleby to the mill weir at Plav over accumulated logs. The second timber rafting (from Terčí Ves) took place from 15 to 19 May 1783, again aimed at the mill weir below Plav, where construction timber for the sluices was delivered. In both timber rafting operations, three smaller rafts of construction timber were dispatched from Terčí Ves, which were joined into one large raft at the paper mill near Blansko by Kaplice. It consisted of 10 rafts, each made up of eight or nine logs. Timber rafting of the same dimensions took place at the beginning of June 1783, this time reaching as far as Vidov. The floated construction timber was intended for the building of sluices at Plav, Vidov, and Špitálský weir, as well as for the construction of a small house for the overseer at the Budějovice timber depot.

In 1783 there was a severe drought; moreover, the previous year had also been low in rainfall. Perhaps it was the lack of water that prompted Riemer at the end of May to submit a proposal for the construction of a new reservoir, this time on the Černá. After its creation, Riemer notes, it will no longer be necessary to wait for the Pohořský stream to refill before the next timber rafting. In periods of low water, the waters from both reservoirs could be combined. The text does not specify which reservoir is being referred to. Most probably, it was the later-disappeared Leberharter reservoir, whose existence is documented by an undated map, probably produced shortly after 1795 (*Fig. 7*). This reservoir was located at the confluence of the Černá and Huťský stream. The second reservoir on the Černá – Zlatá Ktiš – was constructed later, between 1789 and 1796 (according to Theodor Wagner in his 1904 publication). In 1783, the construction of the reservoir was apparently abandoned, as the proposal for its establishment was repeated in an extensive report by the Buquoy estate management office at the beginning of February 1784.

Fig. 7. Situation on the upper reaches of the Černá river in the second half of the 1790s; the map shows the later disappeared Leberhart reservoir (source: *State Regional Archives in Třeboň, Satellite Office Třeboň, archival fond Nové Hrady Estate*, map No. 2 759)

The first rafts to Prague – albeit in limited quantities – were probably floated in the autumn of 1783. During the summer, drought hindered the construction of sluices at the end of the route to České Budějovice, namely at Plav, Vidov, and Špitálský weir; due to low water levels, it was not possible to float construction timber in rafts from the Gratzen Mountains. Although the studied sources do not contain reports describing timber rafting from autumn 1783, Count Buquoy's order of 14 January 1784 suggests that at least trial runs to Prague must have taken place in autumn 1783. 1783 is given as the start of timber rafting in the 1795 report on the navigation system [7], as well as in the commentary on a map of the system produced shortly after 1795 (in the inventory compiled for the maps from the archival fond Nové Hrady Estate, this map is No. 2,760).

The beginning of the navigation work on the Černá river, in the section above its confluence with the Pohořský stream, also falls within 1783. In July 1783, cleaning of the Černá was to commence so that it could subsequently be made navigable, which was carried out in 1785 (according to the commentary on map No. 2,760, held in the archival fond Nové Hrady Estate).

The year 1784 and the subsequent fate of the navigation system

The first explicit mention of rafting from the Gratzen Mountains through České Budějovice onwards to Prague dates from June 1784. In the report of 4 June, Riemer describes a raft consisting of 400 logs travelling to Prague, which, according to his estimate, was to arrive on 14 or 15 June. It was to be loaded with fathom timber from the Libějovice estate of the Buquoy family. A report dated 7 September 1784, dealing with the preparations for timber rafting in 1785, suggests that rafts were again floated in limited quantities that year, and that timber rafting had not yet brought the profit expected by the Count. The entire business struggled with a shortage of raftsmen, and there were evidently some difficulties in gathering a sufficient number of logs to be floated in order to make full use of the navigation system capacity.

Despite the slow start for timber rafting, 1783 and 1784 marked a decisive turning point in the history of the Buquoy navigation system. The successful opening of the waterway from the Gratzen Mountains to České Budějovice crowned the many years of effort by Count Buquoy and his staff – engineer Johann Franz Riemer, the estate officials (administrative, financial, and forestry), and other participants – raftsmen, craftsmen (stonemasons and carpenters), and hired labourers (stone blasters and general assistants).

In the following years, the navigation system was further expanded. The reservoir on the Černá, proposed in 1783, must have been constructed either in 1784 or 1785, since by 1785 logs were already to be floated on the upper reaches of the Černá, and rafts from 1792. At the end of the 1780s, construction began on a second reservoir on the Černá – Zlatá Ktiš – which was finally completed shortly after 1795. At the turn of the 18th and 19th centuries, the Lužný, Huťský, and Tisový streams were made navigable. On the last two, reservoirs of the same name were built.

The construction and operation of the navigation system transformed the previously sparsely settled forests of the Gratzen Mountains into a cultural landscape interwoven with a network of entirely new mountain settlements. The navigation system functioned and prospered throughout the 19th century and nearly the entire first half of the 20th century. Timber rafting was carried out until the summer of 1938. Logs were verifiably floated even in the first half of the 1940s [1, 10].

DISCUSSION

The study builds on previous research on the Buquoy navigation system, focusing on the initial years of its existence. It provides a range of new insights and, in part, clarifies information recorded in the literature, primarily under the influence of Theodor Wagner's works from the late 19th and early 20th centuries.

From the surviving sources, it is possible to fairly clearly trace the gradual expansion of the waterway between 1780 and 1783. By 1783, the Buquoy navigation system for both loose logs and rafts had reached České Budějovice, which corresponds with the data in Wagner's writings and the professional literature. The research also allows the construction of Uhlišťský pond to be dated to 1780, whereas Wagner gives the year 1776 [3]. The sources further indicate that in its early years, the system included the manorial (Buquoy) Velký Ličovský pond (in contemporary sources referred to as Seifritzteich or Seifriedtsteich), which was only later replaced by Kancléřský pond leased from the Český Krumlov prelature.

Thanks in particular to the set of sources from the Nové Hrady Estate archival fond, it was possible to shed light on the organisational and institutional background of the construction and operation of the navigation system – for example, the involvement of the manorial offices and their staff, as well as the active role of Count Buquoy. The information on the first timber rafting trial is particularly valuable, as it documents the technical issues faced by the first raftsmen. Documents from 1783 and 1784 bear witness to the difficult beginnings of timber rafting and its insufficient profitability during the first years of the system's operation.

The limits of the research were set by the fragmentary and ultimately rather restricted source base, so it was not possible to fully resolve a number of questions, and some remain open. This applies, for example, to the question of whether, and to what extent, loose logs was already being floated on the Pohořský stream and the Černá before 1780. Similarly, we know practically nothing about the course and scale of the raft operations in the autumn of 1783. We have only very fragmentary information at our disposal regarding the making of the Černá navigable upstream of its confluence with the Pohořský stream, as well as regarding the construction of the earliest reservoir on the Černá, the so-called Leberhart reservoir. Given that the key archival fond, Nové Hrady Estate, has not yet been processed, it is entirely possible that it still contains documents that could shed more light on the history of the navigation system.

The extensive – though fragmentarily preserved – source material could not be fully utilised in its entirety. More time would be required for that, as well as close cooperation with other specialists, especially archaeologists who could interpret the information relating to the technical aspects of the system's construction, and experts in forest management.

