VODOHOSPODÁŘSKÉ TECHNICKO-EKONOMICKÉ INFORMACE

(WATER MANAGEMENT TECHNICAL AND ECONOMIC INFORMATION)

VTEI / 2025 / 2

60 years ago in VTEI

In VTEI No. 2 from 1965, Alois Veselý from the Department of Water Management Structures (OVHS) in Kroměříž described his improvement proposal No. 315/1964, entitled Triangle ruler for water managers.

Current status:
In the design and operational practice of water managers at all levels, there is still no template of the most commonly used symbols and a universal scale.

Improvements made:
The water management triangle ruler has the shape of a classic triangle ruler of 60°, 90°, 30°, made of transparent plastic with a thickness of 1.0 to 1.5 mm, with the smallest side 140 mm so that it covers the A4 format.

The triangle ruler contains:
1. The six most commonly used scales: 1 : 1,000, 1 : 2,000, 1 : 2,500, 1 : 5,000, 1 : 2,880, 1 : 1,440;

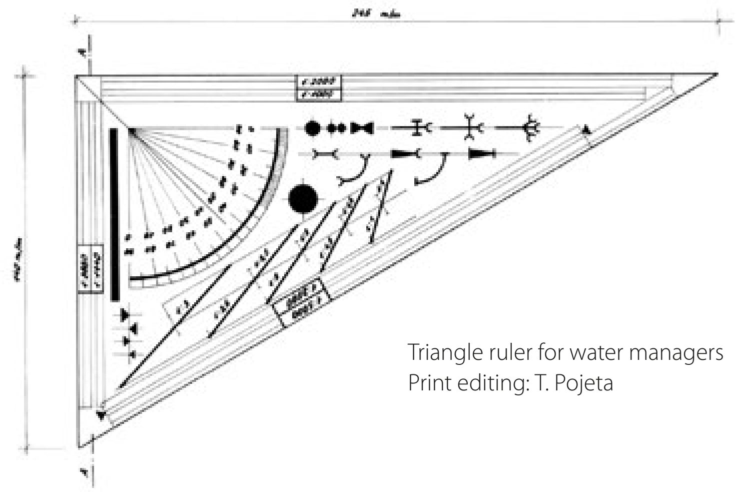
2. A protractor – triangle 30°, 60°, 90° and protractor up to 90°, divided by 1°, numbered back and forth with a cutout for drawing angles;

3. A template of frequently repeated symbols and marks of water management drawings (marks of some pipe fittings, lines for drawing slopes of channels 1 : 1, 1 : 1.5, 1 : 2, 1 : 2.5, 1 : 3) and cutouts for water level marks, description of dimensions, sewer manholes, etc. in three sizes.

Orders for this device are being processed by OVHS Kroměříž, which will provide further details regarding the delivery time and the location from where the device will be shipped. The price is estimated at 16 to 20 Czechoslovak crowns.

From the TGM WRI archives

VTEI Editorial office



Triangle ruler for water managers
Print editing: T. Pojeta

Content


Photo: J. Unucka

Dear readers,

The April issue of our VTEI journal is published just a few days after the celebrations of World Water Day, whose theme and key message for this year is "Save our glaciers"; they are not only an important source of drinking water, but also essential for the proper functioning of agriculture, industry, clean energy production, and healthy ecosystems. Since one of climate change consequences is the warming of our planet, the "frozen part" of our world is shrinking, which also has an impact on the water cycle. Billions of people are experiencing these changes in the form of floods, droughts, landslides, rising sea levels, and damage to ecosystems.

Rapidly melting glaciers are creating uncertainty about the condition of watercourses with profound impacts on the entire planet and people. This year's global campaign for World Water Day calls on everyone – from individuals and families to governments and entire societies – to do what they can to prevent further glacier loss.

So, what do we bring you in the April issue?

As a result of climate change, extreme weather fluctuations are occurring more and more frequently, leading to a lack of precipitation and drought, or, conversely, to extreme precipitation and floods. One of the causes of these changes is human society and its ever-increasing demands on water and other strategic raw materials. The expert article by Ondřej Ledvinka and the team of authors "Historical changes in water use in Czech third-order catchments and indications of potential trends based on new regional climate models by the CHMI" presents the results of the Czech Hydrometeorological Institute regarding the methods of influencing the flow above water gauging stations in the Czech Republic and changes in this influence based on climate change.

In the expert article by Jan Unucka (CHMI Ostrava) and his collaborators and colleagues from the VÚLHM, partial results are presented of monitoring and modelling in experimental forest catchments in Jeseníky PLA. The authors aim to introduce readers to interesting aspects of forestry hydrology in experimental catchments in the Jeseníky Mountains, to familiarize them with research methods, and to select interesting results with regard to new procedures and the extreme floods of September 2024. You can read more in the article "Measurement and modelling of changes in the runoff regime following calamitous decay and regeneration of forest stands in small catchments in the Jeseníky Mountains".

In the expert article "The pond system on the Bečvárka River" by Pavel Richter (TGM WRI), the development of the pond landscape in the Bečvárka River basin is presented, based on the interpretation of archival and current maps, including verification of the current state of the ponds. The main objective of the research was to map the development of the landscape in the locations of disappeared ponds in the basins of the Labe tributaries in Polabí.

The expert article "Assessment of the hydromorphological status of river water bodies in the Czech Republic using HYMOS methodology" by Ján Babej (Global Change) and his colleagues brings an important perspective on a new method of assessing the hydromorphological status and its components, which is part of monitoring of the ecological conditions of water bodies. Based on the request of the Ministry of the Environment, a new methodology for assessing the hydromorphological status of flowing water bodies was created (HYMOS). Its procedures were tested on 15 water bodies divided into 50 sections. HYMOS methodology combines a detailed and aggregated approach, which makes it a flexible tool suitable for both strategic planning at the water body level and for the evaluation of local sections in connection with implemented or planned measures.

Our usual interview is not just about hydrology and water management, but also about travel and sport. This time, we are happy to interview a prominent Czech geographer and, among other things, the discoverer of the sources of the Amazon, Professor Bohumír Janský from the Faculty of Science of Charles University in Prague.

Thanks to the number of various mineral springs and their diversity and chemical composition, Western Bohemia is famous primarily for its spas. Readers will certainly think of the three most famous spa towns in this area – Karlovy Vary, Mariánské Lázně, and Františkovy Lázně. However, the article of our colleague Zuzana Řehořová will guide you through less frequented, and therefore perhaps more interesting and unusual sites and routes around Jáchymov spa. She will also take you on a walking trail describing the history of local water mills to the town of Ostrov, famous, among other things, for the impressive garden surrounding the local castle.

We conclude the April issue with an informative article by Lenka Žaitliková from Association of Young Environmentalists of the Czech Union for Nature Conservation about the Ecological Olympics for secondary school students, which took place in March this year at the premises of TGM WRI in Prague.

Dear readers, we wish you a pleasant and inspiring read.

VTEI Editorial Office

Historical changes in water use in Czech third-order catchments and indications of potential trends based on new regional climate models by the CHMI

ONDŘEJ LEDVINKA, VÍT ŠŤOVÍČEK, KATEŘINA VACKOVÁ, PAVEL COUFAL

Keywords: water withdrawal — water disposal — water accumulation — unaffected discharge — natural discharge — climate scenarios — SPI index — Czech Republic

ABSTRACT

The article presents the results of the Czech Hydrometeorological Institute (CHMI) obtained when addressing the sub-objectives "Scenarios of future water needs for different climate scenarios and individual sectors of water use" (DC 1.1) and "Identification of areas with deficient water resources" (DC 1.2), which are part of TA CR project No. SS02030027 *"Water systems and water management in the Czech Republic in conditions of climate change (Water Centre)"* and constitute specific tasks within the work package WP1 focusing on the future of water. The aim of the CHMI was to calculate and analyse how river flows upstream of gauging stations in Czechia are influenced by water use and to determine how this influence may change in relation to climate change. Mainly, the monthly data of the total discharge influence at gauging stations for the reference period 1991–2020 were analysed. The emphasis was placed on identifying trends in the total influence within individual river basins and localising areas at potential risk of declining water availability and increasing societal demands. For instance, trend slopes were compared across different time periods. Furthermore, an attempt was made to identify areas with deficient water resources based on the SSP2-4.5 and SSP5-8.5 climate scenarios using regional climate models developed at the CHMI. The analysis of the impacts of water withdrawals and climate change on water resources in Czechia revealed significant regional variability. In some regions, such as southern Moravia, northwestern Bohemia, and the Bílina River basin, significant changes in surface and groundwater withdrawals were observed, potentially affecting water availability. Climate scenarios indicate rising air temperatures, with the more pessimistic SSP5-8.5 scenario predicting an increase of up to 5 °C by the end of the century. Regarding precipitation, the SSP2-4.5 scenario suggests a slight increase, while SSP5-8.5 predicts more pronounced changes with higher precipitation totals in the western and southern parts of Czechia. The calculation of the Standardized Precipitation Index (SPI) confirms the occurrence of extreme dry and wet periods, with differences between river basins highlighting the need to tailor water management measures to regional conditions. Adaptation to changes in the hydrological regime, improvement of water resource protection policies, and prevention of the impacts of extreme climatic events must become priorities.

INTRODUCTION

Water is essential for the existence of all living organisms and determines the functioning of human society. As a result of climate change, extreme weather fluctuations are increasingly occurring, leading to a lack of precipitation and the occurrence of droughts or, conversely, to extreme precipitation and floods. One of the causes of these changes is human society and its ever-increasing demand for water and other strategic raw materials [1].

The flow rate of most watercourses in Czechia is influenced by anthropogenic activity, and since the 1950s there has been an extreme increase in pressure on water resources worldwide [2]. The values measured at water-gauging stations more or less reflect human activities, which include the withdrawal of surface water and groundwater for agricultural purposes, especially irrigation, and for supplying the population and industry. On the other hand, there is the wastewater disposal into surface waters (and rarely into groundwater), as well as the deliberate increase or decrease in the flow rate of a watercourse by operating reservoirs [3].

Water is often abstracted from one catchment and disposed into another several kilometres away. For example, in the Svitava catchment, groundwater is abstracted to supply the Brno agglomeration with drinking water and, after use, is led to the Brno-Modřice wastewater treatment plant, which flows into the Svratka [4]. This means that the measured values in both catchments are strongly influenced by anthropogenic activity, and therefore natural discharge cannot be measured directly, but must be calculated [2].

Since a watercourse is the main variable that connects ecosystem components through hydrological, biological, geomorphological, and water quality processes, the estimate of natural discharge (in our case, the so-called unaffected discharge; further generally referred to as QNE) is usually used as a reference quantity for estimating hydrological response to the climate regime, for assessing the ecological status of a river, and for estimating the amount of potentially available water [5].

This paper focuses on the analysis of the impact of water withdrawal, disposal, and accumulation on flow rates at water-gauging stations in Czechia for the reference period 1991–2020. It also includes an assessment of regional differences in the hydrological regime of Czech river catchments and the identification of areas where significant changes in water availability occur. It also assesses areas with potential water resource deficits, based on the SSP2-4.5 and SSP5-8.5 climate scenarios. The results of this analysis will contribute to effective water resource management and a deeper understanding of changes in the water regime.

METHODOLOGY AND DATA USED

Analysis of the influence of water use on discharge (DC 1.1)

In addition to the activities of other consortium members already presented in [6], the main task of the CHMI in DC 1.1 was to analyse the impact of water use on discharge in Czechia. The basis was monthly data on total influence on discharge at water-gauging stations, expressed in percentage as the ratio of discharge changes to QNE. In practice, this variable (and its time series) was designated by the abbreviation OVLTOT. Formally, its calculation can be expressed as

$$\mathrm{OVLTOT} = \frac{\mathrm{DELTA - SUMA}}{\mathrm{QNE}} \cdot 100\ [\%]$$

where:

DELTA	represents	the total impact of operated reservoirs in the catchment above the given station (or the difference between volumes at the beginnings of the months)
SUMA	is	the sum of impacts by withdrawals and disposals

Each variable related to the influence was first converted to $m^3 \cdot s^{-1}$ and given an adequate sign. Negative values of OVLTOT then indicated a predominance of withdrawals (including water accumulation in reservoirs), while positive values were associated with a predominant disposal (including water discharge from reservoirs). These data are regularly uploaded once a year to a CHMI database together with other available data on impacts valid for water-gauging stations (in accordance with Act No. 254/2001 Coll., on waters, as amended; with Decree of the Ministry of Agriculture No. 431/2001 Coll., on the content of the water balance, its method of compilation and on data for the water balance, and to a certain extent also with Decree of the Ministry of Agriculture No. 252/2013 Coll., on the scope of data in records of the state of surface and groundwater and on the method of processing, storing, and transmitting this data to public administration information systems). When calculating QNE, special attention is paid to the distinction between withdrawals only from surface waters (which is reflected in the SUMAY characteristic, which results in unaffected discharge values in the database abbreviated as QNEY) and total withdrawals (i.e. withdrawals from surface water including groundwater; which is reflected in the SUMAX characteristic, which results in unaffected discharge values in the database abbreviated as QNEY). To maintain homogeneity of the time series, only territorially relevant objects with a permit for the withdrawal or disposal of more than 6,000 m^3 per year or 500 m^3 per month are included in the calculation of the SUMA characteristic. The DELTA characteristic only considers reservoirs with a permitted volume of surface water accumulated or dammed greater than 1,000,000 m^3. The reference period 1991–2020 was selected for the current analyses, with a total of 346 gauging stations meeting the criterion for the completeness of the time series.

Simultaneously, an R script for the actual calculation of QNE series was developed at the CHMI. The script functionality depends on using coordinates for the correct location of the influencing object, and therefore it was necessary to check the coordinates of the input data of the influence. Special attention was paid to appropriate location of the beginnings and ends of the conduits in the system of watershed divides so that the point of withdrawal (or disposal) logically falls into the catchment area with the loss (or gain) of water. At the end of work on WP1 (June 2024), the most detailed vector layer published as of 1 July 2024 on the CHMI website with open spatial data [7, 8] was already considered for localising the objects. This layer was constructed on top of the fifth generation Digital Terrain Model of the Czech Republic (DMR 5G; [9]). The resulting QNE values were compared with the values obtained at the TGM WRI, which has been performing their annual calculation and submitted them to the CHMI.

For the purposes of developing the R script and calculating the M-day discharge cadastre for the reference period 1991–2020, input data on discharge influences were compared between three main sources, which were the Integrated System for Fulfilling Reporting Obligations (ISPOP system), files (exports) from the River Basin Authorities, state enterprises, and geographic layers from the VODA Water Management Information Portal available at https://voda.gov.cz/. It was found that the sources differ in the number of objects and the values themselves; however, updating (also in terms of error corrections) of these sources is somewhat decentralised, which can be seen as a great uncertainty. Therefore, a general check of the location of objects, their duplicates, and the values of withdrawals and disposals was performed [10].

Data from the VODA Water Management Information Portal was considered more as supplementary because, at the time of processing (i.e. at the end of work on WP1), it only reached the year 2020, compared to the status on the portal from August 2024 with data reaching back to 2014. Based on gaps in the time series, or changes in the object name and other attributes, objects were selected that could potentially be combined or divided. An analysis of water bodies was also carried out, where both water body and watercourse withdrawals can be reported at the same time. Therefore, objects situated in close proximity to reservoirs were located. All this information about selected objects was subsequently sent to the CHMI regional offices for manual checks via the PostgreSQL database with support for GIS tools (i.e. PostGIS).

For map outputs of the total influence, a third-order catchment layer was selected, including 346 selected water-gauging stations with a complete time series of the total percentage of influence for the hydrological period 1991–2020. The time series of other studied elements were also complete. For each station, the total area of the catchment above it and its share of the area of the third-order catchment in which the station is located were first calculated. The total percentage of influence for each catchment was calculated as the sum of total influence at all stations in the given catchment, with the weight of each station being the calculated share of the catchment area above the given station. The total percentage of influence in individual catchments therefore corresponds primarily to the stations at the mouth or near the mouth, where the largest area is drained.

In the next phase, a trend analysis was performed to determine whether there were statistically significant gradual changes in the time series of elements affecting the discharge of Czech rivers in the selected period. Two statistical significance levels were chosen, namely $\alpha = 0.05$ and $\alpha = 0.01$. The Mann–Kendall test for the presence of a trend [11–13] and its modification proposed in the article [14] were applied so that, in the case of a significant autoregressive coefficient with the assumed first-order autoregressive model, variance of the test statistic was corrected [15–17]. Results for each station and month were summarised in the value of the standardised test statistic Z (indicating the direction of a possible trend), the p-value, and Sen's nonparametric estimate of the trend direction, denoted SEN [18]. These analyses were performed for both monthly and annual time series.

The results were processed using the R package *modifiedmk* [19]. Cases where the p-value fell below the chosen significance level were plotted on maps using arrows at the locations of water-gauging stations. The arrow deviating from the horizontal direction, depending on the sign of the *Z* or SEN values, represented an increasing trend (number of values without a sign) or decreasing trend (number with a minus sign), similar to what was done in other papers dealing with trends in the components of the hydrological cycle in Czechia [20–22]. Map outputs were subsequently created from these analyses.

Identification of areas with deficient water resources (DC 1.2)

The main basis for processing were two datasets with a daily step, mainly for average daily air temperature and daily precipitation:

1. grids created by spatial interpolation of station time series representing 1961–2022, also known in the CHMI as GriSt_DenseNet (horizontal resolution 500 m, but domain limited only to Czechia [23–26]),

2. CSV files representing the results of bias correction of two selected scenarios of the regional climatological model ALADIN-CLIMATE/CZ for 2015–2100 (horizontal resolution 2,325 m [27–31]).

Using grids of average daily temperature and daily precipitation totals of product 1), daily time series of grids of potential evapotranspiration (PET; according to [32]) and climatic water balance were calculated (as the difference between precipitation and PET). The basic CSV files originating from product 2) were converted to GeoTIFF and NetCDF formats. Only two scenarios were used for analysis as others were not yet available: the medium climate scenario SSP2-4.5 and the more pessimistic scenario SSP5-8.5. The CHMI subsequently used rasters of these scenarios to determine the situation in the third-order catchments. For various other needs, the gridded time series were also aggregated into coarser steps, e.g. monthly, so that the series and results derived from them were comparable with the monthly step of discharge characteristics.

Change in average monthly air temperature and average monthly precipitation compared to the normal for 1991–2020 was examined according to both scenarios. SPI (Standardized Precipitation Index) was also calculated, which is used to estimate wet and dry conditions based on precipitation. This index is based on the standard deviation by which observed precipitation differs from the long-term average. However, before calculation, it is necessary to appropriately transform the precipitation time series according to the selected probability distribution [33]. In this case, the SPI12 index was chosen, calculated for a 12-month time window with a gamma distribution. The choice of this window proved to be appropriate because, among other reasons, the influence of seasonality was removed, as demonstrated by statistical tests in the R package *seastests* [34].

On the other hand, it should be emphasised that SPI only considers precipitation, not air temperature. This problem is solved, for example, by the SPEI index (Standardized Precipitation Evapotranspiration Index; see e.g. [35]), which combines both precipitation and air temperature, and its value can have a significant impact on the final results of the analysis. Therefore, it is necessary to interpret the obtained data with some reserve – rather as an illustration of the possible development of precipitation and its (in)sufficiency in this century.

RESULTS AND DISCUSSION

Analysis of the influence of water use on discharge (DC 1.1)

As shown in *Fig. 1*, the highest values of total surface water influence were achieved in the catchments in southern Moravia and the Osoblaha catchment, the Elbe from the Orlice to the Loučná, and in particular the Bílina catchment (however, in this catchment, data were entered from only one gauging station); in contrast, the lowest values were achieved in the catchments of the Rybná and the Lužnice from the Rybná to the Nežárka, the Sázava from the Želivka to the mouth, and the Dyje from the Svratka to the mouth. When groundwater withdrawals were included, high values were again found in the catchments in southern Moravia and in the catchments of western and northwestern Bohemia. The highest values of the degree of influence can be observed in the catchments of the Loděnice, Osoblaha, and Oslava. In contrast, the lowest values were measured in the tributaries of the Freiberg Mulde, Šopava and Flöha, in the catchments of the Morava from the Bečva to the Haná, the Rybná, and the Lužnice from the Rybná to the Nežárka and the Svitava.

From the trend analysis for the reference period 1991–2020, different behaviours can be observed in water withdrawals and disposals at selected water-gauging stations, often creating noticeable clusters in several areas (*Fig. 2*). Overall, however, a zero trend prevails across water withdrawals and disposals. This was found in each of the monitored groups at approximately 230 of the total 346 water-gauging stations (around 65 % of all stations).

In the case of surface water withdrawals, including groundwater, a slightly decreasing and slightly increasing trend was observed at approximately 8 % of all monitored stations. The same ratio was measured at stations with a significantly increasing trend. A significantly decreasing trend was then detected at 47 stations (almost 14 % of all stations), forming noticeable clusters at stations in northern Bohemia (especially the Ploučnice catchment) and eastern Bohemia (the Metuje catchment, the Orlice from the confluence of the Divoká and Tichá Orlice to the mouth, and the Loučná and Elbe from the Loučná to the Chrudimka). Other catchments with a predominance of significantly

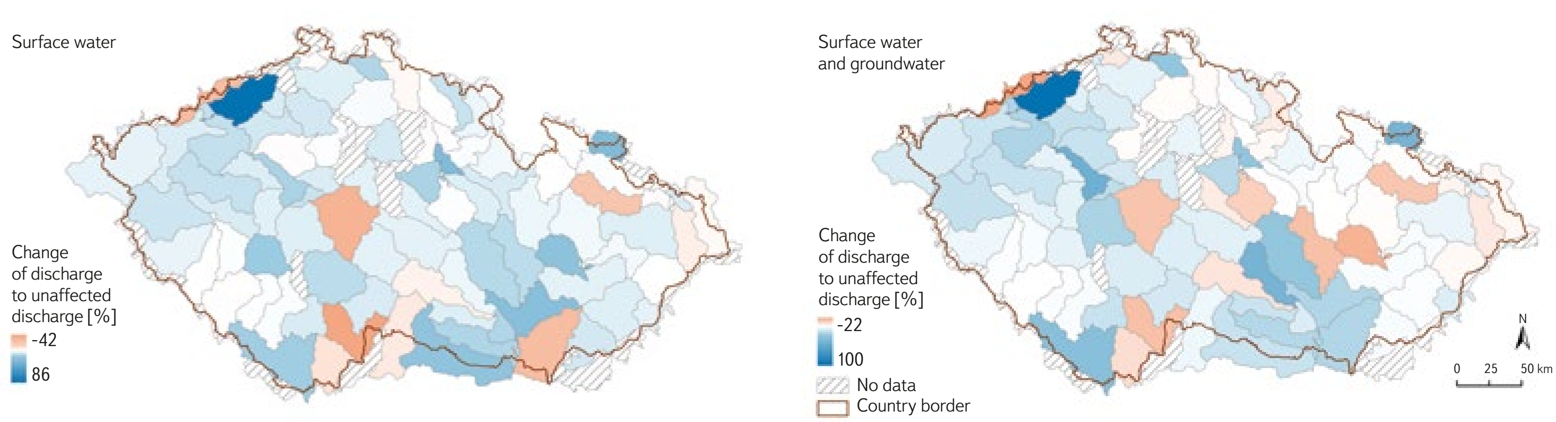


Fig. 1. Ratio of total discharge influence for third-order catchments (reference period 1991–2020)

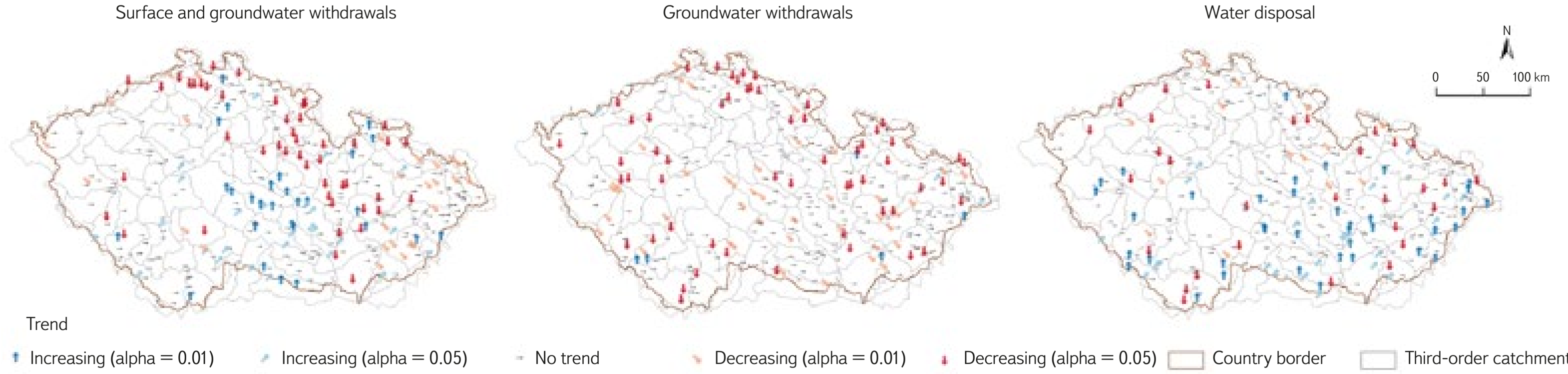


Fig. 2. Trend analysis for water withdrawals and disposals (reference period 1991–2020)

decreasing trends are the catchments of the Moravská Sázava and the Morava from the Moravská Sázava to the Třebůvka, of the Třebůvka and Svitava. Clusters of slightly decreasing trends can also be observed in the catchments in Silesia (the Opava to the Moravice, the Olše and the Oder to the Opava). In contrast, the observed increasing trends create clusters in the Vysočina region (especially the Sázava catchment to the Želivka, the Svratka to the Svitava, and the Oslava and the Jihlava from the Oslava to the Rokytná) and in the Dyje catchment.