CONCLUSION

In the last quarter of the 18th century, a unique navigation system was constructed on the watercourses of the Gratzen Mountains and their foothills, enabling the transport of both loose logs and bound timber on low-discharge streams with a considerable head. The key part of the navigation system lay within the Nové Hrady Estate, owned by the noble Buquoy family. It was created according to a design by the engineer Johann Franz Riemer, who oversaw the construction and played a decisive role in shaping the further development of the navigation system into the form it acquired at the end of the 18th century, in which it then – albeit with certain modifications – endured until the first half of the twentieth century. The principal timber-floating route of the system consisted of the Pohořský stream, the Černá, and the Malše, which flows into the Vltava in České Budějovice.

Construction of the navigation system began at the end of the 1770s. By 1783 the system was ready for the floating of logs and rafts to České Budějovice; from there the rafts continued via České Budějovice and Týn nad Vltavou to Prague. In 1783 the navigation system comprised the Pohořský stream, the Černá from its confluence with the Pohořský stream, and the Malše. At that time three ponds (reservoirs) existed: Pohořský pond (second half of the 1770s) and Uhlišťský pond (1780), both constructed on the streams of the same name, and Velký Ličovský pond below the confluence of the Pohořský stream and the Černá, located outside the main route. Wood depots along the route were located in Terčí (Pohorská) Ves, Ličov, Ponholz, Velešín, and České Budějovice. Whereas logs were floated to the respective depots directly from the uppermost sections of the waterway, timber rafting was somewhat more complex. Logs were driven from the forest to the depot in Terčí Ves, where they were tied together into rafts. At the paper mill near Blansko several rafts floating from Terčí Ves were tied together into one long unit, which then continued to České Budějovice.

From 1785, logs were also floated on the upper course of the Černá, that is, upstream of its confluence with the Pohořský stream. This was preceded by making the Černá navigable and the construction of another reservoir on the Černá, probably the later-disappeared Leberhart reservoir at the confluence of the Černá and the Huťský stream. Due to a lack of sources, we can only form a basic picture of how the navigation system was expanded during the 1780s and 1790s. Subsequent development took the form of making higher reaches of the Černá and its tributaries – the Lužný, Huťský, and Tisový streams – navigable. From 1792, rafts were also to be floated on the upper reaches of the Černá. This is an interesting piece of information, as reports of this navigation are absent in sources from the late 19th and first half of the 20th century. In 1796, Zlatá Ktiš on the Černá was completed, and around 1800 ponds on the Huťský and Tisový streams were established (Mlýnský pond on Lužný stream was older). With this, under the supervision of engineer Riemer, the construction of the entire navigation system was completed.

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Conference Operation of Water Supply and Sewerage Systems 2023, SOVAK CR (source: SOVAK CR)

Interview with Mgr. Martin Pták, Director of the Water Protection Department at the Ministry of the Environment

How is Czech water management coping with droughts, floods, and new legislative requirements? Mgr. Martin Pták, Director of the Water Protection Department at the Ministry of the Environment, discusses the Ministry's current priorities, his professional journey, the challenges facing Czech water management, European legislation, and the need for long-term adaptation to climate change. "Our priorities are clear," he says. "Adaptation, prevention, and cooperation."

Mr. Director, you studied ecology at the Faculty of Science of Charles University. What led you to choose this particular field?

I have been fascinated by water since early childhood. At my grandmother's cottage, there was a stream and a pond right next to the garden, where I spent countless hours building stone dams, wading in the water, and watching various animals; moreover, we were close to the Berounka River. My interest in biology was encouraged by a relative of mine, Tomáš Kučera, who devoted his professional life to botany and taught at the University of West Bohemia in Plzeň. I spent many weekends with him outdoors, particularly mapping habitats. Together with Jindra Duras, he also studied aquatic plants in the Bolevec Pond System in Plzeň, which gave me the opportunity to take part in field research outside my studies and experience practical, applied science. Ecology, or more precisely hydrobiology (which I later chose as my master's specialisation), is, in my view, a kind of 'royal discipline'. It explores the relationships between organisms and their environment, as well as between the organisms themselves. It struck me as the right path to understanding how an ecosystem functions as a whole; thus, one can use knowledge from other branches of biology.

At the beginning of your career, you worked at the Hydrobiological Institute of the Czech Academy of Sciences, where you focused on balance models of phosphorus flow. What did that experience bring to your later professional work?

Yes, it was an excellent experience. As a recent graduate, fresh out of university, I suddenly found myself among colleagues whom I had regarded as prominent figures and leading experts in the field. I had previously known their names only from citations in scientific papers and publications I came across during my studies and while writing my thesis. I saw it as a unique opportunity to learn far more details about topics I had been studying for years. You quickly realise that many processes and phenomena are, in reality, far more complex than how they are presented in textbooks and lecture notes.

On the other hand, it was actually very reassuring to realise that they are normal people, dealing with the same everyday concerns and problems, and who have their own hobbies. The greatest lesson, however, was more about discovering that the academic environment was not really the right fit for me :-).

You have worked both at the Ministry of the Environment and at the Regional Authority of the Pilsen Region. How does this "dual perspective" – from both central and regional levels – help you in your current work?

I have to admit that I went to the Regional Authority in Plzeň more for pragmatic reasons – because of my family. We had a young son, and I was commuting daily from Plzeň to Prague. However, the experience itself was invaluable; it really opened my eyes to how much richer practical work can be. I began to understand much better the perspectives of representatives of public administration or local government, especially at the level of small towns and municipalities. Here, real problems are addressed from the perspective of how things actually work; the approach is more pragmatic, and they often have to deal with personal relationships and neighbour conflicts. From a central level, the view on many issues tends to be more generalised, often considerably simplified. Many times, it is hard to even imagine that some of the situations faced by colleagues at local or regional levels could actually arise in practice. It is definitely important to try to understand their point of view more fully. At the central level, we hope for this kind of mutual understanding as well. I would certainly recommend this experience to many of my colleagues.

Since last November, you have been the Head of the Water Protection Department at the Ministry of the Environment. How do you perceive this new responsibility, and what does it mean to you personally?

I approach this position with a great sense of responsibility and humility. Suddenly, you find yourself in a role where you have to advocate for and defend your own opinions not only with the Ministry's leadership, but also with political representatives, other government departments, and professional organisations. It is not enough to have a good idea; everything must be thought through in detail, including potential impacts and long-term visions. On the other hand, someone in this role must be much more skilled at finding compromises. On a personal level, I also find it very rewarding to engage in much closer communication with the Ministry's leadership, with representatives of other departments, and with political representatives.

What are the current main priorities of the Water Protection Department?

Personally, I consider one of the greatest shortcomings to be the almost unchanged state of wastewater treatment; over the past twenty years, the sector has largely stagnated, giving the impression that it was not necessary to treat wastewater to the highest possible standard in line with the development of the entire field. For a while, this may have been sufficient, but in combination with climate change, the inflow of nutrients into the aquatic environment has once again become an issue. Currently, the Czech Republic faces a major challenge: implementing Directive No. 2024/3019 concerning urban wastewater treatment.

What specific steps in the area of wastewater management do you consider to be a priority?