In the case of withdrawals considering surface water only, a minimum of stations with an increasing trend were found. Decreasing trends were recorded at less than 30 % of the monitored stations, which are relatively evenly distributed throughout Czechia. The predominance of significantly decreasing trends can again be observed in the area of northern Bohemia, especially in the catchments of the Lužická Nisa to the Mandava, the Jizera, and the Kamenice. Other areas with decreasing trends are the catchments of the Berounka and its tributaries, the upper and middle reaches of the Morava, and the catchments of southern Bohemia (the Vltava to the Malše and the Nežárka).

A slight predominance of increasing trends (a total of 62 stations) was found in water disposals compared to decreasing trends (34 stations). Areas with a predominance of increasing trends are the catchments of western Bohemia (the Mže to the confluence with the Radbuza and the Otava to the Volyňka), southern Moravia (the Svratka and Svitava) and eastern Moravia (the Vsetínská and Rožnovská Bečva or the Ostravice). Decreasing trends are more point-wise distributed; smaller clusters occur in the catchments of the Vltava to the Malše, the Rakovník Stream and the Metuje.

Identification of areas with deficient water resources (DC 1.2)

Unlike precipitation, air temperature is, as expected, more evenly distributed between individual river catchments, which allows for analysis of its changes for entire Czechia. Compared to the normal from 1991–2020, changes in the average monthly temperature oscillate between 0 °C and +2 °C for both scenarios until approximately 2055 (*Fig. 3*). From this year, a more significant increase in the change in air temperatures can be observed for both scenarios, especially for the more pessimistic scenario SSP5-8.5. This is also confirmed by the calculated average temperatures for individual decades of the 21st century. While the change in average monthly air temperature compared to the normal in the first four decades (between 2020–2060) on a nationwide scale is around +1 °C, between 2060 and 2070 it exceeds +2 °C in the SSP5-8.5 scenario and continuously increases to an extreme +5 °C towards the end of the century. In contrast, according to the SSP2-4.5 scenario, a more moderate increase in air temperature can be expected, with a maximum change of +2.4 °C between 2080 and 2090.

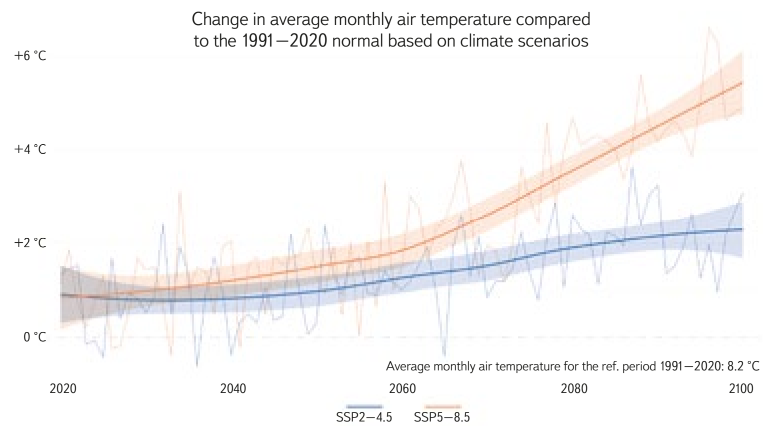


Fig. 3. Change in average monthly air temperature compared to the 1991–2020 normal based on climate scenarios; LOESS regression [36] with a 95% confidence interval shown in bold

For precipitation, predictions are more variable, with the course of events according to different scenarios differing significantly (*Fig. 4*). From a nationwide perspective, according to the SSP2-4.5 scenario, monthly precipitation totals have been around the average of the reference period 1991–2020 (59.9 mm/month) in the long term. From approximately 2040, there is a positive change in precipitation totals, which lasts almost until the end of the century.

In contrast, the SSP5-8.5 scenario suggests more significant changes, similar to the development of air temperatures. Around 2055, there is a positive change in monthly precipitation compared to the 1991–2020 normal. According to this scenario, average monthly totals will increase by up to 15 %, with this growth trend continuing constantly until the end of the century.

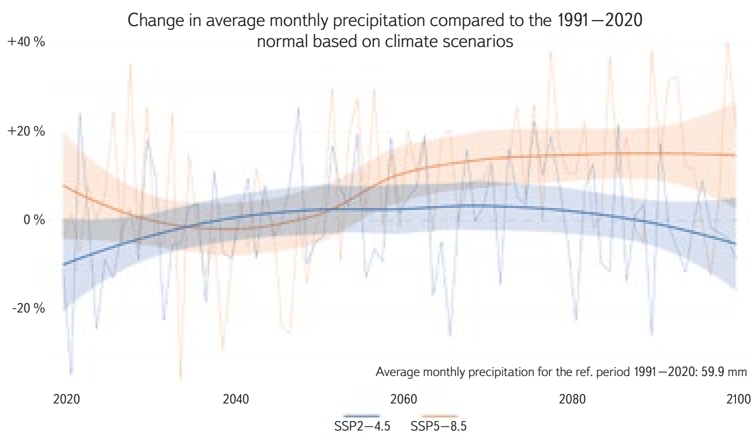


Fig. 4. Change in average monthly precipitation totals compared to the 1991–2020 normal based on climate scenarios; LOESS regression [36] with a 95% confidence interval shown in bold

Although the outlook for the nationwide average monthly precipitation totals may seem relatively optimistic, averages for individual decades show significant differences between third-order river catchments. From the map outputs for both analysed scenarios (*Figs. 5* and *6*), a recurring pattern can be seen at first glance across individual decades. This is the transition of higher precipitation totals in the west of Czechia through a precipitation-poorer area that stretches from north to south, back to the precipitation-richer east of the country. This transition is especially evident in the SSP2-4.5 scenario. While in the west of the country, a positive change in monthly precipitation compared to the normal prevails across all decades, in the northern, central, and southern parts of Czechia this change is slightly negative. The exception is the decade 2020–2030, characterised by a negative change in almost all catchments (national average -7.4 %) and, conversely, the precipitation-rich decade 2070–2080 (average +8.4 %). The scenario SSP5-8.5 predicts an increasing negative change in average monthly precipitation for the north-south belt of Czechia in the first three decades compared to the 1991–2020 normal, while in the east and west there is a transition from slightly positive to zero values. However, for the rest of the century, the prediction ranges exclusively in positive changes in total precipitation across all river catchments. The nationwide average will not fall below +10 % from 2050, with maxima in the decades 2070–2080 (+16.3 %) and 2090–2100 (+17.4 %).

To clarify the map outputs of both air temperatures and precipitation, it should be added that values in some border catchments can sometimes differ significantly from values in neighbouring catchment. This difference is caused by cropping a raster of a certain size by a smaller area of the catchment, which can result in the extraction of only one value/pixel (i.e. the value of the average monthly precipitation/air temperature) for the part of the studied catchment. This is therefore not a calculation error, but the result of the necessary raster extraction.

The last analysis performed was the SPI index calculation, which is used to estimate wet/dry conditions based on total precipitation. Specifically, it is the standard deviation by which observed precipitation would differ from the long-term average and, before calculation, the precipitation time series must first be transformed into a quantity with a standard Gaussian distribution (through its quantile function) using the cumulative distribution function of the probabilistic model which is assumed to be a good description of empirical values [33]. In this case, the index calculated for a twelve-month time window SPI12 (with potential removal of seasonality) with a gamma distribution was chosen.

According to simulated values of total precipitation using the scenario SSP2-4.5, extremely dry periods can be estimated during the 2020s and around 2065, 2082, 2091, and 2094. Exceptionally to extremely dry conditions occur less frequently in the Oder catchment, while the Bílina and Ohře catchments show a more significant episode around 2058. Extremely and exceptionally wet conditions across the catchments were simulated in the late 2040s and especially in the second half of the 2070s, and in the Morava catchment especially in the early 2070s. According to the more pessimistic SSP5-8.5 scenario, dry and wet episodes do not alternate as much. Two more significant periods were simulated. The first period, 2035–2050, includes four significant dry episodes, while the second period, 2075–2095, includes six significant wet episodes. Here, obvious differences can be found between the catchments. For example, the dry episode around 2040 is not evident in the Ostravice, Opava and Morava catchments, while the wet episode in 2055 is not evident in the Oder catchment and in 2086 in the Elbe catchment.

CONCLUSIONS AND RECOMMENDATIONS

This paper presented the basic results that the CHMI reached within the work package WP1 of the *"Water Centre"*. In addition, the shortcomings and uncertainties that accompanied the analyses were briefly outlined. For example, the situation surrounding data related to the influence of discharge in Czech rivers can be understood as very urgent. There are several sources of this data that are not correctly updated, for example, regarding the errors found. Moreover, these data are used in various other projects, which results in the creation of new web (map) applications offering their presentation, which then worsens the orientation of the processors of such data [10]. Given that from 2025 (i.e. initially with data for 2024) the calculation of the unaffected mean monthly discharges will be transferred under the responsibility of the CHMI, it will be necessary to carefully consult the quality of the affected data with the employees of the River Basin Authorities, state enterprises. Otherwise, the developed R script for calculating unaffectedness may be perfect, but it will still not give satisfactory results. For this reason, further maintenance and versioning of the script is planned via the GitHub development platform (e.g. https://github.com/ledvinkao). Its variants are also possible, depending on the data source.

The analysis of the influence on discharge and water resources in Czechia, both in the area of surface and groundwater withdrawals and in relation to climate change predictions, shows the complex and regionally differentiated nature of these changes. The analysis results show significant variability between river catchments, which underlines the need for an individual approach to assessment and management of water resources in different parts of the country. In areas such as southern Moravia, northwestern Bohemia, and the Bílina catchment, significant changes in groundwater and surface water withdrawals are being observed, which may have long-term consequences for water availability in these regions. Conversely, lower impact values were observed in some areas of southern and eastern Bohemia – this may indicate greater water regime stability in these regions.

Climate scenario predictions indicate rising air temperatures throughout the 21st century, with the more pessimistic SSP5-8.5 scenario even suggesting a significant temperature increase of up to 5 °C by the end of the century. Changes in air temperature will have a direct impact on the water balance in Czechia, with regions with higher temperatures facing increased evaporation and changes in the availability of water resources. As for precipitation, the scenario SSP2-4.5 shows a rather moderate increase in precipitation totals with regional differences, while the scenario SSP5 8.5 suggests a significantly higher increase in precipitation, especially in the western and southern parts of Czechia.

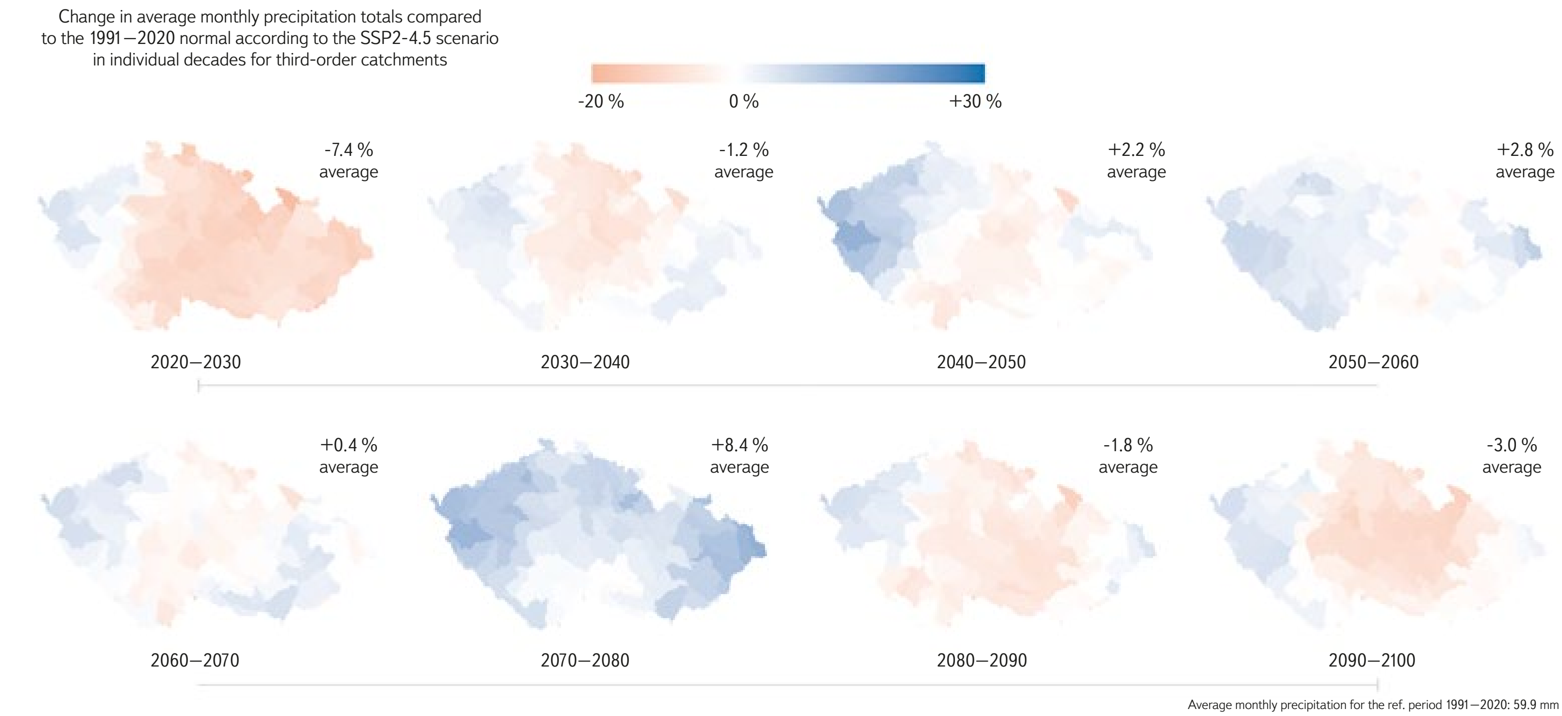


Fig. 5. Change in average monthly precipitation totals compared to the 1991–2020 normal according to the SSP2-4.5 scenario in individual decades for third-order catchments

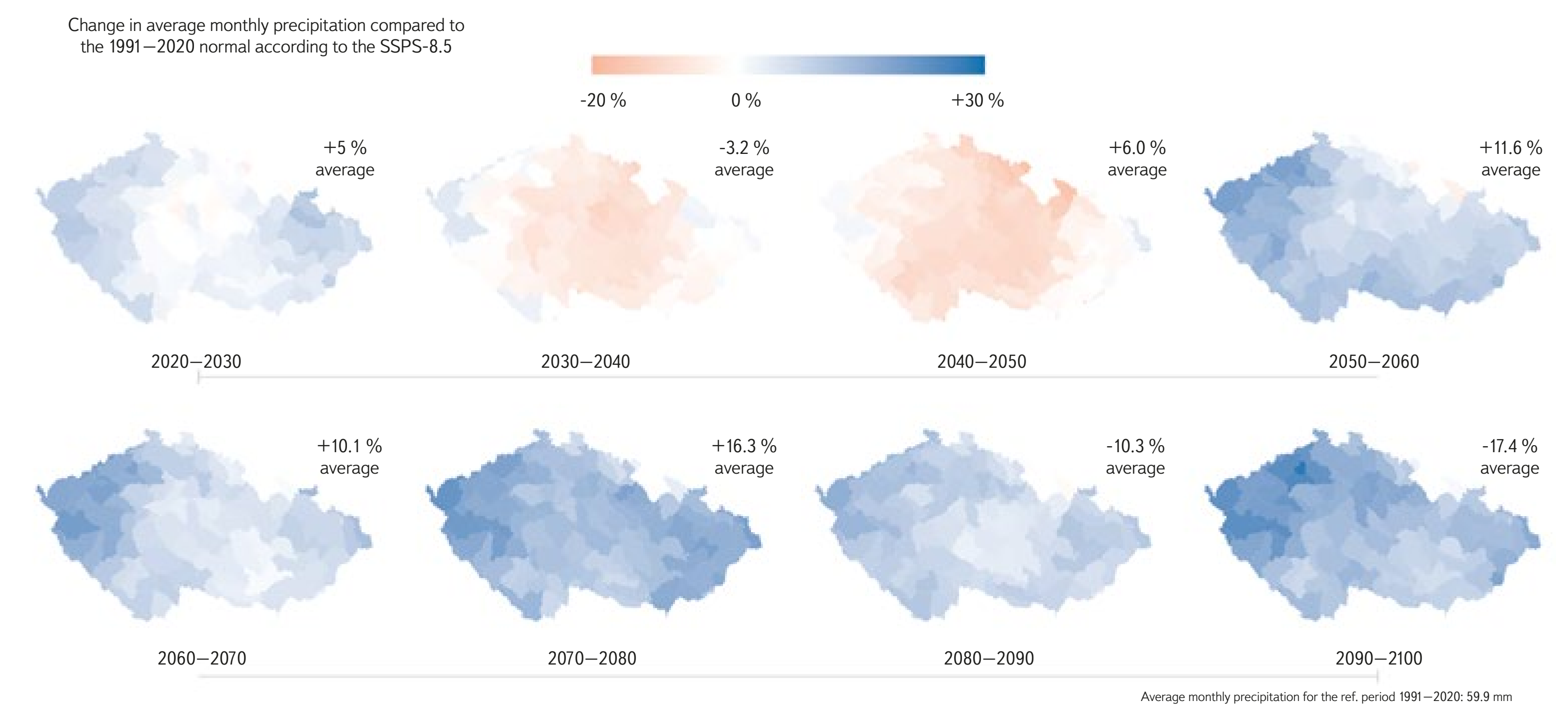


Fig. 6. Change in average monthly precipitation totals compared to the 1991–2020 normal according to the SSP5-8.5 scenario in individual decades for third-order catchments

SPI index calculation confirms the occurrence of extreme dry and wet periods during the 21st century and there are obvious differences between individual catchments. The scenario SSP2-4.5 predicts periods of extreme drought around 2065 and in the 2090s, while extremely wet periods will occur in the late 2040s and 2070s. In the SSP5-8.5 scenario, these fluctuations are less frequent, but more frequent dry and wet periods are still expected in specific decades, with some areas, e.g. the Oder catchment, facing more frequent wet episodes.

Overall, the results indicate the need to adapt water management to the changes that climate change will bring. It is necessary to focus on regional specificities, as climate change will not affect Czechia evenly. It will be necessary to adapt water resource management with regard to the expected development in river catchments, which show different trends in water withdrawal and disposal. This includes not only improving water management policies and strategies for protecting water resources, but also reassessing infrastructure projects and measures to mitigate the impacts of extreme climate conditions such as drought and floods. Preventive measures aimed at retaining water in the landscape will also play an important role.

With regard to the existence of climatological data in grid form, the number of which will certainly rise, Czechia has taken a step in the right direction. Czech water managers may be assisted by additional information derived from grids, such as antecedent precipitation indices or seasonal hydrological predictions whose development has, in fact, already begun with these grids [37, 38].

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Measurement and modelling of changes in the runoff regime following calamitous decay and regeneration of forest stands in small catchments in the Jeseníky Mountains

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Keywords: hydrologic modelling — forest stand modelling — Černá Opava basin — HEC-HMS — MIKE SHE — SWAT

ABSTRACT

The article presents partial results of monitoring and modelling in the experimental forest catchments of Suchý, Sokolí, and Slučí streams, the right-handed tributaries of the Černá Opava in the Jeseníky PLA. These results have been generated since 2022 thanks to the NAZV project No. QK22010189 *"The impact of deforestation on the water regime of small river basins"* with the working title DEFOREST, which also evokes the main goal of the project; to try to capture changes in the dynamics of stands (decay, controlled and spontaneous succession, etc.) and in the runoff regime of these river basins with regard to bark beetle outbreak and the subsequent damage clearing. In all these experimental river basins, monitoring of selected hydrological regime elements (e.g. precipitation on the open area, under-canopy precipitation, volumetric soil moisture, snow gauge sensors) was established, including stationary measurement of water levels in the closing profiles of all three sub-river basins. For modelling of stand changes and hydrological response to these changes, forest stand models (including the self-developed DEFOREST application) and hydrological models HEC-HMS, SIMWE, MIKE SHE and SWAT were used. The extreme flood in September 2024 largely destroyed the water gauging stations and remodelled the watercourse beds, so in 2025 the project team will focus on restoring monitoring.