It would be desirable to once again address the impact of discharged untreated or partially treated wastewater, or to establish systematic support for measures to reduce their discharge, which is a long-term priority from the perspective of water protection. This also involves a broader change in the approach to stormwater management, including the removal of exemptions from charges for its discharge, and similar measures. In the long term, it would also be appropriate to restore the incentive function of pollution charges. And, since I have mentioned the area of charges, I would also point out the need to set a realistic price for groundwater, even though this is not directly related to wastewater issues. However, the matter of increasing charges is quite sensitive and requires consensus across the political spectrum, as we at the Ministry have experienced on several occasions.

What role do river basin plans and flood protection play in this effort?

A very significant one. I would really like to finally activate the role of river basin plans. These are strategic documents that have a strong foundation in the current Water Act, and many tools allow them to be used as a means for a targeted approach to individual water bodies or entire river basins. Fortunately, in practice, it is clear that in some areas, river basin managers and regional authorities, as co-authors of the sub-basin plans, are already using this tool effectively. From the perspective of flood protection, I feel that, in terms of operational management, everything functions basically well within the system. I was very impressed by how, in the period leading up to the floods last September, the cooperation and communication between the forecasting service, the leadership of the affected ministries, local governments, and the Fire and Rescue Service of the Czech Republic functioned. There was trust in the predictive models, which made it possible to issue timely warnings. A few days later, the floods demonstrated their full force. However, the major difference was that it was at least partially possible to prepare for this threat. Of course, I can also point out that it would be desirable to build flood protection measures for towns and municipalities more quickly and flexibly, but this should primarily be a shared goal of the local authorities. It also became clear that crisis communication among all involved parties needs further development. Currently, another major challenge for the Ministry of the Environment is the preparation of the new Flood Information System (POVIS2).

The amendment to the Urban Wastewater Treatment Directive has received a lot of attention. What are the most important changes it will bring, and how will it affect smaller municipalities in particular?

In this sense, the new Urban Wastewater Treatment Directive represents a significant step forward. Moreover, it introduces quite a number of changes, not only in terms of tightening existing requirements but also by introducing some entirely innovative tools. I am a little disappointed that we had to wait twenty years for this moment and were unable to tighten requirements at the national level earlier, but I know that the right conditions have finally emerged, where everyone perceives this change constructively and in unison. For context, the original Directive has been in force since 1991, yet many countries struggled to meet its objectives and requirements even after 2020. The European Commission presented the draft of the new Directive to the Council of Europe at the end of 2022, during the Czech Presidency.

What specific innovations and requirements does the new Directive introduce?

The Directive not only tightens requirements for wastewater treatment and the sewerage of agglomerations, as one might expect, but also addresses and links many other areas that have previously received little attention at the European legislative level. In addition to the points mentioned, it introduces, in particular, a quaternary treatment stage for large wastewater treatment plants, including a new financing approach based on the so-called extended producer responsibility of the pharmaceutical and cosmetics industries. It also introduces objective wastewater monitoring to quantify treatment efficiency, aims to achieve energy neutrality for treatment plants, and establishes a registry for individual treatment systems to oversee their operation. Separately, I would highlight the Directive's focus on addressing discharged untreated or partially treated wastewater, which now includes a requirement to develop so-called integrated plans.

How will the new requirements affect smaller municipalities, and what challenges do they pose?

From the perspective of smaller municipalities or agglomerations addressed by the Directive, the main issue is the already mentioned obligation to connect to a sewerage system. This obligation will now extend to many additional smaller municipalities, as the threshold for applicability has been lowered to half the size of an agglomeration compared to the original Directive. In practice, this means that all municipalities with more than one thousand population equivalents must now be connected to the sewer system. In the Czech Republic, this will affect roughly seven hundred more municipalities, although many already have sewer networks in place. This area will therefore require substantial financial resources, and it will be necessary to seek adequate funding to support the construction of sewer infrastructure, primarily at the European level.

Drought is becoming an increasingly serious challenge. What measures is the Ministry preparing to strengthen the resilience of the landscape and water resources?

This question is rather for my colleagues in the Department for Climate Change Adaptation, but in general, I can say that the Ministry, in cooperation with the Nature Conservation Agency of the Czech Republic, is trying to do quite a lot in this area. I would particularly mention the implementation document known as the National Climate Change Adaptation Action Plan. It contains a list of adaptation measures and tasks, including deadlines, responsibilities for implementation, identification of relevant funding sources, and an estimate of the costs of carrying out the measures. It also includes measures related to wastewater treatment and the protection of both groundwater and surface water, in terms of both quality and quantity.

Personally, I believe that one of the major historical shortcomings has been the various modifications of river channels. It would therefore be desirable to accelerate efforts to facilitate river restorations or to allow smaller watercourses to follow natural processes. By this, I mean the process of natural restoration, without unnecessary human intervention, to slow the runoff of water from the landscape. The effects achieved then influence not only the self-purification processes in the watercourses but also flood protection.

From the perspective of our department, I can mention, for example, the commissioning of a research project aimed at assessing whether, in situations where a drought and water shortage are declared, stricter emission limits could be introduced (that is, more demanding wastewater treatment requirements). Basically, when significantly less water is flowing in a watercourse, and wastewater is discharged into it in unchanged volumes and composition, the concentrations of many substances entering the water naturally increase. In such periods, it would therefore make sense to treat wastewater more effectively to ensure that aquatic life can survive even during the summer months.

Floods represent the opposite extreme – how is the state administration preparing to manage and prevent them?

The topic of floods has been addressed very intensively over the past year. The Ministry of the Environment commissioned the Czech Hydrometeorological Institute to prepare a Report on the Evaluation of the September 2024 Flood, which involved several experts, including from T. G. Masaryk Water Research Institute (*author's note: available on the websites of the Ministry of the Environment and the CHMI*). The floods also demonstrated the necessity of timely warnings, an active role for flood management authorities, and the need to improve communication with the public.

I would also add that, in response to the floods, we prepared an amendment to the Water Act aimed at accelerating the implementation of flood protection measures, including updating the Decree on the Designation of Floodplains. However, the law was not considered by the Chamber of Deputies.

How do you see the role of modern technologies, such as smart monitoring systems and modelling, in the future of water management?

Definitely positively – any tool that can make work easier, faster, or more efficient should be quickly adopted in practice and used appropriately. I am particularly pleased, for example, that operators of water management infrastructure themselves are coming up with innovative and smart solutions in the operation of sewer networks, that various digital models are being used in flood forecasting services, in assessing the impact of individual pollution sources on entire river basins, and for simulating the effects of accidents on water reservoirs. I could talk at great length about each of these. Overall, however, it is truly useful and desirable that these tools are now a standard part of water management.

To what extent does European legislation influence Czech water policy, and where do you see the greatest challenges in its implementation?

The answer is simple – fundamentally. All processes and our activities should aim to achieve a good status of water bodies. This principle is derived from the requirements of Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000, establishing a framework for Community action in the field of water policy aimed at achieving good status of water bodies, as well as from other subsidiary directives. To this end, river basin plans are developed at various levels; EU Member States are expected to achieve good status of water bodies by 2027.

Another area is flood protection, specifically the development of flood management plans, which define objectives for mitigating the impacts of floods and the methods to achieve them, including prevention, technical measures, and flood defence. These plans focus on areas at significant risk and aim to protect human health, the environment, cultural heritage, and economic activities. They also include proposals for technical measures and measures to modify the landscape and water regime.