INTRODUCTION

Forestry-hydrological monitoring in experimental catchments has a relatively long tradition in the Czech Republic, including the experimental catchments of Červík and Malá Ráztoka in the Beskydy Mountains, which have been continuously monitored and evaluated since 1954. For comparison, the oldest experimental basin, the Coweeta Basin in the Appalachian Mountains, began continuous measurements in 1911 [1, 2]. Another long-term monitoring basin, the Hubbard Brook Basin in the USA, has been in operation only since 1955 [3]. Monitoring of meteorological and hydrological elements within the WMO and the CHMI is regulated by professional methodological guidelines, which are also respected by VÚLHM monitoring; it essentially expands these basic data sets with others, such as the already mentioned volumetric soil moisture or the comparison of under-canopy precipitation with precipitation on the open area, which are, among other things, essential elements for the parameterization of hydrological models. Among other attempts to monitor the dynamics of the forest ecosystem regeneration and succession in these catchments was the installation of a set of humidity sensors installed under and outside the moss cover, with the results so far convincing the implementation team of the appropriateness of continuing this monitoring. At the hydrological modelling level, there is a relatively large amount of expert literature and case studies. The most important monographs containing theoretical background and practically focused information include the classic work of Keith Beven [4] or, from the point of view of hydrology and hydraulics, the more broadly conceived textbook by Bedient, Huber, and Vieux [5]. The classic comprehensive studies focused on small and forest basins include the works of Chang [6] and Haan, as well as Barfield and Hayes [7]. In this respect, we should also mention the publications dealing with hydrological modelling on ungauged basins by Wagener, Wheater, and Gupta [8]. Several comprehensive monographs also deal with the issues of forest stand dynamics, disturbance, regeneration and succession, such as the older work of Freelich [9] or the more recent work of Pretzsch [10], which already discusses the principles and tools of modelling forest stand dynamics. The monographs dealing directly with the modelling of forest stands and ecosystems include in particular the works of Weiskittel et al. [11] as well as Fabrika and Pretzsch [12].

DESCRIPTION OF PILOT SITES

In the past, the Černá Opava pilot basin (2-02-01-0030) was used quite intensively for agriculture and industry; these activities took place from the Middle Ages with a peak until the decline in the 19th century. It is currently one of the most valuable basins on the border of the Hrubý and Nízký Jeseník Mountains. Valuable areas from the point of view of nature conservation, as well as forestry and forest hydrology, are represented by small-scale protected areas in this basin, specifically Rejvíz National Nature Reserve, with mountain bogs and *Pinus rotundata* bog forests, and Suchý vrch Nature Reserve, with a boulder field made of Lower Devonian quartzite blocks and relict pine forests. The average basin elevation is 799 m above sea level, while the average slope is 11°.

Tab. 1. Basic hydrologic characteristics of Suchý, Sokolí, and Slučí brook catchments

Year Return Period 2-02-01-0030-00-0-60										
Stream name	**Profile**	**Catchment area [sq. km]**	**Q_A**	**1**	**2**	**5**	**10**	**20**	**50**	**100**
Suchý stream	measurement profile	1.90	0.032	0.643	1.62	3.11	4.35	5.69	7.62	9.19
Sokolí stream	measurement profile	3.98	0.073	1.04	2.63	5.03	7.05	9.22	12.3	14.9
Slučí stream	measurement profile	4.09	0.075	1.04	2.63	5.03	7.05	9.22	12.3	14.9
Days of Occurrence 2-02-01-0030-00-0-60										
			30	**60**	**90**	**120**	**150**	**180**	**210**	
Suchý stream	measurement profile	1.90	0.060	0.043	0.036	0.030	0.026	0.024	0.022	
Sokolí stream	measurement profile	3.98	0.136	0.099	0.081	0.069	0.06	0.055	0.050	
Slučí stream	measurement profile	4.09	0.139	0.101	0.083	0.070	0.062	0.056	0.051	
			240	**270**	**300**	**330**	**355**	**364**		
			0.019	0.017	0.015	0.013	0.0093	0.0069		
			0.044	0.039	0.034	0.029	0.021	0.016		
			0.045	0.040	0.034	0.030	0.022	0.016		

All discharge values are in $m^3 \cdot s^{-1}$.

According to Quitt's classification, the basin is part of the CH4, CH6, and CH7 areas [13]. The orientation of the main Černá Opava thalweg, as well as almost the entire basin, is NNW–SSE. The basin is part of the geomorphological sub--units Medvědská hornatina (4c-7b), Rejvízská hornatina (4c-6b), and Hynčická hornatina (4c-6c). Regionally and geologically, the area is part of the Desenský arch of the Silesian; the basin is dominated by metamorphic rocks (muscovite and biotite phyllites, meta granitoids, quartzites, amphibolites), with some places containing fewer metamorphic volcanic rocks. In the area of Zámecký vrch, blastomylonites of the aforementioned Desenský group are found. In the Jelení vrch massif, we can also find outcrops of crystalline limestone of the Vrbenský group. Here, the boundary between the Hrubý and Nízký Jeseník Mountains is already geologically evident, and east of this line, Palaeozoic greywackes, schists, and claystones appear in the marginal parts of the basin, which are typical of the Kulm of the Nízký Jeseník Mountains. Quaternary sediments are more significantly developed especially in deluvial deposits, around watercourses and in the area of the Rejvíz mires (Velké and Malé Mechové lakes). Within the framework of the hydrogeological regionalization of the Czech Republic, the basin is located in region 6431 – Crystalline of the northern part of the Eastern Sudetes, southeastern part. The transmissivity of the aquifers in the area ranges from 1 to approximately 50 $m^2 \cdot d^{-1}$, thus belonging to transmissivity classes III (medium transmissivity) and IV (low transmissivity), while the specific yield is between 1–5 $l \cdot s^{-1}$ for formations with fractured and fissured flow types [14]. Just behind the Černá Opava watershed, sources within the CHMI groundwater monitoring network are also in operation: PO4008 (Bublavý stream near Rejvíz), PO4015 (Horní Údolí), and PO0509 (Heřmanovice – Roviny). The most common soils are again cambisols, which turn into podzols at higher altitudes, fluvial soils in the lower parts of the valleys of the main watercourses and, in places where mires occur, typical Histosols and gley soils are present, followed by acidic pseudogley cambisols and, rarely, even gleys themselves [13]. The soils are completely acidic and have a relatively low sorption capacity. Among the forest trees, Norway spruce (*Picea abies*) and, in some places, European beech (*Fagus sylvatica*) dominate. In the vicinity of Rejvíz, we can also find mountain pine (*Pinus uncinata*) near the Velké and Malé Mechové lakes, as well as Carpathian birch (*Betula carpatica*) on bogs in the Bublavý stream basin. The edges of the uplands are already turning into bog spruce (*Sphagno-Piceetum*). In addition, the Jeseníky phenotype of European larch (*Larix decidua*) can be found in places. Within the forestry typology, the most represented nutrient series are S and B while, in the vicinity of watercourses, they are the alluvial series L and the acidic series K in the Rejvíz area. The hydrological station CHMI Černá Opava / Mnichov (DBČ 258100) is located in the Černá Opava catchment area. As already mentioned, all the closure profiles of the Slučí, Sokolí, and Suchý streams are also equipped with stationary measurements of water levels, temperatures, and conductivity. Measurements of flow rates and volumetric soil moisture are carried out at regular intervals or when extraordinary outflow situations occur.

The hydrological characteristics of the individual basin closing profiles are shown in *Tab. 1*.

DATA AND METHODS USED

The scope of this article does not allow for the presentation of all results; therefore, the authors have focused on presenting those results that illustrate changes in the runoff regime following disaster decay and regeneration of stands. For the same reason, the results of the MIKE SHE and HEC-HMS model simulations will also be presented, which are most often used in rainfall-runoff modelling due to the complexity of the methods and the possibility of schematization in semi-distributed and fully distributed modes. For clarity of the models, the following data was used:

1. DMR 5G ČÚZK;
2. The actual geodetic measurements;
3. Vegetation cover according to ZABAGED and vegetation data according to ÚHÚL and VÚLHM data;
4. Soil data from VÚMOP;
5. Measurement of volumetric soil moisture from VÚLHM and CHMI;
6. NDVI satellite data and Moisture Index (Copernicus/Sentinel);
7. Measurement of precipitation and other meteorological elements from VÚLHM and CHMI;
8. Measurement of water levels and flows from VÚLHM and CHMI.

The location of sensors in individual river basins is shown in *Fig. 1*.

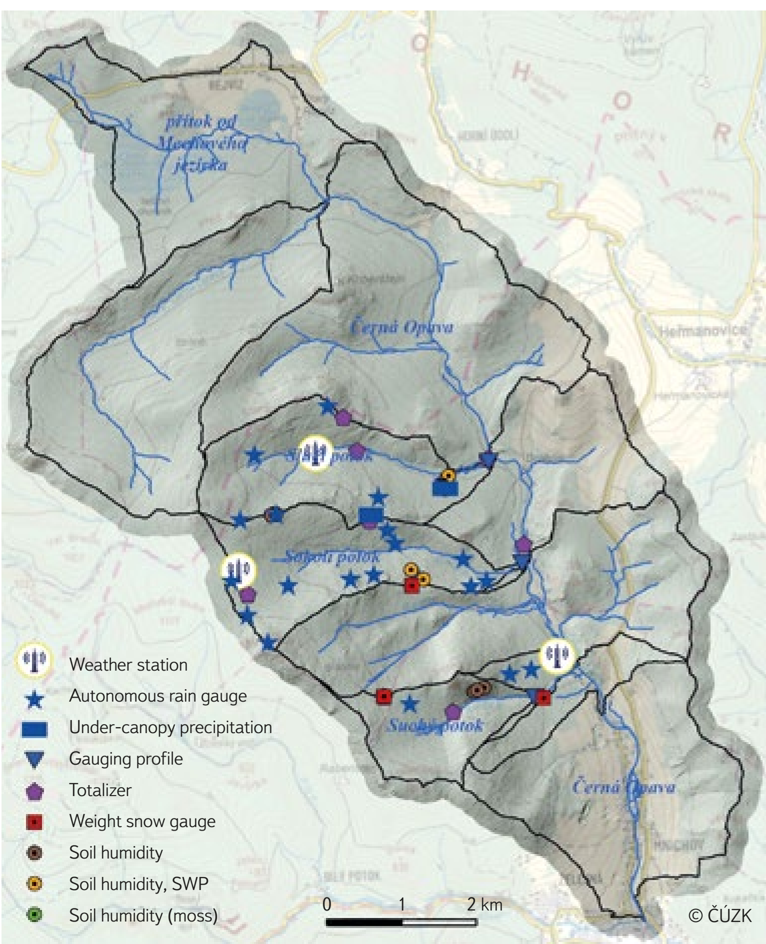

Fig. 1. Distribution of sensors and water gauges on the pilot catchments of Suchý, Sokolí, and Slučí brooks

The models were calibrated for several rainfall-runoff episodes, including those older than the project time scale. One of these calibration episodes is illustrated by the hydrograph for the closing profile of the entire Mnichov basin in *Fig. 2*.

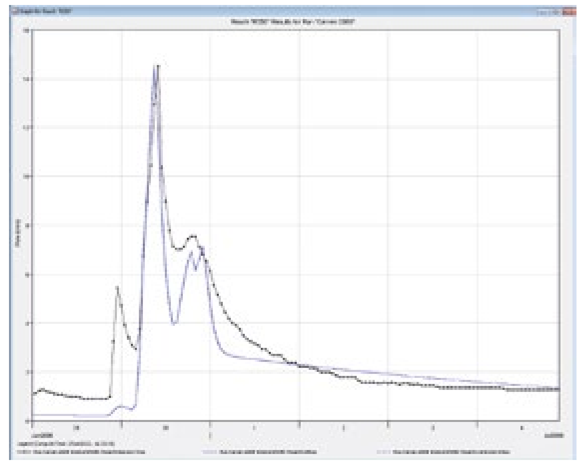

Fig. 2. Calibration of the HEC-HMS model for the rainfall-runoff episode June 2006 and closing profile Černá Opava/Mnichov

SELECTED RESULTS

A s mentioned in the introduction, one of the project specifics is the measurement of volumetric soil moisture on polygons including soil with and without moss cover. For higher representativeness of the measurement, these polygons are located at the interface of forest and open area. The current measurement period does not allow for generalization of the results; however, from the data already available, it is clear that during precipitation episodes, the soil under moss is about 20–30 % less saturated (most likely due to retention of rain water by moss, see *Fig. 3*) and volumetric soil moisture is about 5–20 % lower during precipitation episodes and just after they subside under forest vegetation cover, probably due to water uptake by the root system and transpiration of the stand. In contrast, in precipitation-free episodes they are slightly higher, probably due to lower surface temperatures and evaporation. This dynamics is shown in *Fig. 3*. In the following years, the project team wants to focus more on this issue, also from the point of view of the morphology and species structure of the moss layer and vegetation cover on these polygons.

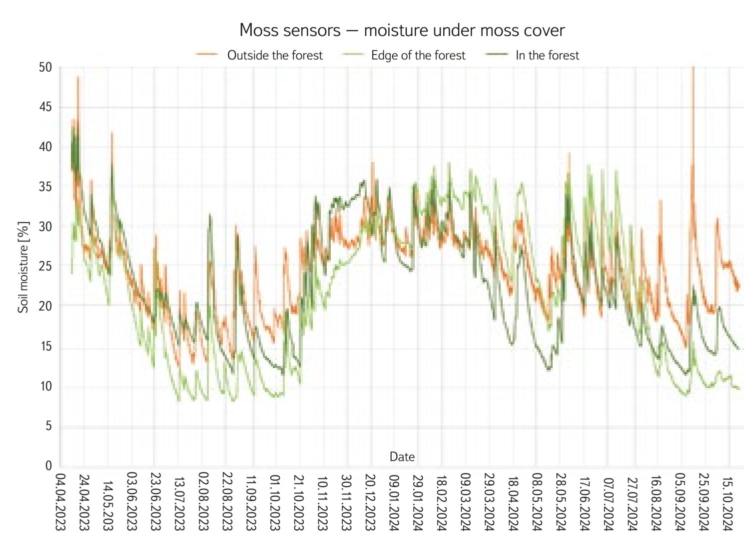

Fig. 3. Volumetric soil moisture under moss cover in the forest, forest edge, and outside the forest

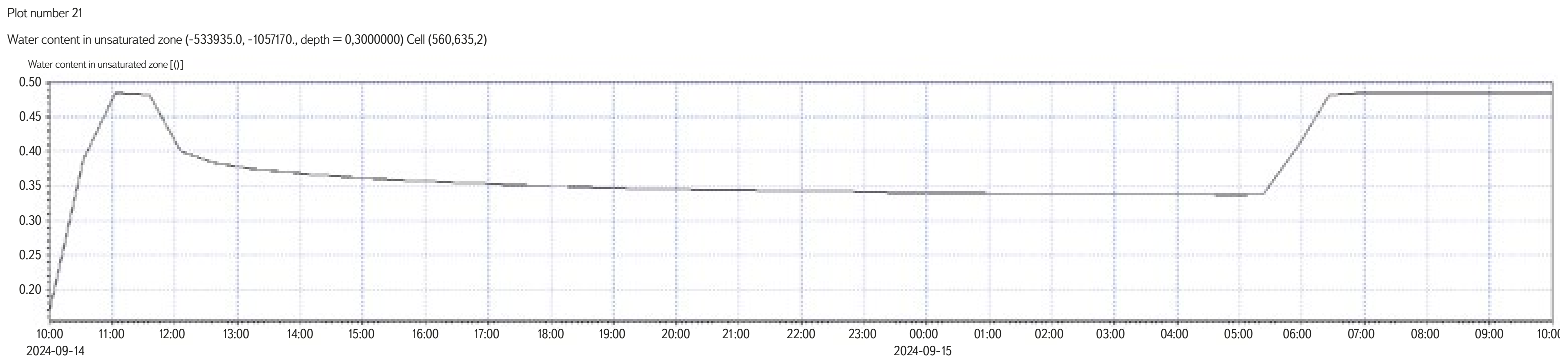

Fig. 4. Soil water volumetric content in 10 cm depth during the rainfall episode 14–16 September 2024 simulated by MIKE SHE model

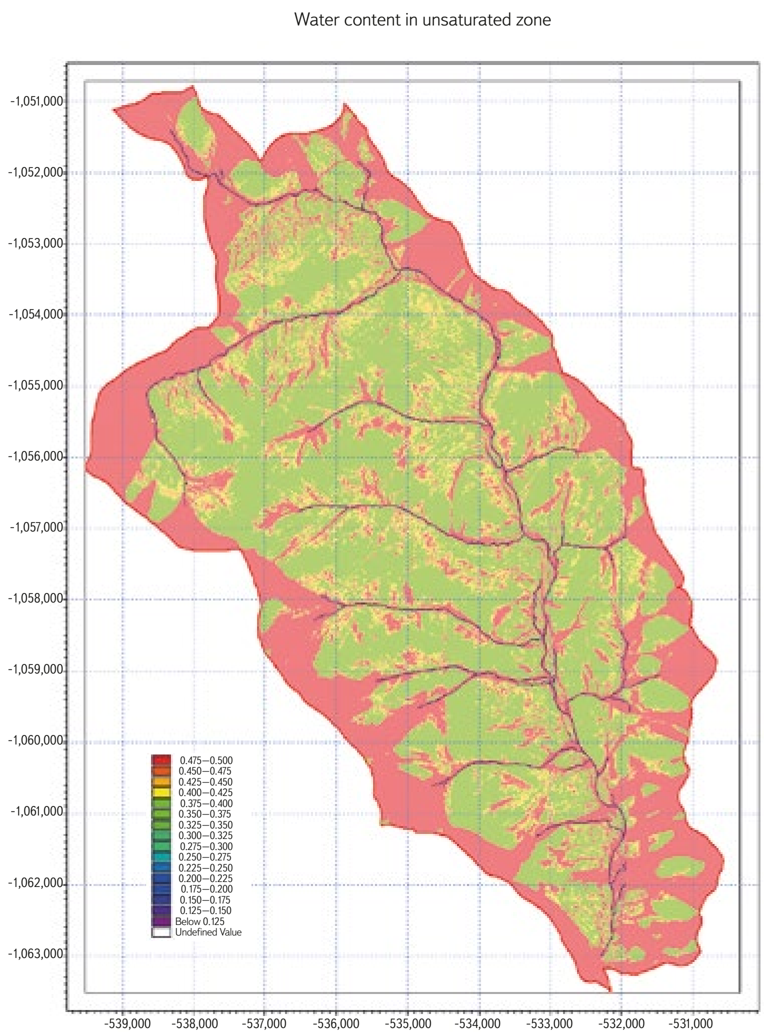

Fig. 5. Volumetric soil moisture content for the rainfall episode 14–16 September 2024 simulated by MIKE SHE model

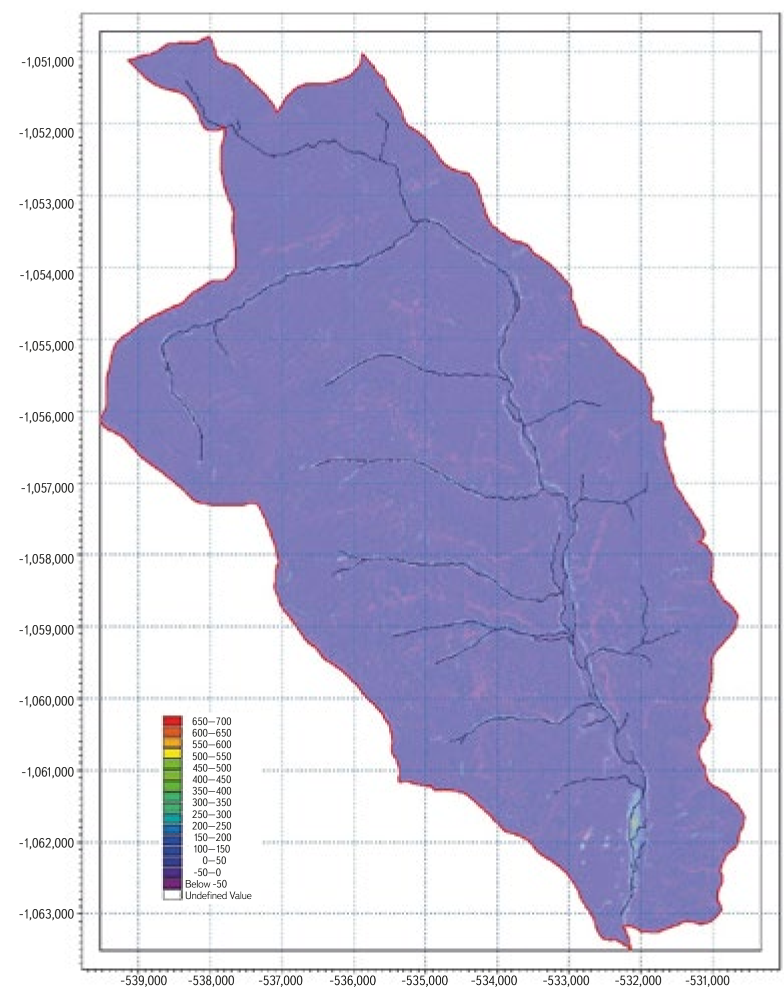

Fig. 6. Return flow values for the rainfall episode 14–16 September 2024 simulated by MIKE SHE model

Fig. 3 also shows significant soil profile saturation during the extreme flood of 13–16 September 2024; then, the sensors in the forest stand and on its edge measured approximately 20% of the soil profile saturation, while the sensor in the open area measured a maximum saturation of 50 %. In this context, the original argument of forest hydrology about the attenuation of flood flows by forest stands arises again. Of course, this hydric forest function also has its limits, but this discussion is beyond the scope and content of this article.

Despite all the complexity of the links in the forest ecosystem, the results to date point to the fact that the forest hydric function is essential in the landscape, which is also demonstrated by the works mentioned in the introduction or the study by Krečmer et al. [15]. However, the fact remains that during extreme rainfall and floods, the retention capacity of forest soils is exceeded and, similarly to other types of land (fields, meadows, etc.), surface runoff dominates. The peak flow on the Mnichov profile was reached on 15 September 2024

Fig. 7. Bank and river bed erosion accelerated by the extreme flood in September 2004 on Sokolí brook (photo: J. Unucka)

at 8:50 CET, with a value of 168 $m^3 \cdot s^{-1}$, which corresponds to the thousand-year water Q_{1000} and a specific runoff of 3.30 $m^3 \cdot s^{-1} \cdot km^{-2}$.

The results of the MIKE SHE model simulation for the flood of 14–15 September 2024 for one of the points of the moss sensor polygon on the Slučí stream are shown in *Fig. 4*. It is evident here that the MIKE SHE calibrated for the basin closing profile similarly simulated extreme saturation values of up to 50 %.

The simulation results, specifically simulated values of volumetric soil moisture and so-called return flow (exfiltration or exit of the groundwater level above the ground level), are shown in *Figs. 5* and *6*. The intensity of stream bed and bank erosion and the movement of sediments and coarse fractions are shown in *Figs. 7* and *8*.

DISCUSSION

Water dynamics in forest stands and basins is undoubtedly a complex phenomenon, which is also influenced by a number of other factors, especially morphometric conditions of the basin (such as hypsographic curve, longitudinal profiles of thalwegs, exposures and slopes of the relief), geological and hydrogeological conditions of the basin, and soil cover where the hydrological transformation of precipitation into runoff dominantly takes place. Likewise, these relationships cannot be simplified to just two extremes – forest and glade. It is necessary to consider the age and species composition of the forest, and the state of the shrub and herb layers. The shrub and herb layers also play a key role in terms of the transformation of runoff and the protection of the soil profile after forest clearance. Nevertheless, the influence of these changes is indisputable, which is supported by the results in other literature, in addition to the works cited in the introduction, such as [16–19]. A specific feature of forest catchments is the role of the moss layer on the hydrological transformation of atmospheric precipitation and soil moisture dynamics. There are not many case studies from real catchments on this issue, rather articles describing laboratory experiments. Papers focusing on the influence of moss on the dynamics of runoff in the catchment include [20 and 21]. The influence of the depths of measuring volumetric soil moisture under moss cover is also discussed in [21]. The combination of measurements, spatial analyses, and modelling in GIS and hydrological modelling as the most effective set of tools and methods for understanding the dynamics of forest catchments cannot be questioned, which can also be found in literature [1, 2, 5, 12 or 22]. The latter work specifically discusses the suitability of the MIKE SHE model for such analyses. For all such analyses, the spatial and temporal context of experiments and studies plays a crucial role. Forest catchments are, with some exceptions, small catchments with an area of a few hectares or square kilometres. The results from these basins cannot be automatically applied to other basins with different climatic, geological, or morphological parameters. Similarly, the results of measurements and simulations in models over a period of four years cannot be generalized – also considering the fact that the standard reference period for deriving hydrological characteristics according to ČSN 75 1400 is 30 years.

Fig. 8. Accelerated erosion by flood in September 2024 caused particular destruction of the rock steps in the channel of Slučí brook (photo: J. Unucka)

CONCLUSION

The team of authors aimed to introduce readers to interesting aspects of forest hydrology in experimental catchments in the Jeseníky Mountains, present research methods, and select interesting results with regard to new procedures or the extreme flood in September 2024. These time series are too short for generalization and, in addition, the entire cycle of forest decay and regeneration, whether spontaneous or controlled, has not yet been completed. Experience from other basins where forestry-hydrological research by VÚLHM and CHMI has been ongoing for a long time (e.g., U dvou louček in the Orlické Mountains, Červík and Malá Ráztoka in the Beskydy Mountains) points to the fact that the combination of *in situ* measurements and mathematical modelling brings the best results. However, it is necessary to consider the uncertainty of input data and methods. The uncertainty of input data can be reduced by selecting suitable basins and representative areas for monitoring hydrometeorological elements. The uncertainty of the methods can be reduced by choosing an appropriate measurement technique (ideally with the possibility of evaluating uncertainties directly during the measurement, e.g. with the YSI FlowTracker2 device) and the mathematical models themselves. In this category, it is appropriate to choose verified and validated tools. CHMI has good experience in operational practice with the HEC-HMS and MIKE SHE models (hydrological forecasting and hydrological studies), therefore they were quite logically preferred. In this regard, it is also worth mentioning that open source GIS tools such as GRASS GIS or SAGA GIS offer much greater possibilities for morphometric and spatial analyses than the ESRI ArcGIS platform. Finally, it is worth mentioning the fundamental fact of the catastrophic flood of September 2024, which de facto interrupted a series of observations of the destruction of water gauge profiles and intensive remodelling of the hydrographic network. Nevertheless, both VÚLHM and CHMI want to continue forestry and hydrological research in these basins, as they consider these results to be essential both in the context of water and forest management and the ecology of mountain basins.

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Photo: J. Unucka

The pond system on the Bečvárka river

PAVEL RICHTER

Keywords: archival maps — watercourses — floodplains of watercourses — ponds

ABSTRACT

The article presents the pond landscape development in the Bečvárka river basin based on the interpretation of archival and current maps, including verification of the current state of pond locations. Eleven ponds with a total area of 65.28 ha were recorded on the map of the 2nd Military Mapping. Sixteen ponds with a total area of 76.64 ha were recorded on the current map. The current ponds' total area is approximately 11 ha larger than the area of the historical ponds. This is despite the fact that almost all individual historical ponds had an area larger than at present. One of the main reasons for this is the later construction of two large ponds in the area. From a comparison of the maps, it is clear that the reduction in the areas of individual historical ponds at present is mainly caused by the overgrowth of the littoral zone.

INTRODUCTION

The main objective of the research, the results of which are presented here, was to map the landscape development in the locations of disappeared ponds in the catchments of the Labe tributaries in the Polabian Lowland based on the interpretation of archival maps, especially with regard to the possible restoration of water retention elements in this landscape. Here, the development of the pond system on the Bečvárka river, or rather in the basin of the Bečvárka water body, is specifically described. The Polabian Lowland currently suffers from a lack of groundwater and there is a large-scale seasonal drying up of small watercourses, mostly straightened and deepened. These phenomena are probably going to reoccur in the future and the associated issues will be accentuated in connection with the expected continued occurrence of extreme climatic events. It is therefore necessary to focus attention and efforts on the restoration of landscape elements with a positive impact on the water regime and, in particular, on water management in the landscape.

SITE DESCRIPTION

Hydrology and administrative division

This pond system is located in surface water body HSL_1630 Bečvárka (Miletínský stream) from the source to the mouth of the Výrovka watercourse. This water body is part of the third order catchment area 1-04-06 Výrovka, which is located in the Elbe catchment area at the watershed of the Upper and Middle Elbe and Lower Vltava sub-catchments. The Bečvárka river originates near Miletín at 440 m above sea level; its length is 22.9 km and as a right-bank tributary it flows into the Výrovka river at river km 23.2 in the Zalešany-Žabonosy-Plaňany area at an altitude of 219 m. According to the Strahler order of watercourses, the Bečvárka river is in the fourth order at the confluence with the Výrovka river. The basin of the Bečvárka water body (Miletínský stream) from the source to the mouth of the Výrovka river consists of seven fourth order basins (HLGP) with a total area of 64.3 km^2 [1, 2]. From an administrative point of view, the water body is located in the Central Bohemian Region, partly in the districts of Kutná Hora (cadastral area Jindice and Solopysky) and Kolín (cadastral area Bečváry, Bošice u Kouřimi, Červený Hrádek u Bečvár, Horní Chvatliny, Mlékovice, Poďousy, Přebozy, Svojšice u Kouřimi, Zásmuky, and Žabonosy). Its catchment area covers seven cadastral areas in the Kutná Hora district and 24 cadastral areas in the Kolín district (*Fig. 1*). From the perspective of drought in the landscape, all cadastral areas in the catchment area are among those at risk of drought, with the exception of cadastral areas in the source areas of the Bečvárka and Miletínský stream (*Fig. 2*) [1].

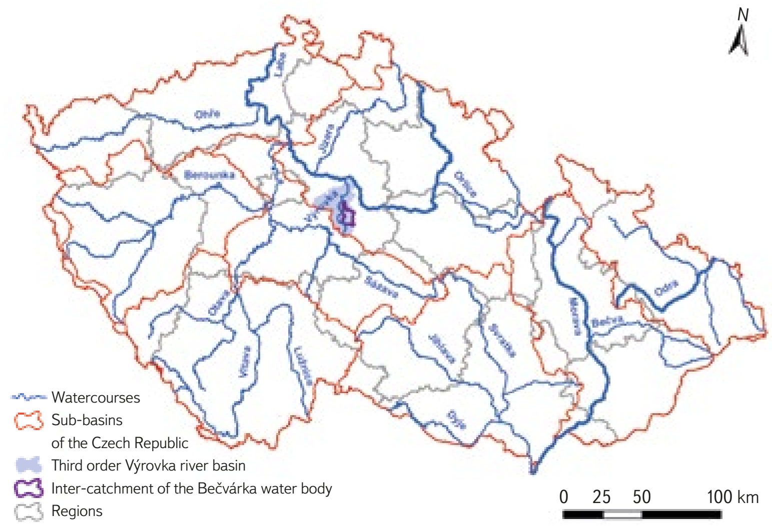

Fig. 1. The researched area in a hydrological and administrative context

Geology, pedology and erosion risk

Geologically, the entire Bečvárka basin is part of the Bohemian Massif. The geological bedrock consists mainly of paragneisses and migmatites of the Kutná Hora Crystalline. Gravels, sands, conglomerates, and sandstones occur in places in the upper and middle parts of the basin. Marls, calcareous claystones and more basic metamorphic rocks (amphibolites and serpentinites) also occur in the middle and lower parts [3].

Soil conditions throughout the basin are heterogeneous, with eight soil types (*Tab. 1*). In the immediate vicinity of watercourses, these are primarily gleys (with a pronounced reductomorphic diagnostic gley horizon as a result of long-term wetting by high groundwater levels) and also fluvial soils (with fluvial diagnostic features resulting from periodic sediment deposition and the occurrence of new formations resulting from water infiltration during flooding).

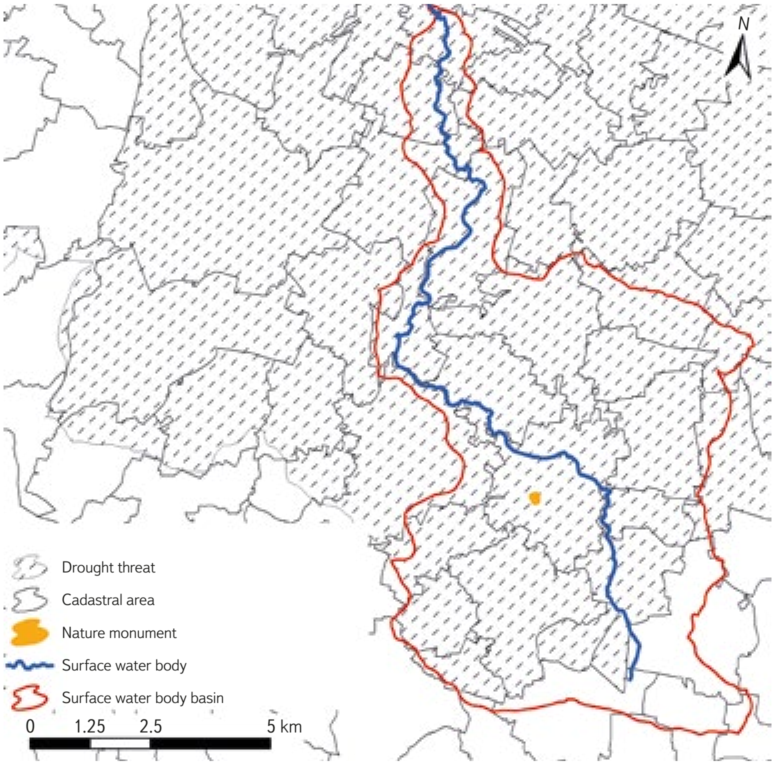

Fig. 2. The Bečvárka water body basin from the perspective of drought issues in the context of nature protection

In the wider area of the basin, brown earths (soils with a profile differentiated into a slightly pronounced eluvial horizon, transitioning without tongue-shaped inlets into a homogeneously brown luvic horizon) and luvisols (soils with the presence of a luvic horizon with dark argillaceous materials, located locally on the periphery of the extension of chernozems from loess) predominate; also, cambisols (soils that form mainly in sloping conditions, only to a lesser extent in flat relief) and chernozems (deep humus soils developed from carbonate sediments) [4, 2].

In connection with the area's diversity, it is also possible to observe different levels of vulnerability of farmed soils to water erosion [5]. In addition to the characteristics of the relief, this is the result of the creation of large plots of land without anti-erosion measures and the cultivation of wide-row crops on slopes. Especially in the upper areas of watercourses, there is a large representation of soils that are moderately and strongly vulnerable to erosion [4]. In the Bečvárka river basin, soils are highly at risk of erosion in the area of the spring near Miletín (brown earths, cambisols), to a greater extent in the section between the municipalities of Červený Hrádek and Bečváry (brown earths, luvisols), in the vicinity of the Mlýnský (Podbečvárský) pond (brown earths), and sporadically also before the confluence with the Výrovka between the municipalities of Přebozy and Žabonosy (chernozems). Otherwise, in the lower parts, in places where the Bečvárka flows into the Výrovka, soils that are not threatened by erosion predominate [5, 2].

Land cover and typology of the current Czech landscape

There are a total of five types of landscapes in the entire Bečvárka river basin, according to the landscape typology of the Czech Republic. Three general types of natural landscapes can be found in the basin. The headwater areas of the Bečvárka river belong partly to the moderately cold landscape of the hills and highlands, while the upper part of the Bečvárka river basin is part of the moderately warm landscapes of the basins and hills, and the rest of the basin is located in the warm landscape of the lowlands. There are also two functional landscape types in the basin area.

Tab. 1. Representation of soil types in the Bečvárka water body basin

Soil type	[km²]	[%]
Chernozem modal	4.22	6.57
Luvic chernozem	5.16	8.03
Gley fluvial soil	2.47	3.84
Gley modal	10.65	16.56
Brown earth luvic	2.2	3.42
Brown earth modal	25.62	39.85
Cambisol modal	5.63	8.75
Luvisol modal	8.35	12.98
Σ	64.30	100

The headwaters of the Bečvárka river are in the forest-field landscape, while the rest of the basin is in the field landscape [6].

Several classifications with varying degrees of accuracy or generalization can be used for land cover. Here, ZABAGED®, CORINE Land Cover (CLC), and LPIS are used. In the Bečvárka river basin, the predominant land cover is classified according to ZABAGED® [7] as arable land and other areas (76.88 %), a significant part is also covered by forest land with trees (9.22 %), permanent grassland (3.67 %), orchards and gardens (3.45 %), and residential buildings (3.08 %). In contrast, the representation of, for example, swamps and marshes on permanent grassland (0.07 %), or on forest land with trees (0.05 %), is marginal. Water areas occupy 1.31 % of this basin (*Tab. 2*).

According to the CLC, which is largely generalized [8], the arable land class excluding irrigated areas prevails, covering 80.38 % of the basin. The following classes are: predominantly agricultural areas with an admixture of natural vegetation, mixed forests, and urban discontinuous development, each covering over 5 % of the basin area. Other classes occupy a very small part of the area. Water bodies make up 0.88 % of the basin and due to the generalization of this type of cover, with only two sites classified as water bodies. One is Mlýnský pond, near Bečváry, and the other is formed by the ponds of Utopenec and Stojespal, near Mlékovice (*Fig. 3, Tab. 3*).

The LPIS records only agriculturally used areas for which economic agriculturalist entities receive subsidies [9]. It means that the entire area of the river basin is not covered by the LPIS, it is only 4,960.2 ha, which represents 77.14 % of the area. In the LPIS, the dominant land use is standard arable land (97.15 %), around 2 % is covered by permanent grassland, while the remaining land use types in the LPIS are negligible (*Fig. 4, Tab. 4*).

Tab. 2. Representation of land cover classified according to ZABAGED® in the Bečvárka water body basin

Landscape cover according to ZABAGED®	[km²]	[%]
Arable land and other	49.477	76.88
Forest with trees	5.928	9.22
Permanent grassland	2.359	3.67
Orchard, garden	2.219	3.45
Settlement features	1.978	3.08
Transport infrastructure	0.901	1.46
Water area	0.841	1.31
Forest with shrubs	0.276	0.43
Ornamental garden, park	0.17	0.26
Surface mining, quarry	0.065	0.1
Marsh, bog on permanent grassland	0.047	0.07
Marsh, bog on forest with trees	0.035	0.05
Watercourse	0.004	0.01
Σ	64.30	100

Protected areas

There is only one natural monument in the described area (*Fig. 2*), namely Lůmek u Bečvár, which was declared on 12 December 1986 covering an area of 0.2499 ha with a legal protection zone of 2.1198 ha. The reason for the declaration was the occurrence of the rare griquaite rock and the rich deposit of Upper Cretaceous fossils [10].

METHODOLOGY

The first step of the research was the selection and subsequent comparison of the current and historical state of the ponds in the catchment area of this water body based on map interpretation. This was followed by a field survey of these sites to verify their current state. To detect the occurrence of historical ponds, the map of the 2nd Military Mapping was used, which is available for viewing on the National Geoportal INSPIRE [11] and also as WMTS [12]. Individual map sheets can also be obtained, which are available on the Oldmaps Application webpage of the Geoinformatics Laboratory of the Faculty of Environment, J. E. Purkyně University in Ústí nad Labem [13].

To display the current state, the latest Basic Topographic Map of the Czech Republic 1 : 10,000 (BTM 10) and the current Orthophoto map of the Czech Republic were used. Both maps are available as a WMS service from the ČÚZK Geoportal [14]. Only ponds with a minimum area of 0.5 ha were considered for the analyses. For a more accurate understanding of the landscape development between the state recorded for the 2nd Military Mapping and the current state, a historical orthophoto map from the 1950s was used. It is available for viewing on the National Geoportal INSPIRE [11] and also as WMTS [12]. Archive orthophoto maps from 1998–2022 are also available using WMS from the Geoportal ČÚZK [14].

To approximate the state of the landscape before the 2nd Military Mapping, especially with regard to the historical occurrence of ponds rather than their exact location, a positionally inaccurate map of Müller's mapping was used, which can be viewed in the map viewer of the Land Surveying Office Archives [15].

Programs used and data processing

Georeferencing of archival maps and connecting current data using WMS or WMTS was carried out in the ArcGIS environment, specifically in the ArcMAP 10.8.2 program. This was followed by the creation of a polygon layer in .shp format. Each polygon was precisely defined by its identification number and the period in which it occurred in the area. The initial data processing was carried out in a GIS environment and involved calculating the area of polygons. The resulting values were then exported to Microsoft Excel 2016 and projected into tables.

Current maps used

Current BTM 10 and Orthophoto map of the Czech Republic

These maps are available as a WMS service from the ČÚZK Geoportal, where they are continuously updated according to the plan (in the case of BTM 10, approximately 1/3 of the Czech Republic per year). The displayed state on BTM 10 may vary both according to parts of the area and according to individual segments, which are updated separately, so it does not show the actual state of the landscape in all directions at a given moment. To process the current BTM 10, data capturing the status as of 6 July 2020 (centre), 10 October 2021 (east), and 2 January 2023 (west) were used. The update of significant elements of the topographic map (railways, roads under the administration of the Directorate of Roads and Highways of the Czech Republic) was carried out over the data documenting the status as of 2 January 2024. The displayed status corresponds to the ZABAGED® data. The entire orthophoto map of the Czech Republic is updated in a two-year cycle. Approximately half of the Czech Republic is updated annually and, since 2020, regional borders have

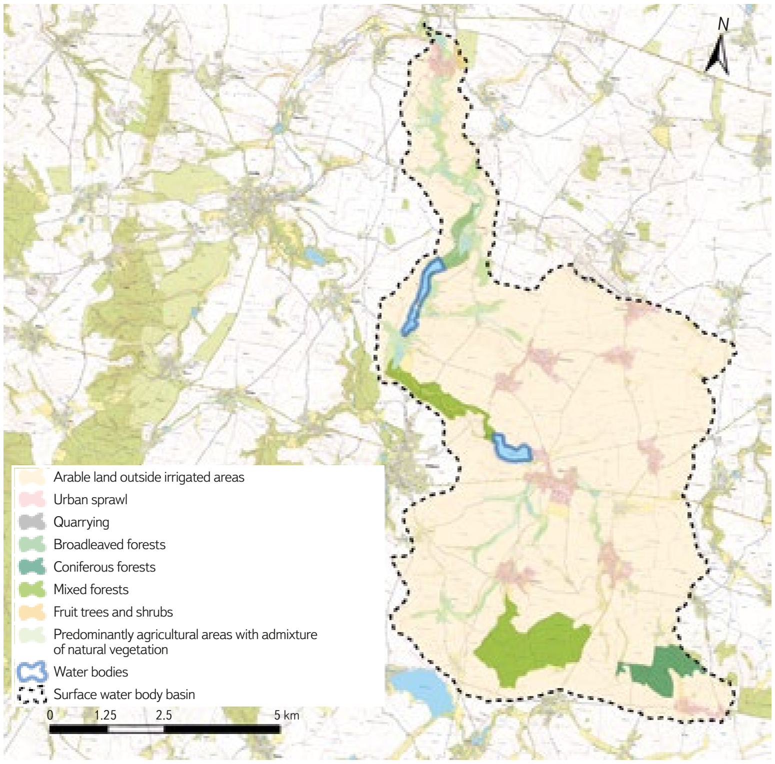

Fig. 3. CORINE Land Cover 2018 in the Bečvárka water body basin in the context of BTM 10

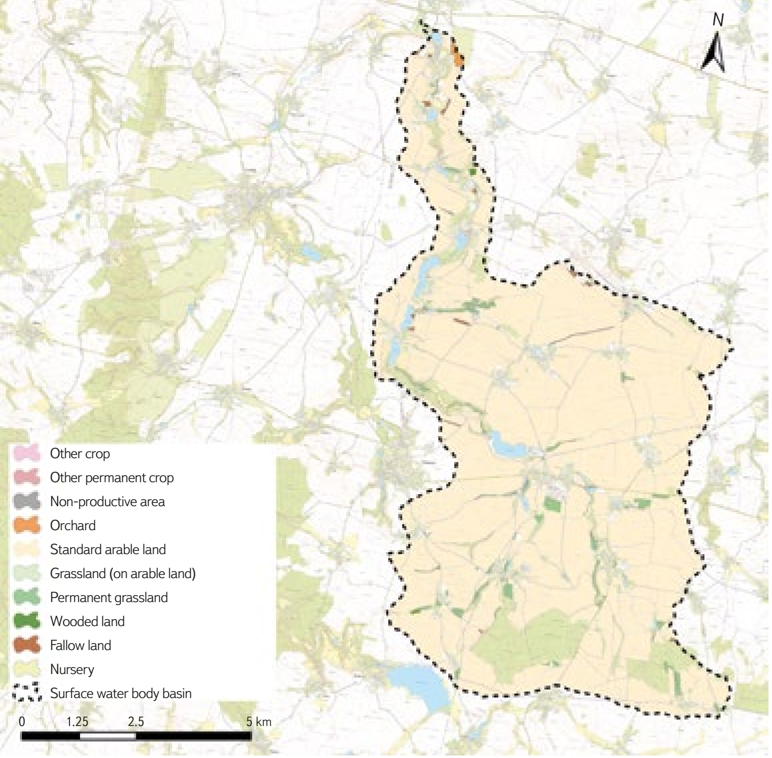

Fig. 4. Land use according to LPIS 2023 in the Bečvárka water body basin in the context of BTM 10

been taken into account in the update. Currently, the western part of the Czech Republic (the border is formed by the Liberec, Central Bohemian, and South Bohemian regions) is covered with images showing the state of the landscape in 2023, while the eastern part shows the state of the landscape in 2024 [14].

Archival maps used

Müller's mapping

The oldest map used here is Müller's map of Bohemia from 1720 at a scale of approximately 1 : 132,000 [16]. A disadvantage for a detailed comparison of landscape development with subsequent map sources is its inadequate positional accuracy. Therefore, it can only be used to display water bodies as a supplement to newer data. Not all watercourses are depicted in it, the drawing is schematic and not entirely adequate [17].

2nd Military Mapping

This mapping brought the first relatively precise map. It was compiled between 1836 and 1852 at a scale of 1 : 28,800. Compared to the First Military Mapping, the accuracy of the depiction increased as a result of previous military triangulation. The 2nd Military Mapping took place at the onset of the Industrial Revolution and the development of intensive agriculture, when the area of arable land increased by half in 100 years and the area of forest reached a historical minimum. The maps also include oldest railway lines [13].

Historical orthophoto map from the 1950s

The historical orthophoto map is composed of aerial photographs originating mainly from 1952–1954, supplemented by images from 1937–1970 and 1996 where other sources are not available in the given period. This orthophoto map was created within the project "*National Inventory of Contaminated Sites (NIKM)*". The aerial survey images were provided by the Military Geographical and Hydrometeorological Office (VGHMÚř) Dobruška and processed into an orthophoto map by GEODIS BRNO, spol. s r. o. [12, 14].