As I have already mentioned, the area of wastewater treatment falls under the Urban Wastewater Treatment Directive, which presents several challenges. I would also highlight a European strategy currently being prepared, namely the Water Resilience Strategy, as well as the major challenge posed by the Nature Restoration Law, which will also have a very significant impact on the water sector.

The challenge for us is, of course, not only the requirements of the individual regulations I have mentioned, but, above all, discussion of their impacts with all the stakeholders involved. This is very demanding, both during the adoption and approval of proposals and, in particular, during implementation of the individual requirements.

Is the Czech Republic succeeding in meeting the objectives of the EU Water Framework Directive?

This is a fairly straightforward question, but it is difficult to answer. The principles of the Water Framework Directive are one of the main drivers of water management and have been applied in practice over a long period. The fundamental principle of the Directive is that if even one of a series of indicators fails to meet the good status threshold for a water body, it becomes impossible to classify the water body as achieving good status; this is known as the "one-out, all-out" principle. The impact of certain substances on the aquatic environment cannot even be controlled in some cases – for example, they may enter through atmospheric deposition. I would also note that the requirements of individual directives do not necessarily correspond with each other. For instance, even if a Member State meets the requirements of the Urban Wastewater Treatment Directive, this may not be sufficient to meet, for example, the phosphorus indicator needed to approach the limit for good status. At present, discussions are ongoing at the level of Member States and the European Commission about what will follow after 2027, and whether, and how, the objectives of the Water Framework Directive might be revised.

Do you draw inspiration from international examples of good practice in your work? If so, which ones have impressed you the most?

Yes, absolutely. In this context, it is probably not useful to talk about wastewater treatment or drinking water treatment, because in the Czech Republic this sector is very advanced, and as I mentioned earlier, modern approaches and technologies are already routinely applied in practice – for example, the new water line at the Central Wastewater Treatment Plant in Prague. Personally, however, I greatly appreciate the approaches seen abroad, particularly in Germany, Austria, and Switzerland, especially regarding stormwater management and, more generally, the promotion of so-called blue-green infrastructure in cities. In these countries, such measures have often been part of legislative requirements for construction for many years and are strictly enforced during the project planning phase.

What personally motivates and fulfils you most about your work?

I would probably say the opportunity to directly influence and change things. It is also the dedication and effort of my colleagues in the department, whom I can rely on in many ways and with whom I have built long-term and friendly relationships.

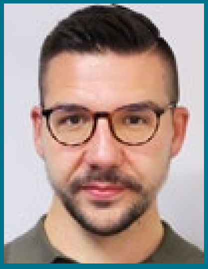
What message would you like to give to young professionals considering a career in water management?

By all means – go for it. As in any sector, it is essential to constantly bring new ideas and innovations, and without young experts, progress is simply not possible.

Thank you for your time, Director, and for sharing your insights with us.

Ing. Josef Nistler

Mgr. Martin Pták



Mgr. Martin Pták was born on 16 November 1986 in Pilsen. After completing his secondary education at a grammar school, he studied ecology at the Faculty of Science, Charles University in Prague, focusing on hydrobiology, specifically the availability of nutrients in pond sediments and their impact on aquatic plant growth. He also gained professional experience in academia, working briefly at the Hydrobiological Institute of the Czech Academy of Sciences in České Budějovice. He then served at both regional and central levels of public administration – from 2013 to 2018, he held a specialist position in the Water Protection Department at the Ministry of the Environment, and from 2018 to 2022, he worked in the Water Management Department of Pilsen Regional Authority. In 2022, he returned to the Ministry of the Environment, serving as Head of the Water Protection Department from August 2022 to November 2024. Since November 2024, he has held the position of Director of the Water Protection Department. He is also a member of the Supervisory Board of T. G. Masaryk Water Research Institute. He lives in Pilsen, is married, and has three children.

Jáchymov III: Where does the radon water come from?

Let us return once more – and for the last time – to Jáchymov, a small town nestled in a deep, forested valley of the Ore Mountains. It lies somewhat hidden, yet in an excellent strategic location, within walking distance of Ostrov, Klínovec, and Boží Dar (in German *Gottesgab*; *Fig. 1*) – the highest town in the Czech Republic, situated right on the border crossing to Oberwiesenthal in Saxony (*Fig. 2*). From Boží Dar, one can also continue into Božídarské rašeliniště Nature Reserve.

However, Jáchymov boasts many other remarkable firsts and renowned "bests". It was here that the world's first radon spa was founded, centred around the construction of the grand Radium Kurhaus (*author's note: today's Radium Palace*) – once one of the most luxurious hotels in Europe (*Fig. 3*). The origins of the spa are closely tied to the discoveries of Marie Curie, the first woman to earn a doctorate from the Sorbonne and to receive two Nobel Prizes. In 1520, Jáchymov also became home to the first pharmacy in Bohemia. To this day, the town remains unique worldwide for its use of brachytherapy ("Jáchymov boxes", BRT), a specialized treatment method found nowhere else. All these remarkable Jáchymov milestones have already been discussed in detail in the April and especially August issues of *VTEI* this year [1, 2]. So now, let us turn our attention to another local marvel that literally shaped Jáchymov's history – Svornost Mine. And let us start from the very beginning.

The spa season

Even a hundred years after Marie Curie's visit to Jáchymov, it still pays to be in the right place at the right time [*see more in 2*]. For instance, visiting Jáchymov Spa in the second half of May this year offered a special opportunity: on Saturday, 24th May, guests could attend the ceremonial opening of the 119th spa season and meet the leadership of the town, the spa, and Svornost mine, including an invitation to the international conference *The legacy of Marie Curie in Jáchymov Spa and the 100th anniversary of her visit* [3]. The highlight of the day's festivities was the blessing of the springs and wishes for a successful spa season delivered by Father Milan Geiger, followed by speeches from František Holý, the Mayor of Jáchymov, Gustav Žaludek, Director of the Spa, and Martin Přibil, Director of Svornost Mine. The ceremony also featured mine workers in traditional uniforms (*Fig. 4*). Svornost Mine – one of Jáchymov's defining landmarks and enduring symbols – is, in many ways, ever-present in the town. Without its "water of life," there would be neither patients nor visitors, no spa at all. Let us therefore take a closer look at its history.

Mining region

The Jáchymov region forms an important part of the Ore Mountain Mining Region (*Erzgebirge* in German), which is composed of 22 areas. Five of these are located on the Czech side: Jáchymov Mining Landscape, Abertamy – Boží Dar – Horní Blatná Mining Landscape, the Red Tower of Death, Krupka Mining Landscape, and Měděník Mining Landscape, while the remaining 17 lie across the border in Saxony. Together, these sites bear powerful witness to the immense influence that mining and ore processing on both sides of the mountains had on the global development of mining and metallurgy. Over 800 years of almost

continuous extraction and processing of ores have shaped in the Ore Mountains a truly unique mining landscape, characterized by an exceptional concentration of technical monuments whose variety and density are unparalleled anywhere in the world. These heritage sites document the methods of mining and refining various types of ores from the 12th to the 20th century – primarily silver, tin, cobalt, arsenic, nickel, iron, and, in more recent times, uranium.

Svornost Mine

Svornost Mine (*Fig. 5*) undoubtedly has its own genius loci and is regarded in Jáchymov as a true "family treasure". It dates back to 1518, although at that time the shaft bore the name Konstantin. It was excavated in the upper part of the town along the newly discovered, rich silver vein Stella, which had been found in Jáchymov in 1516. For the miners of that era, the most important task was the extraction of ore, primarily silver in this case, from the vein. In the 16th century, this meant purely manual labour – the driving of adits, galleries, and shafts was most often done using only a hammer and pick. So, how was the ore actually extracted? The miner would strike the back end of a pick with his hammer so that the tip of the pick drove into the rock, breaking off fragments of stone. This method of extraction gave the adit its characteristic shape, still visible in old mine workings today. It is assumed that during a single shift, a miner wore out 30 to 40 picks. These were loosely fitted into their handles, allowing the miner to replace them easily with new ones. The blunted tools had to be resharpened daily in the mining smithy (*author's note: this information comes from a tour of the exhibition in the former Royal Mint*).

However, after this demanding extraction, the silver-bearing ore usually contained no more than 0.1 % silver, and any further processing to obtain the metal from the ore was at that time extremely complex and costly. Considering that between 1516 and 1554, some 250,000 kilograms of silver were mined in Jáchymov by this method, and that the mine contains more than 120 kilometres of galleries [5], the hard work of the miners of that era still commands great respect today. As early as 1520, thanks to silver mining, Jáchymov was elevated to the status of a free mining town. In 1530, the shaft was renamed *Svornost* (German Einigkeit – "Unity") in commemoration of the reconciliation between the mine's two former rival owners.

Svornost Mine is also the world's first uranium mine. During its operation, silver was extracted here first, followed later by cobalt and other ores, and from 1853 onwards by uraninite, which was used in the local factory producing luminous paints for glass and porcelain (*author's note: this uranium colour factory in Jáchymov operated successfully for almost one hundred years, but was demolished at the beginning of the Second World War*). It is also the oldest functioning mine in Europe. Since 1906, it has been used to obtain radioactive water

Fig. 1. Boží Dar, Ježíšek post office

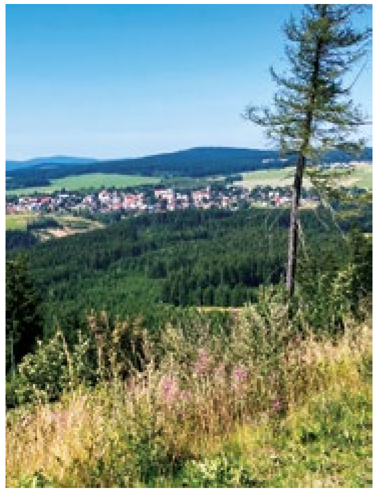


Fig. 2. View from Klínovec to Saxon Oberwiesenthal

Fig. 3. Radium Palace

Fig. 4. Opening of the spa season (May 2025)

for spa purposes. This water, thousands of years old, originates from the depths of the Jáchymov bedrock and becomes naturally enriched with radon; thanks to its rich chemical composition, it has healing properties.

Geological perspective

From a geological perspective, the Jáchymov deposit was a vein-type deposit, with the fillings of these veins composed of ores of silver, arsenic, cobalt, nickel, bismuth, and uranium. They were formed by the penetration of hydrothermal solutions from the underlying magma into fissures created within the older mantle of metamorphic rocks, consisting mainly of phyllites. This process resulted in the formation of two principal vein systems within the deposit: (1) east–west-oriented veins, known as morning veins, and (2) north–south-oriented veins, referred to as midnight veins.

1. **The east–west-oriented morning veins** are weakly mineralised or barren faults that roughly follow the strike of the phyllite sequence, though they differ in dip. Their fillings consist of clay and mylonitised (*author's note: consolidated*)

Fig. 5. Svornost Mine (August 2024)

fragments of the surrounding rocks. Manifestations of hydrothermal mineralisation are sporadic; only in the vicinity of intersections with the north–south-oriented midnight veins does more intense mineralisation occur along these veins. This vein system is characterised by stable structural conditions. The veins reach lengths of up to one kilometre, and their thickness most commonly ranges between 0.5 and 1 metre [4].

2. **The north–south-oriented midnight veins** are far more numerous and more richly mineralised. However, the structural conditions of this system are much less consistent than those of the morning veins. The midnight veins are generally only a few hundred metres long, and their thickness varies considerably. Along the same vein, thickness often fluctuates over very short distances – from just a few centimetres to over a metre – averaging between 10 and 30 centimetres. The vein filling is mostly composed of dolomite, calcite, and quartz, while in some sections of the veins, fluorite is the dominant mineral.

Uranium ore – pitchblende, or uraninite – was extracted in Jáchymov from more than 400 veins, with a total vein surface area of 8,000,000 m^2. However, the average thickness of the uranium mineralisation was only 0.15 mm, making it a poor deposit with low productivity [4].

Hydrogeological perspective

The presence of fault lines, minor tectonic features, and vein structures, which are predominantly hydraulically permeable, favourably influences the infiltration of surface water into the rock complex. From a hydrogeological perspective, the groundwater of the Jáchymov area can be divided into two groups as well: (1) cold waters and (2) thermal waters.

1. **Cold groundwater**, circulating within the metamorphic rocks, is discharged both through surface springs and through outflows in the mine workings. The temperature of these springs corresponds to the depth at which they emerge. Springs at higher levels have lower temperatures, which increase with depth. More substantial water outflows are associated with major open fault lines and vein structures, which enable more active contact of water between surface and deeper parts of the metamorphic complex [4].

2. **Thermal groundwater** is represented by radioactive thermal springs. All currently known radioactive thermal springs in Jáchymov emerge at the twelfth level of Svornost Mine, roughly 500 metres underground, which corresponds to the zone of greatest artificial lowering of the groundwater table. Some of these thermal springs were tapped during geological exploration (e.g., C–1), while others were intersected during mining operations (e.g., Curie) [4].

Following their exposure through mining activities, a system of several springs developed here, which are hydraulically connected and share the same water source and mineralisation, as well as similar chemical composition and nearly identical temperatures. All the springs are also characterised by pronounced radioactivity, which, together with other physicochemical properties of the water, creates a globally unique and extremely valuable natural medicinal resource.

Radioactive healing springs

For balneotherapy, four springs are currently used in Jáchymov, as shown in the map from Svornost Mine (*Fig. 6*):

1. **Curie Spring** is the oldest. It was discovered on 12 March 1864 during further shaft excavation at a depth of approximately 30 metres below the twelfth level. The original discharge of the spring was about 400 l/min, with a temperature of 22.5 °C. (*Author's note: by comparison, the current discharge is around 30 l/min, with an average temperature of 28.8 °C and an average activity of 5.7 kBq/l.*) At the time of its discovery, the spring was so powerful that it completely flooded the shaft, reaching up to 300 m along the Daniel adit on the sixth level [4]. Initially, this was more of a hindrance to the miners, as it obstructed their work, and they attempted to pump the water out. However, like their predecessors 300 years earlier, they soon experienced the beneficial effects of this mine water, which relieved the aches of their fatigued bodies. A significant contribution to this understanding came from the mine manager at the time, Josef Štěp; he, together with the physician Leopold Gottlieb, who, building on the scientific discoveries of the Curie's, investigated the effects of radioactive waters (see [2] for more), initiated a new era in Jáchymov's history, and laid the foundations of local balneology. In honour of Marie Curie, the spring was later named after her. It has been officially used for spa baths since 1924.