Tab. 3. Representation of CORINE Land Cover 2018 classes in the Bečvárka water body basin

Corine Land Cover 2018	Area [km²]	Ratio to total area [%]	Number of segments
Coniferous forest	0.97	1.51	1
Broad-leaved forest	0.38	0.60	1
Mixed forest	3.36	5.22	2
Discontinuous urban fabric	3.23	5.02	9
Non-irrigated arable land	51.72	80.38	1
Fruit trees and berry plantations	0.10	0.15	1
Land principally occupied by agriculture	3.99	6.21	7
Mineral extraction sites	0.03	0.04	1
Water bodies	0.56	0.88	2
∑	64.35	100	25

Tab. 4. Land use representation according to LPIS in the Bečvárka water body basin

LPIS	Area [ha]	Ratio to total area [%]	Number of segments	Average segment size [ha]	Maximum segment size [ha]	Minimum segment size [ha]
Other crop	0.49	0.01	2	0.25	0.36	0.13
Other permanent crop	0.79	0.02	2	0.39	0.57	0.21
Non-productive area	0.50	0.01	2	0.25	0.48	0.02
Orchard	7.35	0.15	1	--	--	--
Standard arable land	4,819.03	97.15	421	11.45	115.20	0.01
Grassland (on arable land)	9.92	0.20	14	0.71	2.53	0.02
Permanent grassland	98.03	1.98	84	1.17	9.06	0.03
Wooded land	3.20	0.06	5	0.64	1.74	0.24
Fallow land	20.38	0.41	36	0.57	3.23	0.01
Nursery	0.51	0.01	1	--	--	--
∑	4,960.20	100	568	--	--	--

Archival orthophoto maps
These orthophoto maps are available as a set for 1998–2022. It is possible to select the display of layers according to the individual years of imaging. Only the part of the area that was imaged during one year is captured. In the layers from 1998 to 2001 the images are black and white, the layers from 2002 onwards contain colour images [14].

RESULTS

The historical pond system on the Bečvárka river recorded in the 2nd Military Mapping included a total of nine ponds (Mlýnský, Stojespal, Mlékovický, Svojšický, Rozkoš, Rybník, Bošický, Mlýnek, and Frčina). Other two ponds were not located directly on the Bečvárka river. Voděradský pond was located on the Voděradský stream immediately before its confluence with the Bečvárka river, and the pond in Poďousy was on the Poďouský stream. In total, there were eleven ponds covering an area of 65.28 ha. All of these ponds have survived to the present day (*Fig. 5, Tab. 5*), or rather, Mlékovický pond is still listed as a pond on current maps, as well as in the land register [18], although it has not been restored since 2013, when its dam was breached during a flood (*Fig. 6*) [19, 20], and this site is overgrown, i.e. it has been left to succession (*Fig. 7–9*) [20]. All the historical ponds are now smaller in size, with the exception of the Voděradský and Bošický ponds. Currently, compared to the situation recorded in the 2nd Military Mapping, five ponds with an area of over 0.5 ha have been added to the Bečvárka basin. For the evaluation of the pond system development on the Bečvárka, two ponds built close together (Horní and Dolní Kunvald) were considered as one object. Horní and Dolní Kunvald are on

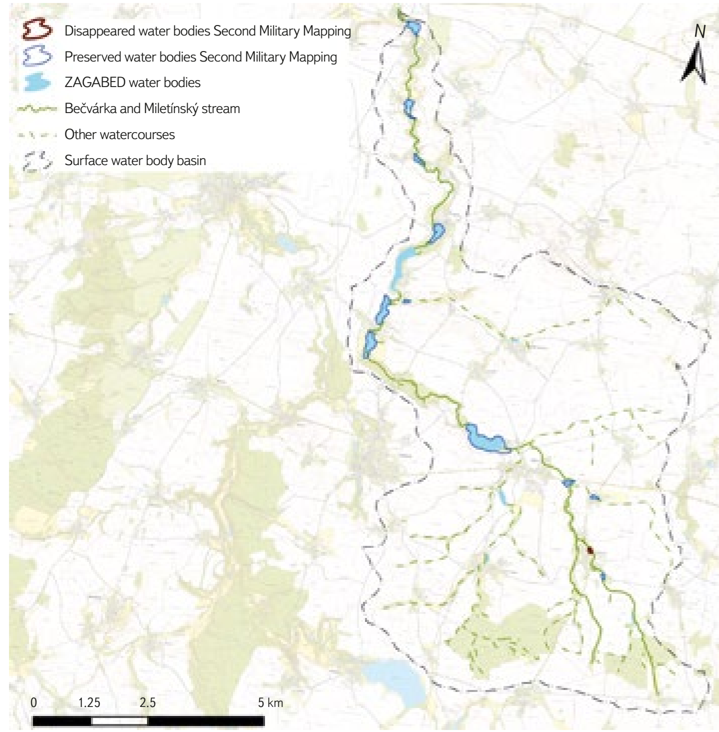

Fig. 5. Development of the pond system in the Bečvárka water body basin from the 2nd Military Mapping to the present in the context of BTM 10

Tab. 5. Development of the pond system area in the Bečvárka water body basin

Current name	Watercourse	Current area [ha]	Historical area [ha]	Ratio of historical area to Current area [%]	Detection on the Müller's map
Mlýnský (Podbečvárský) pond	Bečvárka	21.98	26.82	122.03	Yes
Utopenec	Bečvárka	16.42	--	--	Potentially yes
Stojespal	Bečvárka	7.13	8.53	119.55	Yes
Mlékovický pond	Bečvárka	6.85	7.92	115.66	Yes
Svojšický pond	Bečvárka	5.73	6.40	111.60	Yes
Rozkoš	Bečvárka	4.16	4.99	119.94	Yes
Rybník	Bečvárka	3.21	4.53	141.10	Yes
Bošický pond	Bečvárka	2.05	1.95	95.16	Yes
Mlýnek	Bečvárka	1.39	1.70	122.39	No
Frčina	Bečvárka	0.62	0.78	126.71	No
Horní and Dolní Kunvald	Bečvárka	0.85	--	--	No
Bosňák	Drahobudický stream	3.13	--	--	No
Nameless (Drahobudice)	Drahobudický stream	0.74	--	--	No
Nameless (Poďousy)	Poďouský stream	0.67	0.96	142.42	No
Nameless (Dolní Chvatliny)	Voděradský stream	0.86	--	--	No
Voděradský pond	Voděradský stream	0.84	0.70	83.34	No
∑	--	76.64	65.28	85.18	--

the upper reaches of the Bečvárka, while Utopenec pond is on the middle Bečvárka near Mlékovice, after Stojespal (*Figs. 5* and *7*). In terms of area, it ranks second only to the largest pond in the basin – Mlýnský pond near Bečváry. Medium-sized ponds include Bosňák on the Drahobudický stream (*Fig. 10*). The smallest new ponds are in Drahobudice and Dolní Chvatliny. The total area of the current ponds is approximately 11 ha larger than the area of the historical ponds, even though almost all individual historical ponds had an area larger than now (*Fig. 5, Tab. 5*). From the map comparison, it is clear that this reduction in the area of individual ponds is caused by the overgrowing of the littoral zone of the given historical pond. This can be clearly observed in particular at the ponds of Mlýnský, Rybník, and Stojespal (*Figs. 7, 10,* and *11*). The current state of the ponds of Stojespal, Utopenec, Rybník, Rozkoš, Mlýnský, and Bosňák is shown in *Figs. 12–17*.

Fig. 18 shows the state of the ponds on Müller's map of Bohemia. From this map it can be concluded that the seven largest historical ponds on the Bečvárka already existed at the time of Müller's mapping. In addition, the map shows that there was a smaller pond in the place of the current Utopenec pond, although this pond is not shown on the 2nd Military Mapping. A system of four ponds is drawn on Drahobudický stream, but none of them apparently corresponds to the location of the two current ponds.

DISCUSSION AND CONCLUSION

In the past, all artificially created water bodies with dams or excavated by human activity were considered ponds [21]. Currently, we have a large number of types of water bodies according to their use; at the same time, there are differences between the uses of water bodies designated as ponds. Even

Fig. 6. The gap in Mlékovický Pond dam and the state of vegetation in the flooded area four years after the breach, as of 2017 [20]

Fig. 7. Comparison of the pond system development on the Bečvárka river near Mlékovice village, including the surrounding landscape, shown on a map of the 2nd Military Mapping, on a Historical Orthophotomap from the 1950s, on the current BTM 10, and on the current Orthophotomap of the Czech Republic

Fig. 8. Comparison of pond system development on the Bečvárka river near Mlékovice village, including the surrounding landscape, shown on Archival Orthophotomaps from 2000 to 2019

Fig. 9. The current state of Mlékovický pond (October 2024)

Fig. 10. Comparison of pond system development on the Bečvárka river near Bečváry village, including the surrounding landscape, shown on a map of the 2nd Military Mapping, on a Historical Orthophotomap from the 1950s, on the current BTM 10, and on the current Orthophotomap of the Czech Republic

Fig. 11. Comparison of pond system development on the Bečvárka river near Žabonosy village, including the surrounding landscape, shown on a map of the 2nd Military Mapping, on a Historical Orthophoto map from the 1950s, on the current BTM 10, and on the current Orthophotomap of the Czech Republic

Fig. 12. The current state of Stojespal pond, including a disappeared historical part (October 2024)

Fig. 13. The current state of Utopenec pond (October 2024)

Fig. 14. The current state of Rybník pond, including a disappeared historical part (October 2024)

Fig. 15. The current state of Rozkoš pond (October 2024)

Fig. 16. The current state of Mlýnský pond, including a disappeared historical part (August 2024)

Fig. 17. The current state of Bosňák pond (August 2024)

Fig. 18. The pond system in the Bečvárka water body basin on Müller's map of Bohemia [15]

in the mid-19th century, the difference between a reservoir (fire, agricultural, etc.) and a pond (i.e. a water body intended exclusively for fish farming) was not yet clearly defined. We can therefore consider all water bodies depicted in the 2nd Military Mapping as ponds [21, 22]. However, in the Bečvárka river basin, there was no fundamental issue with distinguishing ponds from other water bodies, as most of them were preserved historical ponds. Any issues were also prevented by the definition of water bodies with a minimum area of 0.5 ha included in the evaluation. The only disappeared pond was the nameless pond in the village of Červený Hrádek. Due to its minimal area, almost exactly half a hectare, it was not considered for the evaluation of the pond system development in the Bečvárka river basin.

The historical pond system in the Bečvárka river basin recorded in the 2nd Military Mapping included a total of eleven ponds, nine of which were directly on the Bečvárka, covering a total area of 65.28 ha. All of these ponds have survived to the present day, although Mlékovický pond has had a ruptured dam since 2013, does not fulfill its original function, and its restoration is uncertain [20]. There are currently 16 ponds (including Mlékovický pond) in this basin with a total area of 76.64 ha; i.e., the area of ponds is currently larger than in the mid-19th century, while the current system of ponds is largely identical to the historical one.

To interpret these results, it is necessary to consider the fact that this is a comparison of only two initial states in terms of the temporal stability of the ponds, namely the 2nd Military Mapping period and the present. The area of the ponds was changing due to management; for example, the pond could have been landfilled and later restored. This could be the case of Voděradský pond, which is not only not visible on the orthophoto map from the 1950s, but its current area is larger than in the past (*Fig. 7*). Originally, there was also a longer-term discharge of ponds for the purpose of so-called summer drainage or silt removal, or the image could have been taken at the time of fishing, so the water body was not shown on the archive aerial photo. This is the case of Mlýnský pond in *Fig. 10*, again on the orthophoto map from the 1950s.

This pond system, with its development, deviates from the data otherwise valid for the entire Czech Republic, which state that the smallest area of ponds was in the mid-19th century and has been increasing slightly since then. Also, a significant part of the ponds recorded in the 2nd Military Mapping in lowlands have not been preserved to the present day [20, 21, 23, 24]. The pond system in the Bečvárka river also differs from the development of pond systems in the Polabian Lowland where, despite certain differences, historical ponds were disappearing significantly [2, 20, 21, 25–29]. A similar trend can be observed in the lowlands of the Morava river basin [30]. To a similarly sporadic extent as in the Bečvárka river basin, the disappearance or reduction of the area of historical ponds occurred only in the Třeboň region; however, the pond landscape there is much more extensive [20].

This fact seems paradoxical at first glance because this basin is used for intensive agriculture and is covered mainly by standard arable land. However, from Bečváry to the confluence with the Výrovka, the Bečvárka flows almost continuously through a relatively narrow and deep canyon, so there is no great pressure to landfill the ponds and replace them with arable land. It seems that in the context of ongoing climate change, such a robust pond system is probably oversized for a watercourse the size of the Bečvárka.

In this context, it can be considered that Mlékovický pond would not have to be restored and would become the subject of some form of protection within nature conservation associated with the appropriate management of this site. After twelve years of succession, this area is certainly more significant in terms of water retention in the landscape than as a pond used in the usual way for fish production today. Moreover, the restoration of the pond would be financially very demanding, given its current state. However, the owner of the pond is a large regional fishing company that manages a significant part of the ponds in the area. Such a solution, respecting the current state, would therefore probably also represent a large financial burden associated with the necessary change of owner.

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Assessment of the hydromorphological status of river water bodies in the Czech Republic using HYMOS methodology

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Keywords: hydromorphological assessment — HYMOS methodology — Water Framework Directive — water body

ABSTRACT

Assessment of the hydromorphological status and its elements (hydrological regime, continuity, morphological conditions) is part of the monitoring of the ecological status of water bodies. Hydromorphology, as a supporting component of biological assessment, has a significant impact on living organisms in aquatic ecosystems. Although the Ministry of the Environment of the Czech Republic (MoE) previously officially approved a methodology for monitoring and assessing the hydromorphological status of waterbodies (HEM methodology), it was only used to a limited extent. In the case of the third river basin management plans, hydromorphology was assessed exclusively based on remote sensing data according to the *Procedure for Determining Significant Impacts on Morphology and Hydrological Regime*. Based on the Ministry's request, a new methodology for assessing the hydromorphological status of water bodies category rivers (HYMOS) was developed within the TA CR project. This methodology takes into account new requirements and current knowledge in the field of hydromorphology, while also minimizing the drawbacks of previous methodologies, particularly regarding time and cost efficiency in the assessment process. The final version of the methodology was tested on 15 water bodies divided into 50 reaches. A score was calculated for each of these reaches to assess the hydrological regime, continuity, morphological conditions, and overall hydromorphological status. Subsequently, a score for the entire water body was determined, including classification into a status category. The assessment results indicated that for large watercourses, where anthropogenic influences are reflected over long reaches, the aggregated value for the entire water body often provides sufficiently meaningful information. In contrast, for water bodies including small and medium-sized watercourses, which are heterogeneous in terms of hydromorphological types and anthropogenic pressures, assessments at the water body level are overly aggregated and fail to identify critical segments. While reporting the status of water bodies requires presenting data for the entire water body, designing measures to improve hydromorphological status benefits from working with detailed reach-level data. Therefore, the HYMOS methodology combines detailed and aggregated approaches, making it a flexible tool suitable for both strategic planning at the water body level and for assessing local reaches in relation to implemented or planned measures.

INTRODUCTION

The Water Framework Directive (WFD) (2000/60/EC) [1] obliges EU Member States to assess the hydromorphological status of surface waters. Together with biological, chemical, and physico-chemical components, it forms part of the monitoring of the ecological status of water bodies. The term "hydromorphology" includes information on geomorphological and hydrological processes occurring in watercourses, including their longitudinal, lateral, and vertical continuity. According to the WFD, the assessment of the hydromorphology of water bodies of the river category is divided into three main elements:

1. hydrological regime,
2. watercourse continuity,
3. morphological conditions.

The objective of the hydromorphological assessment is to determine the extent of anthropogenic influence on water bodies within these elements. The hydromorphological assessment is used in many steps of the planning process under the WFD. It plays a role in defining water bodies, analysing significant impacts, determining heavily modified water bodies, selecting the location of monitoring profiles and, last but not least, in designing effective measures to achieve good status or potential of a water body, which is the main objective of the WFD. The basic legislative document regulating the assessment of the hydromorphological status of water bodies at the European level is the aforementioned WFD. In Czech legislation, this issue is regulated by Act No. 254/2001 Coll., the so-called Water Act, and Decree No. 98/2011 Coll., which determines the method and scope of the surface water status assessment. The correct and consistent implementation of the WFD in accordance with the European Union objectives is supported by the methodological guidelines of the *Common Implementation Strategy* (CIS) and the relevant standards. In the field of hydromorphological assessment, these are the standards ČSN EN 14614 [2] and ČSN EN 15843 [3].

In the Czech Republic, the hydromorphological status of water bodies is currently formally assessed using the Hydroecological Monitoring (HEM) methodology [4, 5], which has been officially accepted by the Ministry of the Environment (MoE). However, this methodology has only been used to a limited extent and the assessment data have not yet been officially reported as part of regular reports on the status of water bodies. The methodology users often pointed out its time-consuming nature, especially in collecting field data and subsequent calculations, as well as a higher degree of subjectivity in assessing individual indicators. Although the methodology meets the basic requirements of Czech and European legislation, significant progress has been made in the field of assessing the hydromorphology of watercourses since its inception, which has also been reflected in the updates of the relevant standards. This development has shown the need to revise the existing approach so that it better reflects new requirements and current knowledge. In response to these challenges, a new methodology for assessing the hydromorphological status of water bodies was developed within TA CR project No. SS05010135 *"Development of a methodology for monitoring and assessing hydromorphological characteristics of watercourses"*, referred to by the acronym *HYMOS – Methodology for assessing the ecological status of flowing surface water bodies (river category) using hydromorphological elements*. The aim of this article is to briefly introduce this methodology and show its applicability using the example of the assessment of 15 selected water bodies in the Czech Republic.

METHODOLOGY

HYMOS Methodology

General characteristics of the methodology

The methodology was developed primarily for the assessment of flowing surface water bodies, both natural and heavily modified. However, it is not intended for the assessment of artificial water bodies. Considering the need for a flexible approach to the assessment of hydromorphology, it was also designed to allow the assessment of watercourses that are not defined as water bodies. In developing the methodology, emphasis was placed on the legislative framework and standards listed in the introductory chapter. The results of the European project REFORM (REstoring rivers FOR effective catchment Management) [6] and the Morphological Quality Index (MQI) methodology [7], which was developed within the aforementioned project, played a significant role in its development. Based on new findings from the REFORM project and the MQI methodology, the EN 14614 standard (2020, original version approved in 2005) has been updated. The procedure for the identification of significant impacts on morphology and hydrological regime [8] was also an important starting point for the development of the new methodology.

Based on current requirements and recommendations, the HYMOS methodology includes both the assessment of forms and processes, while monitoring processes not only in the assessed reach, but also above it, for example influencing sediment transport affecting the deepening of the watercourse downstream. The methodology views watercourses as dynamically changing systems that develop over time, with a possible change from one channel planform to another. For this reason, the methodology does not determine a reference status based on archival maps, although archival maps serve as an important basis for identifying anthropogenic modifications in the past. The full version of the methodology is freely available on the official website of the HYMOS project (https://hymos.czechglobe.cz/) [9]. From the website, the user also has access to a specialized database [10], which contains morphological characteristics of water bodies and defined reaches, as well as to a web application and software for automating the assessment of hydromorphological status [11].

Reference conditions

As opposed to previous methodologies, reference conditions are not determined as specific characteristics of individual assessed indicators for individual types of watercourses, e.g. in the form of precise values of the variability of the riverbed width or the number of natural substrate types. In the past, this approach often led to inaccuracies in the assessment. The reference conditions are now defined in accordance with the WFD and the findings of the REFORM project as follows:

- for indicators expressing the effects of anthropogenic pressures (e.g. bank stabilization, channel bed modification), reference conditions are defined as the absence of pressures or their minimal presence, which does not have a significant impact on fluvial processes, morphology, or natural development of the channel;
- for indicators expressing the "functionality" of a watercourse and its response to anthropogenic pressures (e.g. bed substrate, bed elements), reference conditions are defined as the presence of forms and processes that are expected for a watercourse located in given physical-geographical conditions (e.g. valley slope and shape, intensity of sediment input).

This method of determining reference conditions places higher expert demands on the methodology users. In order to facilitate the assessment as much as possible, a hydromorphological typology of watercourses was created within the HYMOS project. It is based on a combination of the following key parameters: valley slope, confinement index (the ratio of floodplain width to channel width), potential input of coarse sediments to the river, and the size of a watercourse (according to Strahler stream order). Based on these parameters, hydromorphological types of watercourses were created, with accompanying descriptions of characteristic morphological parameters of the river. These descriptions serve as a guide for hydromorphological assessment. The parameters entering the typology are also used when dividing water bodies into (relatively) homogeneous reaches, which allows for a more accurate and consistent assessment.

Division of water bodies into reaches

Water bodies defined in the Czech Republic often show a high degree of inhomogeneity. Within a single water body, there are usually different hydromorphological types of watercourses, which differ in their response to anthropogenic pressures. This definition is not fully in line with the WFD requirements or with the recommendations of the CIS Guidelines No. 3 and 10 [12, 13]. Given the requirement to maintain the existing definition of water bodies, it was necessary to divide them into more homogeneous reaches for the purposes of assessing hydromorphological status. The following criteria were used to define the reaches:

- hydromorphological typology parameters – valley slope and shape, potential input of coarse sediments, and size of the watercourse;
- channel planform – e.g. change from meandering to straight or otherwise modified planform;
- the occurrence of structures affecting the longitudinal continuity of the watercourse – primarily dams of water reservoirs, flow-through ponds and other barriers that disrupt the flow natural processes and sediment transport;
- riparian zone use – changes between natural vegetation cover, cultural landscape, mosaic landscape, and built-up areas serve as placeholder information for potential changes in riverbed morphology.

Basic characteristics of the defined reaches, such as the slope of the valley and the watercourse, confinement index, stream order, and other relevant parameters are available in a publicly accessible database on the HYMOS project website [10].

The assessment of hydromorphological indicatorsis carried out at the level of these reaches, and the methodology allows a choice of two assessment approaches. Both approaches comply with legislative requirements and their choice is left to the methodology user:

1. Assessment of the entire reach length: This approach provides the most accurate picture of hydromorphological status as it reflects all characteristics within the entire reach. The disadvantage is that it is time-consuming, especially when collecting field data.
2. Assessment on a shorter representative "sub-reach": Assessment is carried out on a selected sub-reach; subsequently, its characteristics are extrapolated to the entire reach. This approach is less time-consuming, however, provides less detailed information on the hydromorphological status. The choice of sub-reach is key to ensuring representativeness of the results.