2. **C–1 Spring** was discovered during geological exploration in 1960. It was drilled from the twelfth level of Svornost Mine to a depth of 240 m. The spring has an average discharge of around 40 l/min, a temperature of approximately 29.6 °C, and an average activity of 11.5 kBq/l [4].

3. **Academician Běhounek Spring** (*author's note: often referred to simply as* Běhounek) (*Fig. 7*) is the most important source of radioactive water for the spa operation. It was discovered as a result of geological exploration carried out between 1962 and 1963, during which nine boreholes were drilled at the twelfth level of Svornost Mine. One of these (borehole HG–1, at a depth of 152.7 m) intercepted a powerful spring with a discharge of 570 l/min and a temperature of 28.6 °C. Its radon concentration was 10 kBq/l [4]. The spring was named in honour of Dr František Běhounek, a prominent Czech physicist and chemist, who had been a student of Marie Curie at the Sorbonne in his youth and maintained a warm connection to Jáchymov.
Together with Curie and C–1 springs, Academician Běhounek Spring provided a sufficient supply of medicinal radioactive water for baths for patients in the treatment houses, thereby contributing to the intensive development of the spa industry in Jáchymov.

4. **Agricola Spring** is the newest of the local springs, discovered in 2000 by borehole HJ–14 at a depth of 132 m. It has a discharge of 5 l/min and a temperature of 28 °C, with a radon concentration of 25 kBq/l [3]. This spring is also named after a notable historical figure associated with Jáchymov. Georgius Agricola, born Georg Bauer, worked in the 16th century in Jáchymov as the town physician. In addition to studying medicine in Italy, he was educated at German universities and also engaged in mineralogy, mining, and metallurgy. Presumably for this reason, he focused particularly on the health of miners and the treatment of their specific illnesses, as well as on the therapeutic properties of the local waters and minerals. His scientific work laid the foundations for modern mineralogy and the sciences related to mining and metallurgical activities. A commemorative plaque in the spa honours him as well (*Fig. 8*).

All four of these springs are still used for treatment today, with patients receiving a mixture of their waters during baths. The water is conveyed via pipelines to a radioactive water retention tank with a capacity of 150 m^3, built into the rock massif at the twelfth level of Svornost Mine. From this tank, the water is pumped into an accumulation reservoir with a capacity of 300 m^3 located on the Barbora level, 100 m below the surface. From there, it is transported by gravity along the Daniel level through a pipeline nearly 3 km long to the individual balneotherapy facilities of the treatment spa. The entire system of collection and transport of radioactive water from Svornost Mine to the points of use is closed to prevent the escape of radon from the water [4].

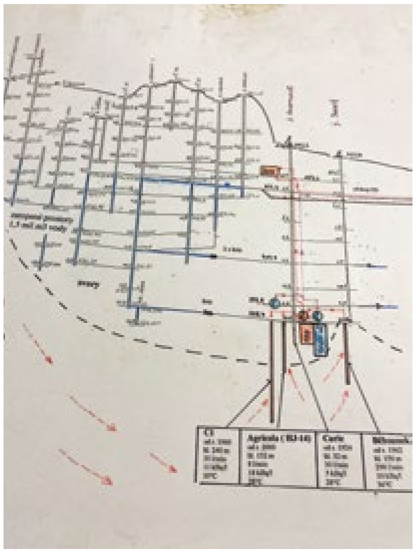


Fig. 6. Svornost Mine, spring map


Fig. 7. Svornost Mine, Academician Běhounek Spring

Fig. 8. G. Agricola memorial plaque in Jáchymov

Fig. 9. Svornost Mine after descending to the 12th level underground


Fig. 10. Most tunnels in Svornost Mine are not illuminated, so a helmet with a headlamp is very useful

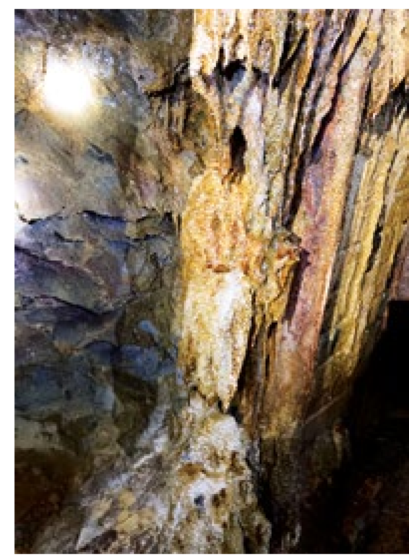


Fig. 11. Svornost Mine – the richest geological site in the world


Fig. 12. Rich speleothem decoration


Fig. 13. St Barbora Chapel in Svornost Mine

Fig. 14. A mine employee pumps Běhounek Spring into the test basin

Half a kilometre underground

Entering the depths of Svornost Mine – that is, descending to the twelfth level, roughly 500 metres underground – is not entirely impossible for patients or visitors to the Jáchymov spa. Guided tours with expert commentary are occasionally organised. All that is required is sturdy footwear and warm clothing – mine staff then provide a blue protective coat and a helmet with a headlamp – and perhaps a little courage, as visitors voluntarily plunge in a metal cage through darkness and cold, icy water dripping on them, while the hoist wails deafeningly.

But it is worth it. Below, only a few technical instructions remain on very well-worn doors (*Fig. 9*), marking the end of the familiar, civilised world. The tunnels are dark, damp, and cold, and each person is truly on their own here (*Fig. 10*). Yet, when illuminated by the headlamps on the helmets, the walls seem to come alive, playing with all the colours of a wide variety of ores and minerals – limestone, sulphur, iron, as well as silver, tin, cobalt, and others (*Fig. 11*). After all, Jáchymov hosts 17 metal-bearing ores and over 400 different minerals. Our guide adds that this makes Svornost Mine the richest geological site in the world. Complex stalactites are also often seen here, thriving in the cold, damp conditions (*Fig. 12*).

One of the few permanently illuminated spots is the altar dedicated to Saint Barbara, the patron saint of all miners (*Fig. 13*). Miners and mine workers came here to pray, and after the end of the Second World War and during the 1950s, political prisoners also prayed here while working in the uranium mines. The tiny chapel is therefore carefully maintained at all times, and even contains flowers.

The mine tour continues through more dark tunnels until the guide stops at a large mining installation with a tank and Academician Běhounek Spring (*Fig. 14*). From this point, the richest of the four springs is distributed to the various spa buildings throughout Jáchymov. In one of the side tunnels, the original mine carts and parts of historic pumps are still on display (*Figs. 15a, b*).

The circuit of the twelfth level of Svornost Mine lasts only about an hour, after which it is back into the metal hoist cage heading upwards – towards light, warmth, and fresh air. Looking back at the upper part of the mine, an interesting detail comes into view: a propeller that keeps turning (*Fig. 16*). Indeed, we have been in the oldest functioning mine in Europe and the world's first uranium mine (*Fig. 17*).

The "Granny" went down

Here, a historical aside is in order. As mentioned in the August issue of VTEI [2], Marie Curie visited Jáchymov in June 1925. She spent several days there and was accommodated at the Radium Palace Hotel. Her guide at the time included the aforementioned František Běhounek, her student and young collaborator from the Sorbonne, who was very familiar with Jáchymov. As part of a conference held this June to celebrate the 100th anniversary of this visit [3], Professor Ing. Tomáš Čechák, CSc., from CTU shared a charming anecdote from her time in the town. Academician Běhounek reportedly recalled Madame Curie as follows: "On 17 June, the Granny descended into Svornost Mine. I was 26 years old, she was 57, yet she went down. She humbly accepted the greasy hat that had previously been worn by God knows who, and signed the visitors' book there." (*Author's note: this visitors' book was on display for viewing during the aforementioned conference,* see *Fig. 18*).

It should be noted that the 57-year-old "Granny" (bábinka), as the young Běhounek called Marie Curie, repeatedly shocked him with her boundless energy and curiosity. At her request, for example, they set out for the highest peak of the Ore Mountains, Klínovec (1,244 m a.s.l.), and she then insisted that they return to Jáchymov on foot, because she wanted to "breathe in the fresh mountain air." It is said that her Czech entourage could barely keep up with her at the time.

Adit No. 1

Just about 100 metres from Svornost Mine, in the direction of the centre of Jáchymov, lies Adit No. 1. Although it is near the surface, it is still cool inside. The adit is 260 m long and was driven in 1952 to verify uranium mineralisation. Silver was also mined here, from a silver vein called Jan Evangelista. Unlike Svornost, its tunnels are illuminated, so remnants of the silver vein are still visible on the walls (*Fig. 19*). Also on display are finds from Svornost and Jáchymov labour camps from the period 1949–1961, that is, from the "harsh" years when tens of thousands of political prisoners, sentenced to long terms, were forced to work in ten local concentration camps (*Fig. 20*). A reminder of them are the so-called katry (*Fig. 21*), massive metal grilles used to confine prisoners underground (*author's note: from this term, the Czech expression "sedět za katrem" – to be in prison – later emerged*).

Jáchymov cemetery

A lasting reminder of the political prisoners in Jáchymov is also the local cemetery beneath the Church of All Saints, known as the Hospital Church (*Fig. 22*). It was established between 1516 and 1520, making it the oldest functioning historic building in the town. Why is it called Hospital? Because, from 1530 onwards, a municipal hospital stood next to the church, operating for over 400 years. In 1955 it was completely destroyed by fire and was never rebuilt; today, an urn grove occupies its site.

While the tombstones in some parts of the cemetery are already crumbling and gradually being reclaimed by nature, the graves of former miners and political prisoners are carefully maintained as a testament to the nation's memory (*Fig. 23*). In the Ore Mountains, and especially in Jáchymov, one is often struck by the thought of how turbulent and "harsh" (krušný) the wartime and postwar periods must have been here, with concentration camps and forced labour for political prisoners. However, the Czech name of the mountains (Krušné) comes from the verb krušit, meaning "to mine," and thus refers to this rich mining region, crisscrossed with hundreds of kilometres of underground adits; it has nothing to do with hardship or suffering.

Jáchymov levels

After uranium mining at Svornost ended in 1964, the mine was transferred to Jáchymov Spa and has since been used solely for pumping radon water for therapeutic purposes and for operating the radioactive waste repository managed by the State Office for Nuclear Safety. In 1979, reconstruction of the mine began, alongside the driving of the New Svornost Drainage Adit (*author's note: information from a lecture by the director of Jáchymov Spa, MUDr. Jindřich Maršík, MBA, at the conference on 12 June 2025*; see [3]) (*Fig. 24*). Today, it is hard to believe that, after mining ended, the area around the mine was completely covered with enormous spoil heaps from the underground workings, and that the entire valley was filled with mounds of stone. After six decades, however, the land is once again green with forest, and the restored landscape presents a welcoming face. The only remnants of the ever-present spoil heaps are the terraced slopes, so typical of the former mining landscape. The main street and the elongated town square follow the valley of the Jáchymovský Stream, while all the side streets and alleys on the steep slopes on either side reveal that the town still depends on kilometres of retaining walls and dozens of staircases (*Fig. 25*).

On one of the hills above the spa centre stands the Chapel of Saint Barbara, built in 1777 and also dedicated to the patron saint of all miners (*Fig. 26*). This chapel is quite unusual, however, as it has two small towers on its roof, symbolising the unity of the local miners and metallurgists in Jáchymov, who together initiated its construction. Another interesting fact is that in 1917 the chapel was moved to the hill above the spa park, including its interior furnishings, because

Fig. 15 a, b. Original carts and pump components

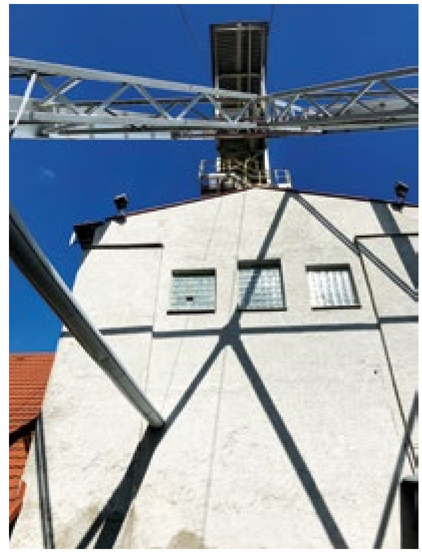


Fig. 16. The Svornost Mine propeller

Fig. 17. The author of the text was also 57 when she went down Svornost Mine; for F. Běhounek definitely a "Granny" (August 2024)