Tab. 1. Overview of assessed indicators, their scope, assessment method and the most common data sources for assessment. Indicators highlighted in orange are those evaluated using an alternative approach in cases where the required data – such as remote sensing data or data from gauging stations are unavailable. The letter next to each indicator denotes its affiliation with a specific element of the hydromorphological status (H = hydrological regime, C = continuity, M = morphological conditions)

Serial number		Indicator		Scope of assessment	Assessment method
1.		Hydrological regime	H	All watercourse types (with gauging stations)	Influence of flow rates, presence of diversion channels, peaking and maintenance of minimum residual flow rates.
1.	1.1	Hydrological regime above the assessed reach	H	All watercourse types (without gauging stations)	Water abstractions and discharges, water reservoirs (expert assessment of their impact), diversion channels, peaking and maintenance of minimum residual flows.
	1.2	Hydrological regime within the assessed reach	H		
2.		Backwater	H	All watercourse types	Backwater coefficient = sum of obstacle heights / difference in altitude between the beginning and end of the assessed reach.
3.		Migration permeability	C	Watercourses with an order according to Strahler ≥ 4	Number of migration-impermeable obstacles and maximum length of permeable reach.
4.		Sediment transport above the assessed reach	C	All watercourse types	Determination of the relative area of the catchment above the assessed reach where obstacles affect sediment transport, assessment graded according to the type of obstacle.
5.		Sediment transport within the assessed reach	C	All watercourse types	Number and type of obstacles interfering with sediment transport.
6.		Erodible floodplain area	C	Watercourses in unconfined valleys	Objects preventing/limiting lateral movements of the riverbed (stabilization, building development in the floodplain, etc.).
7.		Connectivity of valley slopes and riverbed	C	Watercourses in confined valleys	Objects disrupting the transport of material from valley slopes to the riverbed (e.g. transport infrastructure).
8.	8.1	Plan shape	M	Watercourses in unconfined valleys,with valley slope < 2 %	Comparison of the current state with historical maps or a plan shape corresponding to physical and geographical conditions.
	8.2	Renaturation processes	M		Renaturation processes (bank erosion).
	8.3	Significant shortening of the riverbed route	M		Changing the meandering flow to a straight one (serrated with low tortuosity), comparing the current state with historical maps.
9.	9.1	The frequency and extent of floodplain flooding	C	Watercourses in unconfined valleys (availability of distance data)	Capacity index = channel width/floodplain width at flow rate Q5.
	9.2	Accelerated deepening of the riverbed	C	Watercourses in unconfined valleys	Signs of a deepening riverbed (high bank erosion, exposed bridge pier foundations).
9.	9.1	Deepening the riverbed	C	Watercourses in unconfined valleys (absence of distance data)	Deepening index = channel width / channel depth.
	9.2	Dams and barriers in the floodplain	C		The length of dams and barriers in a strip of 2x the width of the riverbed.
	9.3	Accelerated deepening of the riverbed	C	Watercourses in unconfined valleys	Signs of a deepening riverbed (high bank erosion, exposed bridge pier foundations).
10.	10.1	Variability of cross-sectional profile	M	All watercourse types	Changes in the cross-sectional profile shape (variability of the riverbed width and depth) with respect to the hydromorphological type of the riverbed.
	10.2	Partial cross-sectional variability	M		In the case of an impact on the cross-sectional profile over a length greater than 33 %, partial preservation of the variability of depths or widths capable of providing habitats is assessed.
11.	11.1	Riverbed stabilization and stabilization thresholds	M	All watercourse types	Riverbed stabilization and stabilization objects (thresholds, steps, slides).
	11.2	Impermeable riverbed stabilization	MC		Riverbed stabilization which completely disrupt the exchange of substances and energy between surface water and groundwater.
	11.3	Piped and covered reaches	M		Piped and covered reaches
12.	12.1	Bank stabilization	MC	All watercourse types	Bank stabilization
	12.2	Hard bank stabilization	MC		Stabilizations that significantly reduce the watercourse ecological quality (e.g. stone and concrete paving, concrete panels, etc.).
13.		Riverbed substrate	M	All types (except deep riverbeds)	Influence on the riverbed substrate composition, colmatation, reinforced layers, deepening into the bedrock, covering of coarse substrate with fine sediments.
14.	14.1	Riverbed shapes	M	All watercourse types	Changes in the representation of riverbed shapes with respect to the hydromorphological type of the riverbed.
	14.2	Partial preservation / restoration of riverbed shapes	M		In the case of an impact on the riverbed shapes over a length greater than 33 %, the presence of shapes capable of providing habitats for living organisms is assessed.

Serial number		Indicator		Scope of assessment	Assessment method
15.		Coarse river timber	M	All types (except streams with a natural absence of woody vegetation)	Coarse river timber in the riverbed
16.		Bank erosion	C	Watercourses in unconfined valleys (except low energy streams)	Eroded banks
17.		Fluvial landforms in the floodplain	M	Watercourses in unconfined valleys	The occurrence of shapes in the floodplain and their hydrological connection with the riverbed.
18.	18.1	Linear extent of functional riparian vegetation	M	All watercourse types	Occurrence of linear vegetation along the bank edge (assessed on both banks).
	18.2	Use of riparian zone and floodplain	M	All watercourse types	Occurrence of natural surface types in a strip of 2 riverbed widths on both banks.
19.	19.1	Management of riparian vegetation and coarse river timber	M	All watercourse types	Frequency and extent of riparian vegetation removal (felling, mowing) and removal of coarse river timber from the riverbed.
	19.2	Sediment management	M	All watercourse types	Frequency of sediment removal from the riverbed.

Indicators for assessing hydromorphological status

The indicators used to assess the hydromorphological status and its elements (hydrological regime, continuity, and morphological conditions) are based on the requirements defined in the ČSN EN 14614 standard. The selection of indicators is based on current scientific knowledge and their demonstrated relationship to the assessed biological components, such as fish, macrophytes, or macroinvertebrates.

Each indicator is defined in terms of its function in the assessment and scope of application, i.e. for which types of watercourses it is applicable. An overview of the indicators is given in *Tab. 1*, which contains a brief description of the assessment method and specifies to which types of watercourses the given indicator applies. As opposed to previous approaches, it is no longer necessary to record detailed information for indicators, such as percentages of bed substrate types or channel bed elements, for assessment purposes. Instead, the degree of deviation from the reference status in categories is directly assessed, which significantly reduces the time required for data collection in the field. Indicators are rated in three to five categories, which also contributes to reducing the degree of subjectivity. Field data can be collected directly via a form in the mobile app (a web platform adapted for any mobile device), eliminating the need for additional transcription of data from paper forms. During the testing of HYMOS methodology, the speed of assessment was compared with HEM methodology. The comparison carried out on 15 selected sections of watercourses showed that actual data collection in the field using HYMOS methodology was approximately twice as fast as when using HEM methodology.

Principle of calculating hydromorphological status

Indicators are assessed in categories, each of which is assigned a point score. This system allows calculation of the status of all hydromorphological status elements (hydrological regime, continuity, morphological conditions), overall hydromorphological status of the reach and, subsequently, of the water body. Scoring is based on the MQI methodology [7] and was validated and adjusted based on data obtained during the project to correspond to the conditions of the Czech Republic. The point score of category 1, which represents the reference status, is always 0 and with an increasing value of the assessment category, which signals a higher degree of anthropogenic influence, the point score also increases.

The assessment of the hydromorphological condition is calculated as the sum of points obtained from the evaluation of individual indicators, which is then divided by the maximum possible score for the given indicators. Each indicator influences the final assessment to a different extent. The calculation is performed according to the following formula:

$$HMS = 1 - \left(\frac{S_{assessment}}{S_{max}}\right)$$

where:

HMS	is	hydromorphological status
$S_{assessment}$		the sum of the points obtained by assessing the indicators
S_{max}		the maximum sum of the points for the assessed indicators

Indicators that are not assessed are not included in the calculation of the maximum score. This calculation procedure is also used for the individual hydromorphological elements.

When calculating the score, the assessment reliability is also considered. If the assessment of an indicator is less reliable (e.g. due to lack of or incomplete data), the user marks two assessment categories and then the difference between these categories is calculated and the deviation caused by this uncertainty is included in the overall score.

Tab. 2. Threshold values for the assessment of hydromorphological status and its elements

Assessment class	Assessment description	HMS Threshold values
1	High	$0.85 \leq HMS \leq 1.00$
2	Good	$0.70 \leq HMS < 0.85$
3	Moderate	$0.40 \leq HMS < 0.70$
4	Damaged	$0.20 \leq HMS < 0.40$
5	Destroyed	$0.00 \leq HMS < 0.20$

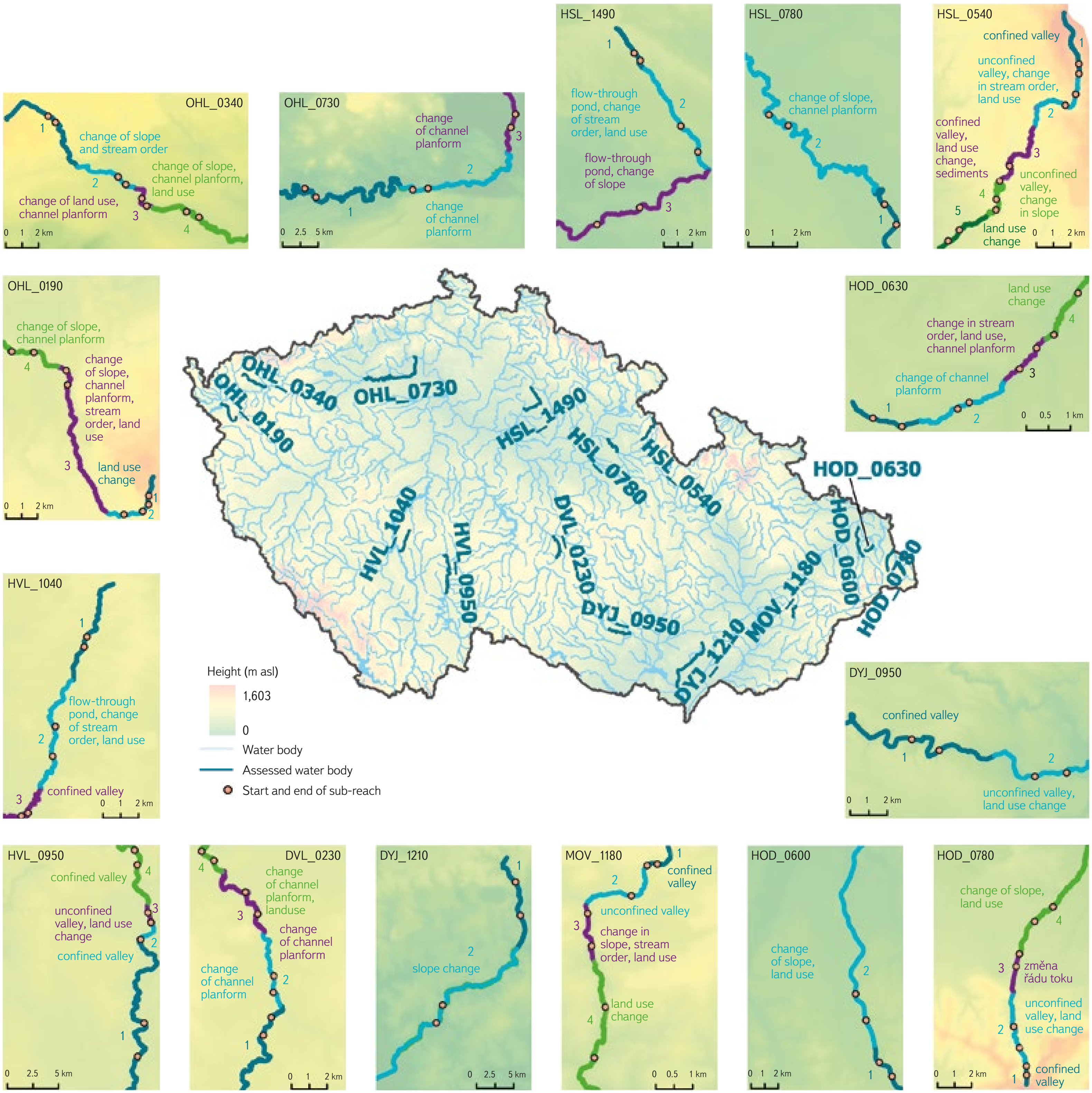


Fig. 1. The map depicts the selected assessed water bodies (their full names are listed in *Tab. 3*), the division of water bodies into reaches (reaches are colour-marked, their numbering corresponds to *Tab. 3*), and the parameters used for this division. It also shows the sequential numbering of reaches and the location of sub-reaches where field assessments were conducted.

Tab. 3. Results of the assessment of selected water bodies – results for river reaches and entire water bodies

WB name	WB and reach ID	Length [m]	HM score	HM status	HYDR score	HYDR status	CONT score	CONT status	MORPH score	MORPH status	Main pressures	WB HM status	WB HYDR status	WB CONT status	WB MORPH status
The Zlatý Stream from the Mlynský Stream up to its confluence with the Šlapanka River, and the Šlapanka River up to its confluence with the Sázava River	DVL_0230_1	9,454	0.67 (+0.04)	3 (2)	0.59 (+0.17)	3 (2)	0.69	3	0.75	2	4	3	3	3	2
	DVL_0230_2	5,019	0.55 (+0.04)	3	0.50 (+0.17)	3	0.52	3	0.70	2	4, 5, 8.1, 9, 10.1, 14.1				
	DVL_0230_3	7,566	0.7 (+0.04)	2	0.50 (+0.17)	3	0.63	3	0.86	1	4, 5				
	DVL_0230_4	2,709	0.35 (+0.04)	4	0.35 (+0.17)	4 (3)	0.29	4	0.43	3	2, 4, 5, 6, 8.1, 9, 10.1, 11.1, 12, 14.1, 15				
The Jihlava River from the Mohelno Reservoir up to the Oslava River	DYJ_0950_1	12,357	0.73	2	0.59	3	0.52	3	0.95	1	3, 4, 5	3	3	3	2
	DYJ_0950_2	6,877	0.35	4	0.41	3	0.31	4	0.46	3	2, 3, 4, 5, 8.1, 9, 10.1, 13, 14.1, 15, 16, 18.2				
The Trkmanka River from its source up to the Spálený Stream	DYJ_1210_1	6,378	0.60	3	0.82	2	0.71	2	0.54	3	8.1, 9, 10.1, 13, 14.1, 18.2	3	2	2	3
	DYJ_1210_2	13,776	0.61	3	0.82	2	0.89	1	0.43	3	8.1, 10.1, 13, 14.1, 18.1, 18,2				
The Ostravice River from the River Morávka up to the River Lučina	HOD_0600_1	3,729	0.33	4	0.50	3	0.33	4	0.31	4	3, 4, 5, 6, 8.1, 10.1, 12.1, 14.1, 15, 16, 18.1, 18.2, 19.1	4	3	4	3
	HOD_0600_2	16,605	0.39	4	0.50	3	0.33	4	0.42	3	3, 4, 5, 6, 8.1, 10.1, 12.1, 14.1, 15, 16				
The Říčky Stream from its source up to its confluence with the Lučina River	HOD_0630_1	1,834	0.75	2	1.00	1	0.83	2	0.69	3	13	2	1	2	2
	HOD_0630_2	2,921	0.94	1	1.00	1	0.92	1	1.00	1	-				
	HOD_0630_3	1,571	0.85	1	1.00	1	0.78	2	0.82	2	3				
	HOD_0630_4	2,051	0.77	2	1.00	1	0.78	2	0.67	3	3				
The Ropičanka River from its source up to its confluence with the Olše River	HOD_0780_1	1,112	1.00	1	1.00	1	1.00	1	1.00	1		3	2	4	3
	HOD_0780_2	5,011	0.47	3	0.68	3	0.41	3	0.43	3	3, 5, 6, 10.1, 11.1, 12.1, 14.1, 15, 16, 18.2				
	HOD_0780_3	2,322	0.47	3	0.76	2	0.28	4	0.48	3	3, 5, 6, 9, 10.1, 11.1, 12.1, 14.1, 15, 16				
	HOD_0780_4	8,356	0.38	4	0.68	3	0.20	4	0.40	3	3, 5, 6, 8.1, 9, 10.1, 11.1, 12.1, 14.1, 15, 16				
The Bělá River from its source up to the Dlouhá Strouha River	HSL_0540_1	4,432	0.95	1	0.82	2	1.00	1	1.00	1	-	2	2	3	2
	HSL_0540_2	5,957	0.54	3	0.76	2	0.58	3	0.47	3	5, 10.1, 11.1, 12, 15, 16, 19.1				
	HSL_0540_3	5,444	0.83	2	0.82	2	0.63	3	0.91	1	-				
	HSL_0540_4	3,546	0.78	2	0.68	3	0.81	2	0.82	2	-				
	HSL_0540_5	3,759	0.55	3	0.68	3	0.37	4	0.55	3	6, 9, 10.1, 12, 18.2				
The Orlice River from the confluence of the Tichá Orlice and Divoká Orlice Rivers up to the Dědina River	HSL_0780_1	3,562	0.43	3	0.50	3	0.50	3	0.38	4	5, 6, 8.1, 10.1, 12, 13, 15, 18.2	2	3	2	2
	HSL_0780_2	14,122	0.78	2	0.65	3	0.78	2	0.82	2	-				

WB name	WB and reach ID	Length [m]	HM score	HM status	HYDR score	HYDR status	CONT score	CONT status	MORPH score	MORPH status	Main pressures	WB HM status	WB HYDR status	WB CONT status	WB MORPH status
The Mrlina River from its source up to the Hasinský Stream	HSL_1490_1	3,986	0.64	3	0.59	3	0.63	3	0.74	2	2, 5, 11.3, 13				
	HSL_1490_2	9,561	0.43	3	0.68	3	0.30	4	0.55	3	4, 5, 8.1, 9, 10.1, 13, 14.1	3	3	4	3
	HSL_1490_3	14,961	0.41	3	0.59	3	0.28	4	0.55	3	2, 4, 5, 8.1, 9, 10.1, 13, 14.1				
The Lužnice River from the Nežárka River up to the Košínský Stream	HVL_0950_1	22,397	0.43	3	0.35	4	0.50	3	0.51	3	2, 3, 5, 8.1, 9, 10.1, 13, 14.1, 16				
	HVL_0950_2	2,572	0.45	3	0.35	4	0.55	3	0.58	3	2, 3, 10.1, 13, 14.1	3	4	3	3
	HVL_0950_3	1,998	0.30	4	0.35	4	0.22	4	0.34	4	2, 3, 5, 9, 10.1, 13, 14.1, 15, 16, 18.1, 18.2				
	HVL_0950_4	8,512	0.41	3	0.35	4	0.48	3	0.55	3	2, 3, 5, 10.1, 13, 14.1, 18.2				
The Hrejkovický Stream from its source up to the backwater of the Orlík I Reservoir	HVL_1040_1	7,158	0.51	3	0.76	2	0.44	3	0.55	3	2, 3, 5, 8.1, 10.1, 13, 14.1, 15				
	HVL_1040_2	8,963	0.70	2	1.00	1	0.52	3	0.75	2	3, 4, 9	2	1	3	2
	HVL_1040_3	4,695	0.94	1	1.00	1	0.80	2	1.00	1	3				
The Dřevnice River from its source up to the backwater of the Slušovice Reservoir	MOV_1180_1	1,119	0.96	1	1.00	1	0.94	1	0.97	1					
	MOV_1180_2	1,209	0.97	1	1.00	1	0.93	1	0.99	1	11.1	3	1	3	3
	MOV_1180_3	1,735	0.79	2	0.94	1	0.80	2	0.68	3	11.1				
	MOV_1180_4	4,493	0.52	3	1.00	1	0.50	3	0.36	4	8.1, 9, 10.1, 12.1, 14.1, 15, 16				
The Lipoltovský Stream from its source up to its confluence with the Odrava River	OHL_0190_1	2,198	1.00	1	1.00	1	1.00	1	1.00	1					
	OHL_0190_2	3,269	0.67	3	1.00	1	0.66	3	0.59	3	5, 14.1, 19.1	2	2	2	2
	OHL_0190_3	12,709	0.81	2	1.00	1	0.78	2	0.80	2	4, 8.1				
	OHL_0190_4	4,727	0.71	2	1.00	1	0.91	1	0.51	3	8.1, 10.1, 14.1				
The Chodovský Stream from its source up to its confluence with the Ohře River	OHL_0340_1	8,078	0.92	1	1.00	1	0.74	2	0.99	1	5				
	OHL_0340_2	4,636	0.40	3	0.47	3	0.26	4	0.48	3	1, 8.1, 9, 10.1, 11.3, 12.1, 12.2, 14.1, 15, 16	3	3	3	2
	OHL_0340_3	2,179	0.31	4	0.41	3	0.39	4	0.26	4	1, 6, 8.1, 9, 10.1, 12.1, 12.2, 13, 14.1, 15, 16, 18.1, 18.2				
	OHL_0340_4	8,778	0.63	3	0.24	4	0.65	3	0.80	2	1, 5, 6				
The Ohře River from the Chomutovka River up to its confluence with the Elbe River	OHL_0730_1	35,522	0.61	3	0.59	3	0.57	3	0.65	3	3, 4, 5, 10.1, 14.1, 18.2				
	OHL_0730_2	21,937	0.57	3	0.59	3	0.54	3	0.61	3	3, 4, 5, 8.1, 10.1	3	3	3	3
	OHL_0730_3	9,394	0.48	3	0.65	3	0.59	3	0.39	4	3, 5, 8.1, 10.1, 14.1, 15, 16				

(WB name = water body name, WB and reach ID = identifier of the water body and section, Length = reach length in meters, HM score = hydromorphological score of the reach, HM status = hydromorphological class of the reach, WB HM score = hydromorphological score of the water body. As with the hydromorphological status, abbreviations are used for the individual elements of the hydromorphological status assessment, HYDR = hydrological regime, KONT = continuity, MORFO = morphological conditions. Main pressures = indicators that contribute most to the poor hydromorphological status, with numbering corresponding to *Tab. 1*)

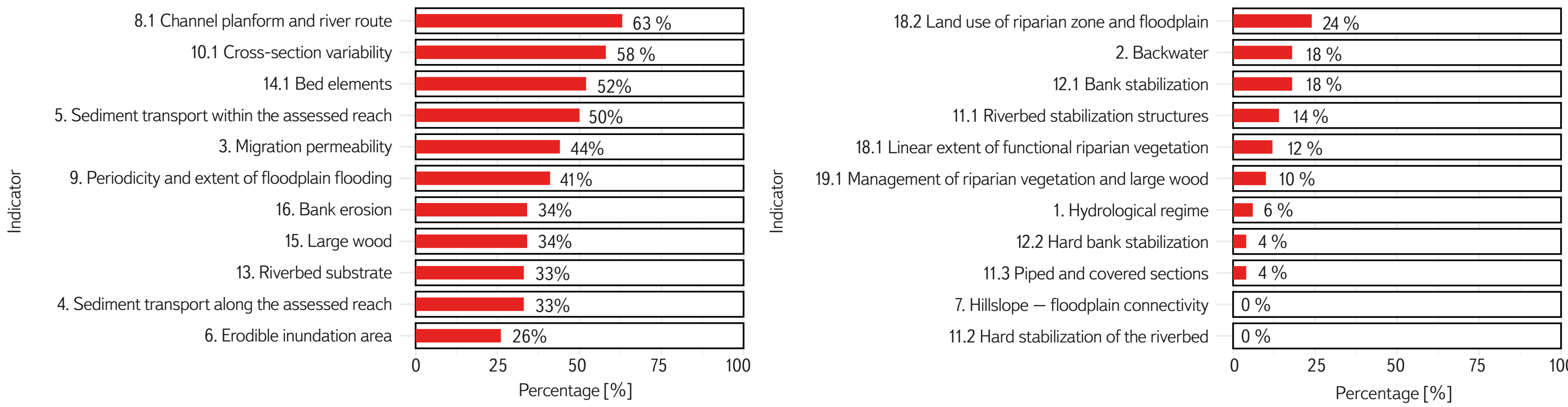


Fig. 2. Relative frequency of occurrence of indicators (main pressures) contributing to the impaired status of assessed reaches

The calculated score for hydromorphology and its components ranges from 0 to 1, with a value of 1 corresponding to natural conditions and 0 indicating heavily degraded conditions. Threshold values for individual assessment classes are given in *Tab. 2*. Calculations are performed automatically by the software, based on the assessment entered into the form in the web app.

For reporting purposes, assessment result for the entire water body must be provided. This can be calculated using the following formula:

$$HMS_{VÚ} = \frac{\sum_{i=1}^{n} HMS_i \times 1_i}{\sum_{i=1}^{n} 1_i}$$

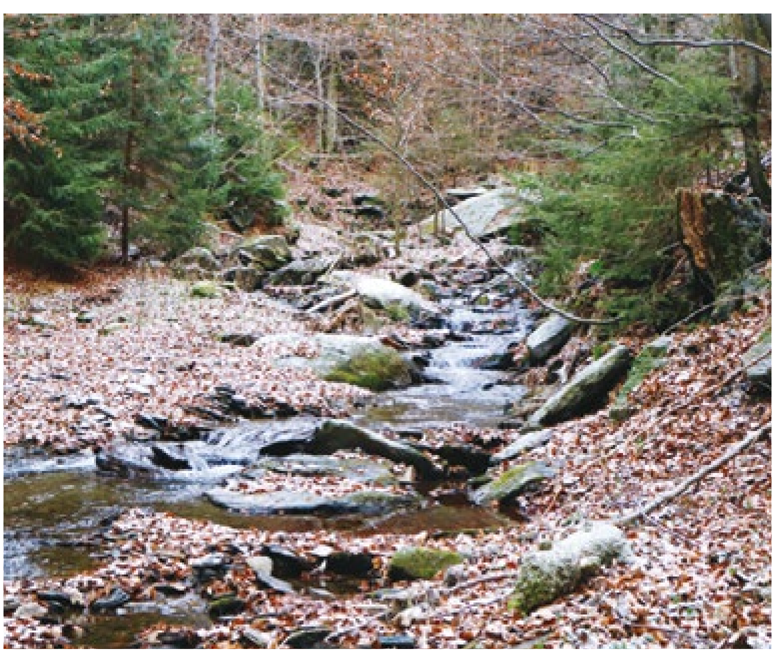
where:

$HMS_{VÚ}$	is	hydromorphological status of the water body
HMS_i		hydromorphological status of the i reach
l_i		the length of the i reach

Water body assessment

HYMOS methodology was applied to 15 selected water bodies, which are evenly represented in all main river basins of the Czech Republic – three water bodies in each river basin. For the purpose of demonstrating applicability of the methodology, water bodies were selected that cover different hydromorphological types of watercourses, i.e. streams with different slopes (high/low), in confined and unconfined valleys, small and large streams, with different intensities of coarse sediment input. Another selection criterion was the intention to include water bodies with different intensities of anthropogenic pressures. An overview of the selected water bodies, including their division into reaches, is shown in *Fig. 1*.

Indicators 1 to 8 and 18 (listed in *Tab. 1*) were assessed over the entire reach length based on remote sensing data. Indicator 9, relating to the periodicity and extent of floodplain flooding, was assessed over the entire length, if the relevant remote sensing data were available (floodplain extent layer for a 5-year recurrence interval). The remaining indicators were assessed within shorter sub-reaches (*Fig. 1*). The sub-reaches were defined based on an analysis of the land use in the strip around the watercourse, aerial photographs, virtual



Reach 1 – confined valley with a steep slope (over 2 %), no anthropogenic pressures (high status)

Reach 2 – unconfined valley with a steep slope (over 2 %), modified channel morphology and disruption of longitudinal continuity (moderate status)

Reach 3 – confined valley with a slope over 2 %, anthropogenic pressures caused by local disruption of longitudinal continuity and limited connectivity between valley slopes and the channel due to road infrastructure (good status)

Reach 4 – unconfined valley with a slope of 0.5–2 %, local modifications of the cross-sectional profile (good status)

Reach 5 – unconfined valley with a slope of 0.5–2 %, flowing through a village and its built-up area (moderate status)

Reach 5 – unconfined valley with a slope of 0.5–2 %, flowing through a village and its built-up area (moderate status)

Fig. 3. Reaches of the Bělá water body from its source to the Dlouhá strouha stream, illustrating the variability of physico-geographical conditions and the influence of anthropogenic pressures

tours (Street View), and the presence of sctructures, with the aim of best capturing the extent of anthropogenic pressures in a given reach.

RESULTS AND DISCUSSION

A total of 15 water bodies were assessed, which were divided into 50 reaches. For each of these reaches, both the score for individual elements of hydromorphological assessment (hydrological regime, continuity, morphological conditions) and overall hydromorphological status were calculated. Each reach was also assigned to the corresponding classification class. The summary results are presented in *Tab. 3.*

Almost half of the assessed reaches were classified as class 3 based on the degree of hydromorphological impact. Eleven reaches were in good status, nine in very good, and seven were assessed as poor. No reach was classified as bad (classification status 5) High status was typical for parts of the watercourse in the upper reaches with a steep slope, often in confined valleys. However, these parts usually only represent a smaller proportion of total water body length. Longer reaches with high status are only found in the Říčka water body, from its source to its confluence with the Lučina watercourse. Reaches in confined valleys, where the intensity of anthropogenic modifications is usually lower (e.g. lower part of Hrejkovický stream), were also found to be in good or high status. Reaches of Lipoltovský stream, the meandering parts of the Orlice and the Šlapanka water bodies can also be described as ecologically valuable.

Analysis of the main anthropogenic pressures and the response of watercourses to their effects (*Fig. 2*) showed that the most common reason for the impaired result of hydromorphological assessment was modification of the channel planform. This type of modification is often associated with low cross-sectional variability and insufficient presence of the corresponding riverbed elements. Other pressures include disruption of the watercourse longitudinal continuity, which limits sediment transport and fish migration. In more than one third of cases, the absence of bank erosion and large wood also contributed to lower assessment. Field data show that, despite modifications to the cross-sectional profile, banks are usually not stabilized over long reaches. This provides a suitable condition for spontaneous renaturation during floods, especially in streams with higher energy (watercourses with a more pronounced slope, flow rate, and narrower undersized channel).

For the purposes of reporting under the WFD, it is necessary to calculate the hydromorphological status and its elements for water bodies. The assessment of selected water bodies is given in *Tab. 3*. However, this approach has certain limits. Water bodies usually include different hydromorphological types and are exposed to different anthropogenic pressures that differ in intensity; from this point of view, they are not homogeneous. The calculated classification level value is a weighted average of assessments for individual water body reaches. Analysis of selected water bodies shows that the calculation for one body can only be sufficient for large watercourses, where anthropogenic influence is manifested over long distances.

Examples are the Ohře water body from the Chomutovka stream to the mouth of the Elbe, the Lužnice water body from the Nežárka iver to the Košínský stream, and the Ostravice water body from the Morávka river to the Lučina stream. In the case of smaller and medium-sized watercourses, assessment for the water body is usually too aggregated. A good example is the Bělá water body, from the source to the Dlouhá strouha stream, where reaches in a confined and unconfined valley alternate, and each of these reaches shows a different degree of anthropogenic influence (*Fig. 3*). Although it is necessary to calculate values for the water body for reporting purposes, more detailed information for individual reaches also represents an important basis that can support more accurate identification of critical reaches and more effective design of measures by environmental protection authorities and watercourse managers.

CONCLUSION

In this paper, we have presented a new methodology for assessing hydromorphological status of flowing water bodies. Compared to previous methodologies, the main advantages can be considered the following:

1. Working with distance data
   10 out of 19 indicators can be assessed based on remote sensing data, with selected indicators already being assessed within the project.
2. Reducing time requirements
   The defined methodology, software, and apps enable fast and efficient data collection in the field and immediate assessment of hydromorphological status without the need for transcribing field data and further calculations. HYMOS methodology is up to twice as fast as HEM; when testing during the project, its user needed only half the time compared to the user of HEM methodology.
3. Reducing subjectivity of assessment
   Assessing indicators in categories and the method of defining the assessment increases the probability that two different assessors will assess the same indicator identically.
4. Ensuring consistency between the calculated hydromorphological status and the conditions observed in the field
   The defined assessment gives the assessor greater freedom in the assessment, thus preventing situations where, in the past, a watercourse was assessed according to a type that does not correspond to its actual character.
5. Analysis of main anthropogenic pressures and response of watercourses to their effects
   After calculation, the software shows which indicators contributed most to poor hydromorphological status, which allows for precise identification of the main anthropogenic pressures acting in the assessed reach.

HYMOS methodology meets current requirements of the WFD and the ČSN EN 14614 standard for assessment of hydromorphological elements of water bodies; it also allows for assessment of watercourses that are not defined as water bodies. In the methodology, watercourses are seen as dynamically changing systems, which shifts the emphasis to assessment of processes such as sediment transport, bank erosion, or riverbed development. The methodology also considers anthropogenic changes above the assessed reach, which can affect processes and shapes in the given reach. Although the methodology is designed for a comprehensive assessment of these processes, it is not intended for monitoring very small changes that are difficult to define with a categorized assessment. Compared to previous methodologies, HYMOS methodology brings significant changes in the approach to assessing hydromorphological status. Nevertheless, a number of recorded parameters, such as transverse structures in the channel or stabilization of riverbanks and riverbed, remain the same or differ only minimally. Thanks to this, data obtained using older methodologies can also be used for assessment according to HYMOS methodology, especially if the original definition of the assessed reaches is maintained. In the event of a change in their definition, the need to reassess percentage values related to the length of the reach cannot be ruled out in order to correspond to the new definition.

HYMOS methodology allows for assessment of hydromorphological status at the level of individual homogeneous reaches, which provides valuable information for detailed analyses and planning of measures. Based on these partial assessments, an aggregated value of hydromorphological status for the entire water body can then be calculated, which is required for reporting purposes in accordance with the WFD. This combination of detailed and aggregated approaches makes HYMOS methodology a flexible tool that can be used not only for strategic planning at the water body level, but also for assessment of local reaches in connection with implemented or planned measures.

Due to the project timeframe, it was not possible to use HYMOS methodology for assessing the hydromorphological status of watercourses in the third planning cycle. However, its application is expected in subsequent planning cycles, which are planned at least at the national level. The importance of the hydromorphological status of watercourses is also highlighted in the Nature Restoration Law (Regulation (EU) 2024/1991), approved last year, which places emphasis on the restoration of free-flowing rivers. HYMOS methodology [9] was developed with these requirements in mind and provides broad analytical and methodological support for their fulfilment.

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Interview with Prof. RNDr. Bohumír Janský, CSc., from the Faculty of Science, Charles University in Prague

On the following pages, we will travel, play sports, and also compare. It was my great pleasure to interview my teacher, now a colleague, and a personality whom I greatly respect not only in the field of hydrology, water management, and physical geography. We will reminisce about the past years and talk about the present and the near future with the discoverer of the sources of the Amazon and a prominent Czech geographer, Prof. RNDr. Bohumír Janský, CSc., from the Faculty of Science, Charles University in Prague.

Professor, since we know each other quite well, I will ask you a direct question, and I will direct it towards the East. Today, Russia is viewed in many negative ways; you often travelled there during communism, participated in excursions, and gave lectures there. How do you remember the years spent on Baikal?

I first visited Baikal in 1978, then as a young assistant at the Department of Physical Geography as part of a student exchange with Lomonosov University under the guidance of Professor Král. During this excursion we flew an incredible 16,000 km, which I cannot even imagine today, in times of economic and time constraints. Among other things, at the Lomonosov University summer camp in Crimea, we and the students defeated their first-league team Lokomotiv Moscow, who were training there, in a friendly football match, thanks to which the entire Bakhchisaray knew us. In total, I took part in fifteen such excursions throughout the Soviet Union, including the polar Urals, the Arctic Ocean coast with the Kola and Taimyr peninsulas; later, I visited Kamchatka with Russian students. Those were wonderful years; for geographers, excursions are the most important and valuable thing of all, when they see everything in context.

In 1981, as part of a scholarship stay, I gave a lecture on hydrology at Irkutsk University. Thanks to this stay, together with Russian graduate students I went to Baikal again, specifically Olkhon Island, for three whole months. I worked there at the world-famous Limnological Institute of the Academy of Sciences in Listvyanka at the mouth of the Angara River and was professionally involved in the Baikal hydrological balance. As part of the then freshwater testing of bathyscaphes that were brought there for testing from the Pacific Ocean, I dived to a depth of 1,200 m and was able to taste the water samples taken from this depth. It was, of course, delicious; they even made the local vodka named Baikal from it, which I then received as a gift by mail and I have it to this day. I then presented this experience with great enthusiasm during a for me very important internship in Switzerland at ETH Zurich, where I led several excursions with Swiss students right after the Velvet Revolution. Today, ETH Zurich has its own hydrochemical laboratory on Baikal. I can say that I was there at its inception.

However, I have a funny story connected with Baikal. Thanks to my experience, after the Velvet Revolution, a group of Czech surfers approached me and asked if I would help them plan the ideal route for crossing it. I talked them out of the longitudinal route, about 630 km; however, the transverse route, 120 km north of Olkhon Island, seemed realistic. When we finally arrived there, the captain, who had been drinking, did not know exactly where to anchor, so we looked for the shore using searchlights. In the morning, we woke up on a boat stuck on a sandbar in absolutely windless weather and waited for the wind for several days. In the end, I came up with the idea of taking advantage of the breeze flow, i.e. the wind blowing from the land to the sea at night and in the morning. So, we set off from Sarma with six surfers at two in the morning. By the way, in the deep darkness, we temporarily lost the Soviet Union surfing champion. However, around ten o'clock, at the northern cape of Olkhon Island, the breeze died down. Fortunately, after about an hour, the *Sarma* – the local downwind from the mountains – blew at our backs and the surfers covered the rest of the route to Ust-Barguzin, which is about 60 km, in perhaps an hour and a half. By then, everyone knew about us and a welcoming delegation with national television awaited us on the shore, where I sang the well-known song "Slavnoye more, svyashchenij Baikal" with the National Artist of the Soviet Union. Subsequently, our Karel Gott sang the song (*laughs*).

However, your lifelong love is Latin America, whose physical geography you have been lecturing on at the Faculty for many years. What captivated you about it? More from the perspective of hydrology and water management, or the people?

It all started when I was about eight years old, when my grandfather, a monarchist, landowner and educated man, brought me the pulp magazine *Gauchos – shepherds of semi-wild herds in the pampas*, which completely enchanted me. I opened Kuchař's World Atlas, saw the colour blue on the map (*rivers and lakes, author's note*) and my interest in South America and geography never left me. I have always been fascinated by water; even at elementary school, my friends and I would measure flow rates in streams, catch trout in our hands, and skate twelve kilometres to school in Plasy on the frozen Střela river. I enjoyed geography so much that I even occasionally taught it to my classmates from the lower grades at secondary school, of course as a substitute after agreement with the professor. When I was lecturing on Latin America at the university, I considered it necessary to learn Spanish in order to better understand the subject. So, I attended the so-called Intex at the castle in Poděbrady, which was intended for our foreign experts. By the way, my Spanish teacher, Dr. Jaroslav Nigrin, acted as an interpreter at a personal conversation between our then president Gustáv Husák and Fidel Castro. In the late 1980s, the university's international office called me to ask if I wanted to fly to Peru, saying they had bought a ticket and the person in question had fallen ill... without hesitation, I happily agreed. I flew there on 10 October 1989 – originally planned for six weeks. From Peru, I then followed what was happening across the ocean in our country; on 18 November, on the front page of the newspaper, I saw the faculty building with a window into my office and next to it a photo of Václav Havel with Alexandr Vondra, whom I had taught at the faculty for years and who had even started his diploma thesis with me before switching to geomorphology. However, I ended up staying in Peru for almost a year – I accepted guest positions at universities in Lima, Cusco and Arequipa and did not return to my homeland until June 1990.

I have been lecturing at the faculty for decades now; in addition to hydrology and oceanography, I also lecture on the geography of Latin America, including

Fig. 1. Opening of a travelling exhibition around South American universities for 25 years since the discovery of the sources of the Amazon by Czech scientists

a seminar where we invite diplomats, businessmen, artists, and other globetrotters. I also serve as the chairman of the Czech Ibero-American Society, which I find very fulfilling. We map social and cultural life – everything that is happening in the Czech Republic on the topic of Latin America. We are in touch with seven bilingual grammar schools, with whom we organize a competition on Latin America with the announcement of the winners in the historical Náprstek Museum. And that is beautiful.

As part of organizing exhibitions and lectures, you have visited many prestigious as well as regional universities around the world. What is the attitude of their students towards hydrology? Do you remember anything that surprised you?

In the first hydrology lecture, I always tell our students that they are no longer in secondary school, so they have to discuss with us or critically contradict the information they have obtained through argument, mainly in seminars designed for this purpose. However, this is still incomparable with the Western world, and it could even be a small regional university in Peru. I probably experienced the warmest welcome at the University of San Antonio Abad in Cusco, where students took me on numerous excursions around the area, such as to the Madre de Dios river in the Amazon; they also regularly invited me to visit their families, and the local geography professor even offered me free housing in his apartment right on the Plaza de Armas, opposite the famous cathedral. I, in turn, tried to integrate myself into university life there by learning the Lord's Prayer in Spanish for the church service, which was always held an hour before classes. The dean appreciated it and told me that none of the invited foreign guests had done this before.

I also think that students at smaller universities are more grateful for the information they receive, and after lectures, it is quite common for teachers to be applauded or even tapped on the desk, like at universities in Seville or Heidelberg. This was also true of Irkutsk University, by the way. There, May Day celebrations were the crowning glory; students were provided support funds to last the celebrations, in the form of a bottle of vodka for three people, which, imagine, was paid for by the faculty (!). But seriously, here, the overall approach of students to education, and this also applies to engaging in discussions during classes, is much more reluctant, and we lack in this area compared to the rest of the world.

You are still one of the busiest teachers at the Faculty of Science at Charles University. How have teaching opportunities changed in this regard since the turn of the millennium, when I studied physical geography with you myself? And in general: in your opinion, is interest in water studies growing or declining over time compared to then?

Today, in addition to standard lectures on hydrography, hydrology and oceanography, we have other specialized subjects such as water management and protection, hydrological extremes and, for English-speaking students, a lecture on Flood Risk Management. Thanks to my many years of effort, and I am truly proud of it, we have managed to establish and accredit a completely new study programme, which is cross-sectionally covered by teachers from the ranks of hydrologists, geologists, ecologists, biologists, and chemists dealing with water. At the bachelor's level, it is Surface water and Groundwater, and at the master's level, Hydrology and Hydrogeology. Students will thus gain a comprehensive overview of the nature, use, quality, and protection of water, both surface and groundwater. No other university in the Czech Republic offers this, and I dare say that it has attracted a number of new students. We would like to compete better with technical fields focused on water, or agricultural fields.

Therefore, we try to work with the most modern technologies and devices; for mapping, we use a set of several drones of different sizes as well as total geodetic stations, flow trackers, and ADCP floats for measuring river flows, advanced GIS technologies. In Šumava we have had a number of stations measuring for over twenty years; we have meteorological stations at the source of the Amazon and in Kyrgyzstan. The South American one is at an altitude of 5,300 m above sea level, i.e. higher than the American station on Denali (Mt. McKinley). It sends the measured data every hour via satellite. We organize international field courses in physical geography in cooperation with the universities of Heidelberg and Milan. We have also prepared a master's degree programme, which students will complete at three universities (Heidelberg, Milan, Prague), receiving three diplomas. We are also waiting for stronger demographic years, so that we can afford a greater selection of students in the entrance exams. If, for example, every fourth student succeeds, we have a greater guarantee that students will want to stay in that field and geography is their priority. If we accept almost everyone, many of them drop out after the first year for various reasons. Regional universities also compete with us in that life in Prague is expensive for students and they can get a degree anywhere other than Prague. I would like future employers to ask, as is common in Western countries, not just whether an applicant graduated, but also from which university.

I am convinced that regional universities, and this is true in general, cannot provide the same professional level of education for those who really want to succeed in their field or scientific discipline. I say this with all seriousness as a member of the National Accreditation Authority. We currently have over forty small, regional private universities, which is probably a record for the number of inhabitants. It is good business, but the quality of teaching varies, including the demands of thesis writing, and students often do not have access to the latest research findings. Otherwise, I personally was lucky to always surround myself with people interested in science and a given field of study, who are not necessarily first-class students, but rather students who think objectively, logically, and geographically. These are people who work in the field with joy and enthusiasm, where they obtain valuable data in order to research and subsequently publish. Many of them then became my colleagues.

With a team of hydrologists, including myself as a PhD student, you have been researching lakes, river water quality, and bogs for a long time. What can be taken away from those years of continuous research as the most important insight into their functioning and importance for the Czech countryside?

I believe – and we are talking about soil, lakes, bogs and watercourses – that what we have here, i.e. water in the landscape – that we must not only protect but also multiply its reserves for the future. For example, on the Liboc stream, there is 1.5 to 1.6 times more evaporation than precipitation, the righthand streams of the Ohře regularly dry up in the summer, and the Rakovník, Žatec, and Podbořany districts are deeply passive in terms of balance. However, the solution may not necessarily be just the construction of new dams according to the General LAPV, although we will probably have no other choice in these passive areas in the future. As part of the project of the Technology Agency of the Czech Republic, my colleagues and I are working on the restoration of historical small water reservoirs in the headwaters of rivers, or even the possible restoration of ponds. However, I feel a lot of resistance from nature conservationists there, even though those reservoirs functioned well for more than a hundred years until the 1960s, fulfilling both a retention and an accumulation function. Both are important – one helps to solve the adverse consequences of floods, the other of droughts.

Fig. 2. Visiting the greenhouse of the Botanical Garden of the Faculty of Science of Charles University in Prague, the oldest continuously functioning botanical garden in the Czech Republic

Fig. 3. On the edge of the Colco canyon in the southern Peru, one of the deepest canyons of South America

For larger dams, it is difficult to make decisions based on the pros and cons. Where, in the long term, the positives outweigh the negatives, politicians (whom I certainly do not envy) have an easier time making decisions than in places where dams are not wanted in the long term. From a nationwide perspective, as climate change progresses, it will probably be necessary to build new reservoirs, especially the water management ones. However, we must not forget about the restoration of river ecosystems, construction of wetlands and pools, reduction of the speed of water runoff from the landscape through less soil compaction, improving its structure, and construction of anti-erosion measures in the landscape. We have known all this for a long time, but it is more difficult to implement this knowledge in reality.

As for the quality of river water, after the Velvet Revolution there was a significant improvement in the water quality in our streams from quality class IV–V to class II–III.; this was due to a decrease in fertilizer application and, in particular, the massive construction of municipal and industrial wastewater treatment plants with European money, often directly from Germany because two-thirds of our land drains into Germany. There has been a huge shift there. However, over the past ten years, the water quality has not improved, and even – especially in small streams in the countryside – has deteriorated due to the increase in water temperature. Therefore, it is necessary to convince the responsible ministries and municipalities to build sewerage and wastewater treatment plants even in the smallest municipalities with up to two thousand inhabitants. And despite the huge progress, I see a great debt as well as potential in this.

I would also like to mention the long-term project to monitor the stability of moraine dams in Kyrgyzstan. What is the situation there today and has the Kyrgyz side managed to follow up on our research?