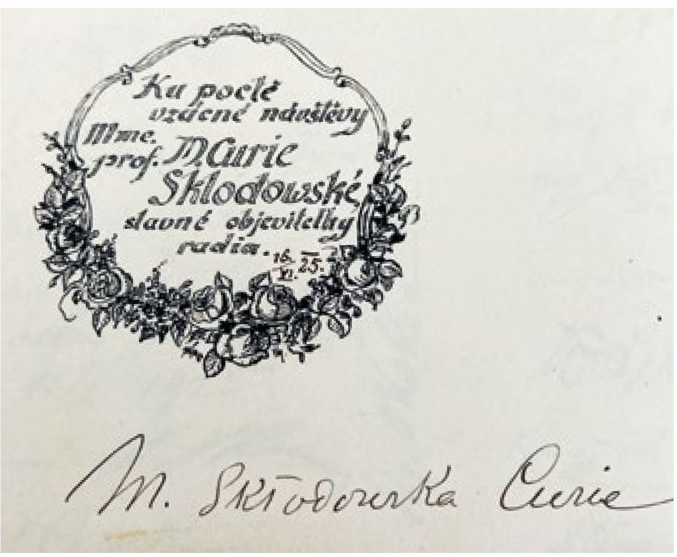


Fig. 18. Marie Curie's signature

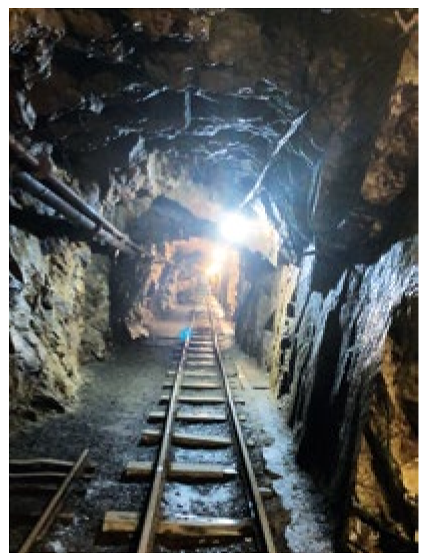


Fig. 19. Adit No. 1

Fig. 20. Original objects from the Jáchymov labour camps

Fig. 21. Adit No. 1, metal grille

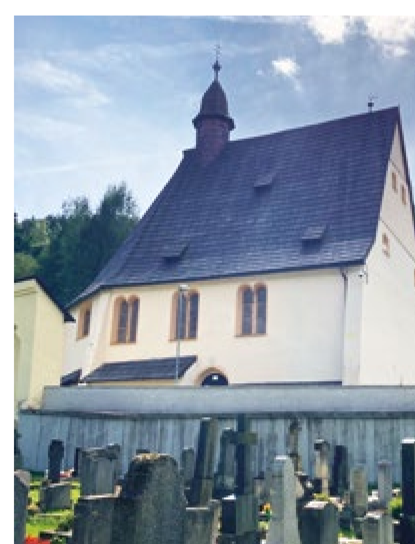


Fig. 22. Hospital Church


Fig. 23. Grave of Jáchymov prisoners

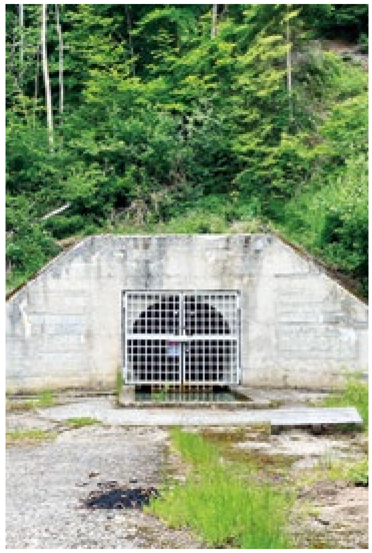


Fig. 24. New drainage adit


Fig. 25. Jáchymov levels


Fig. 26. St Barbora Chapel


Fig. 27. One of the local natural phenomena


Fig. 28. Radon Trail


Fig. 29. Pianist and composer Marek Kovářík (Běhounek Spa House, May 2025)

it originally stood in the town centre on the site of today's Hotel Astoria, where it had begun to obstruct the developing spa facilities.

The Radon Trail

In the April issue of *VTEI* [1], we became acquainted with two routes in Jáchymov – the Valley of the Mills and the Mill Trail. Now, let us take a walk along another route, which also passes through Jáchymov and the surrounding forests full of curiosities (*Fig. 27*). In addition to offering charming views of the Jáchymov levels already mentioned, it has educational value. This is the Radon Trail, established in Jáchymov in 2011 in cooperation with the town authorities. Two years ago, the trail was replaced with a newer, more popularised version. Its primary purpose is to serve as an educational tool, raising awareness of radon in the local environment, methods of measurement, potential risks associated with exposure, and possibilities for prevention.

That the world's first radon trail was established in Jáchymov is more than logical. The reason lies both in the local geological conditions – the bedrock, crisscrossed with historic adits, allows radon to penetrate buildings – and in the use of construction materials from mining waste, which contain radioactive elements and emit gamma radiation. The town has actively addressed this long-standing issue, and an obvious partner and provider of expert support is the State Office for Nuclear Safety, which continuously monitors the local radiation situation. Another partner in establishing the trail was the Ministry of Industry and Trade.

The Radon Trail has a total of ten stops with information panels, from which visitors gradually learn about radioactivity, natural sources of ionising radiation and radon, as well as its effects on human health, the ways radon penetrates buildings, and more. Perhaps the most surprising finding along the trail is that the most significant source of radiation exposure for humans comes from nature itself – specifically, the radioactive gas radon, which is present all around us.

The final two panels focus directly on the spa and its treatments. The trail returns to them along a fresh forest path (*Fig. 28*). Were it not for the still-legible inscription on an old bench made of planks – "they can close you up, but they must let you out" – it would be hard to believe, on this sunlit path, just how turbulent the history of Svornost Mine, and indeed of Jáchymov as a whole, has been.

Jáchymov lives

To end on a more optimistic note, let us return to Jáchymov's traditional balneology, the many satisfied patients from all over the world, and their highly effective treatment with unique radon baths, originally known as radioactive emanations. Visitors to Jáchymov – this spa town nestled in the forests of the Ore Mountains – are always eager to return, some even as many as twenty times in succession, to undergo treatment and recharge their vital energy. Thanks to them, Jáchymov is now awakening to a new era. Historic buildings are being restored, new shops and guesthouses are opening to accommodate visitors, and the spa houses offer a rich social and cultural programme – including lectures, guided excursions, and concerts of popular, dance, and classical music, often featuring promising young artists (*Fig. 29*).

Photos on pp. 52–59: Z. Řehořová

Acknowledgements

I would like to express my gratitude to the management of Svornost Mine for the opportunity to descend to the twelfth level, 500 metres underground, and for the guided tour with expert commentary. My thanks also go to the Head Physician of the spa, MUDr. Jindřich Maršík, MBA, Prof. Ing. Tomáš Čechák, CSc., and the other speakers at the conference The legacy of Marie Curie in Jáchymov Spa and the 100th anniversary of her visit for their highly engaging presentations. I am deeply grateful that, during the conference, I had the chance to meet, for the last time, the Chair of the State Office for Nuclear Safety, Ing. Dana Drábová, Ph.D., Dr.h.c., who sadly passed away while this article was being prepared.

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"U DVOU LOUČEK" RESEARCH CATCHMENT

The final feature this year will focus on the Orlické Mountains, specifically U Dvou Louček research catchment. This is an experimental forested catchment located in the upper reaches of the Orlické Mountains (880–950 m a.s.l.) within the Anenský Stream basin, covering an area of 33 ha. The bedrock consists of gneisses and schists, while the soils are predominantly composed of cambisols and podzols, with organosols occurring locally, particularly in areas surrounding springs. The dominant tree species is Norway spruce (*Picea abies*), which is mixed with fir and broadleaf species, particularly at the edges of stands and on scree outcrops. At higher elevations, blue spruce (*Picea pungens*) can also be found, which was extensively used in the past for reforesting areas damaged by air pollution. Systematic observations were established in 1992, with the primary motivation being the monitoring of changes in climatic and hydrological characteristics in areas damaged by air pollution. As with other experimental catchments of the Forestry and Game Management Research Institute and the Czech Hydrometeorological Institute, measurements of precipitation are conducted here in open areas as well as under the canopy. In addition, the chemical composition of the precipitation is monitored, along with volumetric soil moisture and groundwater levels in several dozen shallow wells. Water levels and discharge are measured and evaluated at the closing profile and on one of the tributaries. Measurements and modelling in hydrological and ecological (stand) models are intended to help answer the question of how forest health and successional dynamics influence the quantity and quality of water, not only in mountain catchments. In this regard, comparative sites include the Červík and Malá Ráztoka catchments in the Beskydy Mountains, as well as the Suchý, Sokolí, Slučí, and Svinný Stream catchments in the Jeseníky Mountains.

Text ad photo by doc. RNDr. Jan Unucka, Ph.D.