First, there were two development cooperation projects. They concerned dangerous lakes located in front of melting glacier lobes. In cooperation with geologist Michal Černý from the Jihlava company Geomin and local Kyrgyz experts, we have been assessing the stability of moraine dams since 2005 as protection against flash floods during their potential outburst (GLOF phenomenon, "*Glacial Lake Outburst Flood*"). We flew by helicopter over individual mountain valleys and assessed the level of potential danger of glacial lake dams bursting. After identifying the least stable ones, we then conducted a detailed

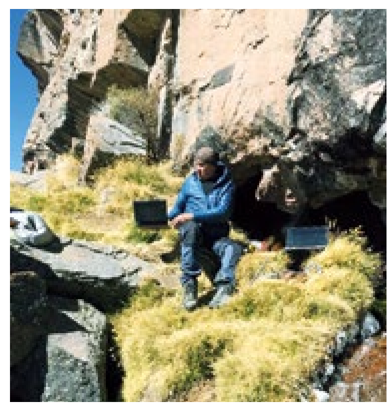

Fig. 4. At the Amazon's rock spring, one of the two sources of the Carhuasanta River below the top of Mismi in the Chila Mountains in the Peruvian Andes

Fig. 5. Installation of the climatological station in the source of the Amazon River in Peru (5,051 m above sea level), the second highest climatological station in South America

Fig. 6. Hydrological research in Ala Archa National Park in the Tyan-Shan Mountains in North Kyrgyzstan

field survey. In the capital city of Bishkek and on Lake Issyk-Kul, we participated in the organization of three international conferences on risk processes in high mountains with the participation of foreign experts and local politicians. Among the twelve dangerous lakes identified, we paid the most attention to Petrova Lake in southern Tian Shan. Using geophysical and geodetic methods, we investigated the stability of the dam and created a detailed bathymetric map of the lake, which reaches the area of our Rožmberk Pond. The importance of this research lies in the fact that it is located above the area of the major Kumtor gold mine. If it were to burst, the mine infrastructure would be destroyed and, in particular, the toxic tailings pond cyanides and heavy metals would be washed out. This would result in a huge ecological disaster on the Naryn River.

In recent years, we have left the country due to political instability and clashes between Uzbeks and Kyrgyz, but this year we would like to return to the country after twenty years since the beginning of the project and once again assess the stability of the Petrova Lake dam with numerous so-called thermokarst depressions and lakes, where the melting glacier is constantly bringing a mass of water into it and the lake volume is constantly increasing over time.

Unfortunately, the Czechs' very good reputation in Kyrgyzstan – and this was also true during the times of Czechoslovakia, when many Kyrgyz studied here – was ruined by the failed project to build dams and hydroelectric power plants on the Naryn River (a tributary of the Syr Darya); then, a company that had not built anything abroad or in the Czech Republic before that time was involved at the government level and won the construction tender. We probably all still remember that embarrassment in the media. We have several quality companies that, if they had participated in the tender at the time, could have made a billion-dollar business for the Czech Republic. At the same time, however, we were evaluated as the best Czech development project for many years of work in Kyrgyzstan and reducing natural risks. Subsequently, in 2012, another project was carried out under the patronage of NATO – it also has its own security research, finding water sources for the drying up Aral Sea. And that was really interesting, especially considering today's political situation. I received a recommendation directly from NATO headquarters in Brussels to include Russian scientists in the project, supposedly as part of the then rapprochement of the two armies. I remember that back in Bishkek, I witnessed a "friendship" between local Russian soldiers and soldiers from the American Manas base. And everyone got on very well back then...

I know that as the discoverer of the Amazon's sources, you are preparing a grand voyage for Netflix from its mouth to its sources. What exactly do you want to say or prove with this journey?

Brazilian director Yuri Sanada is preparing a series of films about the Amazon for Netflix, YouTube, and perhaps even Hollywood. He recently approached me asking if I would like to collaborate with him on a two-year expedition to produce films about the Amazon for these companies. In addition, he was excited to learn that we were celebrating a hundred years of diplomatic relations with South American countries and that our exhibition, organized to mark the twenty-fifth anniversary of the discovery of the sources of the Amazon, was travelling through Latin American countries and universities. In addition to Chile (two universities in Santiago) and Argentina (Buenos Aires, Mendoza), the exhibition will also stop at the Catholic University in Rio de Janeiro, where the rector is a Jesuit who knows the work of the Czech priest, missionary, and creator of the first map of the Amazon, Samuel Fritz, so it will all be somehow symbolically joined together.

After the exhibition opens at this university, I should also give a lecture at the University of Belém at the mouth of the Amazon, from where a boat, powered by solar panels, will set sail upstream of the Amazon following in the footsteps of Samuel Fritz. Incidentally, Jesuit missionaries, including those from the then province of Bohemia, left significant traces throughout Latin America. This is evidenced not only by church monuments, but also by the settlements they founded.

But back to the planned expedition. The ship should also be equipped with satellite navigation for precise measurement of the length of the Amazon, so that it can finally be decided whether it is longer than the Nile. And there are also the long-standing, now perhaps extinguished passions regarding the discovery of its sources; we narrowly overtook a twenty-member helicopter expedition financed by the National Geographic Society under the leadership of Andrzej Pietowski, who had been preparing the expedition for two years and had three million dollars for it. The Czechs managed it with seven people on horses, in tents, and with a budget of 300,000 CZK. And we still had some left (*laughs*). It was a special meeting in the valley of the Lloqueta River. When they learned from us what our expedition had done in the field and with the help of the most modern equipment, they decided to fill an entire issue of National Geographic magazine with articles and make a film about the source area. However, six months later, at a press conference in New York, they announced to the world that they had discovered the main source of the Amazon in the summer… Ten years had passed since I gave a lecture on the sources of the Amazon at the conference of the Association of American Geographers (AAG) in Washington. It was attended by several hundred geographers, as well as most of the participants in the National Geographic Society expedition to the sources of the Amazon in 2000. Professor Pietowski apologized to me in front of everyone and generously supported us publicly. So, an American happy ending!

Professor, do you have any other hydrological or geographical dreams and goals that you would like to achieve?

I would like to visit Baikal again, the places I went to decades ago, to meet people I knew, if they are still alive, and to write a new book about this unique lake. But that is not possible now – I cannot go to a country that continues the terrible war in Ukraine.

I have many memories of Baikal and Siberia, and they cannot be forgotten. Two hours north by jeep from Baikal, I experienced the most extreme cold in the Boday Bo gold mine, in the Lena River basin; it was 55 degrees Celsius below zero. I would not want to freeze like that again, but I would very much like to soak up the atmosphere of the old times. Hopefully, after finishing my memoirs called *Albertovské povídky* (*Albert's Stories*), I will still find time for that. And the second wish is to successfully complete the pilgrimage of our exhibition through South American countries, so that the discoveries of Czech geographers and Jesuit missionaries become more widely known to people, for example students or politicians and diplomats. It could help further research and perhaps even business in these beautiful countries. Last but not least, I would like to publish the long-awaited *Atlas of Czech Lakes*, which we have been talking about at our department for about twenty years. Hopefully I will see it happen.

Finally, let me ask a personal rather than a hydrological question. I know that you used to play football very well. Do you still play and do your children follow your steps in this respect?

The older son Martin played football for Sparta as a child, then switched to athletics, where he now competes very successfully in the hurdles for Dukla. Simultaneously, he has to focus on completing his studies at the University of Chemistry and Technology, where his thesis topic is natural stimulants from the Amazon, which he extracts in the laboratory from natural materials and samples sent from companies in Brazil. He then compares active ingredients, such as aphrodisiacs, obtained from natural products with synthetic ones, which are found in most commercial products, mainly due to price, and are not as effective. Latin America thus remains in the family. My younger son Adam played hockey for Vlašim and Sparta, and for a while he also played football for Vltavín Holešovice, before following his older brother's example and ending up in athletics and hurdles. He is also finishing his studies in German at the Na Pražačce secondary school, so he also has to work hard. And I – I support my club Sokol Mladotice, which now plays in the 1st B class and Viktoria Pilsen in the league. I started playing football in the district championship in Mladotice and experienced three promotions. On the pitch in Plasy I also met a well-known Sparta player, Vít Lavička, who is younger than me, so I may have taught him something of his art (*laughs*). Now I just ride my bike along the Vltava to the north and back along the other bank and I am proud that I can still ride those forty to fifty kilometres on a classic bike without the help of an electric motor. And once or twice a week I go swimming. I am happy about that and I hope that my health and strength will last!

Professor, thank you for taking the time to be interviewed for VTEI journal. It was a very pleasant conversation and reminiscing. We wish you a lot of success in your travels around the world and in your further scientific work!

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Prof. RNDr. Bohumír Janský, CSc.

Prof. RNDr. Bohumír Janský, CSc., was born on 30 July 1951 in Pilsen, and spent his youth in Mladotice in the northern Pilsen region. After graduating from secondary school in Plasy, he studied geography and biology at the Faculty of Science of Charles University. He lectures on physical geography, hydrology, limnology, oceanography, Latin American geography, and water management and protection at the Faculty of Science of Charles University. He has supervised 12 successful doctoral dissertations and more than 80 diploma theses. His research focuses on hydrography, hydrology, limnology, water protection, and natural hazard analysis. Since 1990 he has been involved in the Czech-German Magdeburg Seminars on Water Protection. Since the same year he has been engaged in research in the headwaters of the Amazon in Peru, where he led two Czech and one international expedition. Since 2005, he has led research teams at the Faculty of Science of Charles University within the Czech development cooperation projects in Kyrgyzstan, focused on research on glacial torrent lakes. From 2012 to 2014, he led an international team within a NATO project that dealt with the water management situation in post-Soviet Central Asia. He is an honorary member of the Czech and Slovak Geographical Societies. He received the Award of the Minister of the Environment of the Government of the Czech Republic for his lifelong contribution to environmental protection. In 2007, the President of Peru awarded him the highest state decoration "For Extraordinary Merit", with the right to use the title "Komtur", for his long-term pedagogical activity at Peruvian universities and for his research into the sources of the Amazon. He has given more than 60 lectures at foreign universities and international conferences.

Photo: J. Unucka

Jáchymov: following the mills

WEST BOHEMIAN SPA

West Bohemia is traditionally considered an area famous primarily for its spas. And for a good reason; the number of various mineral springs and gases and the variety of their chemical composition provide ideal conditions for balneology. The number of springs reaching several hundred makes this region completely unique on a European scale. By combining not only thermal waters, high-quality medical facilities and glorious promenades, but also beautiful countryside inviting for walks and a wide range of sports activities, West Bohemian spas encourage the patients' physical and mental healing.

The most famous of the West Bohemian spa towns are, of course, the classic trio of Karlovy Vary (*Fig. 1*), founded in the 14th century, Mariánské Lázně on the edge of Slavkov Forest, and the classicist Františkovy Lázně. Together with several other European spas, they were inscribed on the UNESCO World Heritage List under the title The Great Spa Towns of Europe. From their very beginnings, these three towns participated in the building and shaping of the Czech spa phenomenon, which then fundamentally influenced the history and social image of the surrounding European countries.

However, the list does not end with this famous triangle. In the vicinity there are, for example, the "climatic" Kynžvart spa or the newly reconstructed Kyselka spa. The Korunní spa, once famous for its mineral water, has unfortunately disappeared.

JÁCHYMOV

Jáchymov occupies a unique place in this spa area. This historic town near Karlovy Vary is located close to the border with Germany – the border crossing at Boží Dar is within a pleasant walking distance of seven kilometres. Although Jáchymov has always been part of the Kingdom of Bohemia, most of its cultural history is connected with the German population and many German names and inscriptions remain on houses, maps, and the local cemetery to this day. The founder of the city was Count Stephan Schlick (known in Czech as Štěpán Šlik) from the famous noble family of Schlick.

The great cultural and social flourishing of Jáchymov was related to the local "silver rush" in the 16th century, when the first Lutheran church in our country was built here – the Church of St. Joachim (*Fig. 2*). The famous parish priest Johannes Mathesius (1504–1565), a disciple of Martin Luther, with whom he studied in Nuremberg, worked there; at that time, Jáchymov was the second most populous town in the Kingdom of Bohemia. Its historic centre, consisting of a collection of Gothic-Renaissance patrician houses, is today an urban monument zone.

JÁCHYMOV STREAMS

Fig. 3 shows the newly renovated Astoria spa house; to its left is the Jáchymov Spa Visitor Information Centre, and to the far left is U Vodopádu restaurant, frequented by tourists; adjacent to the rock massif from behind, it offers unique natural nooks and crannies with many water features. The rivers and streams with numerous lakes, pools, and bridges are quite typical for Jáchymov and serve not only for walks by spa guests, but also significantly influence the local beneficial climate of the Ore Mountains foothills (*Fig. 4*).

Given that Jáchymov is currently a small town covering an area of about 51 km^2, where only about 2,400 permanent residents live, it might seem incredible that a total of four streams converge in such a small area. Moreover, it is said that our great-great…grandfathers from the times of the 2nd Military Mapping were confused by the German names of the local streams, so they simply labelled individual tributaries alphabetically (e.g. Weseritz A and Weseritz B) in the sense of "something flows here, but no one knows what it is called" and did not bother with it any further.

In any case, today we know that the main watercourse of Jáchymov is the Jáchymovský stream (*Fig. 5*) flowing throughout the town and often also under its surface. This is probably one of the main reasons why the spa park maintains a pleasantly humid climate even in the height of summer and its vegetation thrives so well (*Fig. 6*). In the spa centre, (1) Klínovecký stream flows into Jáchymovský stream; as is already clear from its name Klínovecký stream originates on the slopes of Klínovec and merges with the second local tributary, (2) Veseřice, roughly below the bottom cable car station. A tributary of the Klínovecký stream is (3) Stísněný stream, which rises in the bogs near Boží Dar. The last local stream is called (4) Suchá and flows into Jáchymovský stream in the Valley of Mills. Jáchymov stream, enhanced by all these tributaries, then continues through a picturesque valley to Ostrov, where it flows into the Bystřice river.

FOLLOWING THE MILLS

Jáchymov is nestled in the middle of forests, and thus invites to walks and trips. There are many walking trails, well-marked according to length and level of difficulty, so there is something for everybody. Of the more interesting ones, it is worth mentioning the local nature trail About Radon and the nature trail Jáchymov Hell. Their focus is certainly evident from their names (*Author's note: you can read more about radon treatment and Svornost mine in one of the next VTEI issues*).

VALLEY OF MILLS

There are two tourist trails that start directly in the spa centre of Jáchymov and lead through the beautiful valley of Jáchymovský stream, depending on the level of difficulty. The shorter and easier one is called the Valley of Mills (Údolí mlýnků) and leads from the entrance to the largest spa building, Radium Palace, towards the local sports centre with its tennis courts, and continues along a forest path for about one kilometre to the stream (*Fig. 7*). It is lined with about 60 hand-made mills of various ages, from top to bottom – some are wooden, others metal or plastic (*Fig. 8*). Sometimes the mills even depict specific local objects, such as the Chapel of St. Anne or the mining tower of Svornost mine.

Apart from the spa guests, the trail is especially popular with families with children. The sight of young parents taking hammers, screwdrivers, and other tools out of their backpacks to repair a broken mill or make a new one is typical here, and very refreshing.


Fig. 1. The Teplá river in Karlovy Vary; it flows into the Ohře by Ostrovský bridge

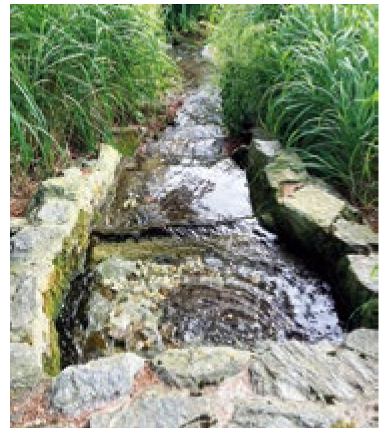
Fig. 5. Jáchymovský stream


Fig. 6. Spa park


Fig. 7. A forest path invites to relaxing activities


Fig. 2. Late Gothic Church of St. Joachim


Fig. 3. Jáchymov spa centre


Fig. 4. The spa park with a footbridge over the Jáchymovský stream

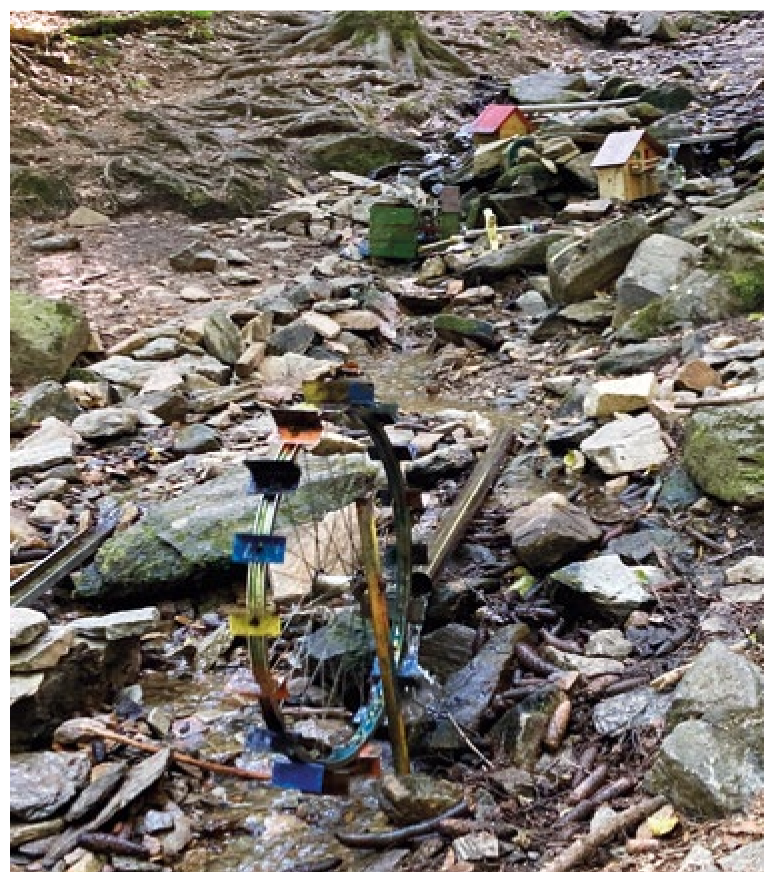
Fig. 8. The Walley of Mills is a Jáchymov rarity

Fig. 9. The Mill Trail offers beautiful forest nooks and views of the surrounding landscape

Fig. 10. The Bystřice river in Ostrov

MILL TRAIL

The second trail also starts at the tennis courts, but is more time consuming and physically demanding. It is called the Mill Trail (Mlýnská stezka, sometimes also Severin's Promenade; *Fig. 9*) and leads through the picturesque Mill Valley between Jáchymov and Ostrov (*Author's note: also known as Ostrov nad Ohří*). This area served as a manufacturing base for the town of Jáchymov from the time immemorial. The trail's name is related to the mill development along Jáchymovský stream. The first important period of this area was, as already mentioned, the 16th with its silver mining; the spread of water wheels significantly contributed to increasing the efficiency of various manufacturing processes, such as papermaking. The second glorious era came in the 19th century thanks to the rise of industry, the widespread use of electricity, and the invention of water turbines.

This romantic forest path, leading along a cascade of historical waterworks, used to have the German name Roseggerweg; it then almost fell into oblivion. It was only in the last hundred years, thanks to the development of spa tourism in the area, that the trail was revived. The modern projects "*Land of Living Waters I*" and "*Land of Living Waters II*", implemented by the civic association "Local Action Groups of the Ore Mountains West", also contributed significantly to this. Their main goal was to actively involve residents in the restoration of nature trails and all the water facilities – water wheels and mills, mineral springs, streams, wells – as part of rural development and the restoration of cultural and natural heritage, which would significantly increase the quality of the environment and the attractiveness of rural areas, and thus support the economic situation of this region.

The Mill Trail has become a very popular tourist route, with many resting places. These include Moučný Mill and Panský Mill (both on the site of today's Radium Palace Hotel), Maderův Mill, which, in addition to flour milling, also had the privilege of brewing beer, the Drainage Tunnel, which still drains water from Jáchymov mines, and Petterův/Petrův Mill, once the most productive of all the mills in the area. Its establishment dates back to 1532 and, in addition to traditional milling activities, it also housed a sawmill. It also had a beer brewing privilege. It is the oldest preserved water mill in the Czech Republic; the remains of its historical masonry and the mill drive can still be found in the forest. Other mills on the route included Horní Speknerův (originally an iron hammer mill, then a grain mill and later a sawmill; today the new owner is fighting to save it, having built a small hydroelectric power plant here), Trinksův Mill (also known as Upper Paper Mill), on whose site U Vlčků restaurant currently stands, and Blahův Mill (Lower Paper Mill), which operated until the mid-20th century. Nowadays, it serves as a guesthouse. The last mill on the right bank of Jáchymovský stream was Dolní Speknerův Mill, just before the village of Horní Žďár (*Author's note: now part of the town of Ostrov*). It originally served as an iron hammer mill, later as a grain mill. From 1919, it was used for electricity production. There are three more resting places before the very centre of Ostrov: the Farm, which used a water wheel to power the threshing machine, the U Václava Mill, which from 1901 also housed a bakery and U Václava Inn, and finally the U Semeráda Mill, also called the Flour Mill, because flour was ground here and traditional dark bread was baked.

OSTROV

The Mill Trail with all its resting places leads to Ostrov, a town just ten kilometres from Karlovy Vary. Ostrov is approximately the same size as Jáchymov, but has many times more inhabitants (around 16,000). It lies on the Bystřice river (*Fig. 10*), into which the Jáchymovský stream flows. The town settlement is documented from the beginning of the 13th century, when it was already a prosperous town. Today Ostrov offers many historical monuments, but also cultural, social, and sporting activities.

THE CHATEAU AND THE "EIGHTH WONDER OF THE WORLD"

Probably the most significant and interesting monument of Ostrov is the chateau (*Fig. 11*), built on the foundations of the original medieval castle. It is a large chateau complex consisting of several buildings and surrounded by an impressive garden (*Figs. 12, 13*). Its original form was shaped in the spirit of Mannerism, then Baroque and the High Baroque. Over time, the most important engineers, surveyors, and builders participated in its creation. Some of their plans are still available today in the exhibition in the chateau building. The chateau garden is crossed by the Bystřice river; from the very beginning, plans were primarily made for its use and distribution of its water throughout the complex (*Fig. 14*). Therefore, both parts of the garden were equipped with various water features – fountains and spouts, water bodies with sculptures, a maze, a garden theatre, ponds with swans, and an extensive system of canals, along which it was possible to float in boats. The chateau garden was therefore ever since the 17th century referred to as the "eighth wonder of the world", so it is no surprise that it became the model for many gardens of noble residences in Europe,

Fig. 11. The Ostrov chateau

Fig. 12. The chateau garden gate

Fig. 13. The chateau summer pavilion was originally surrounded by lakes with swans

for example in France, Italy, Austria, and the Netherlands. During its heyday, one of the owners of the estate was the aforementioned Count Stephan Schlick (Štěpán Šlik), founder of Jáchymov. However, after his death in 1526 in the battle against the Turks at Mohács, the wealthy Šlik family continued to operate here.

The Ostrov chateau is still the pride of the West Bohemian region, and its architecture and the freely accessible chateau garden with a beautiful park layout (*Fig. 15*), is a model of very successful maintenance and preservation of natural heritage in a town centre.

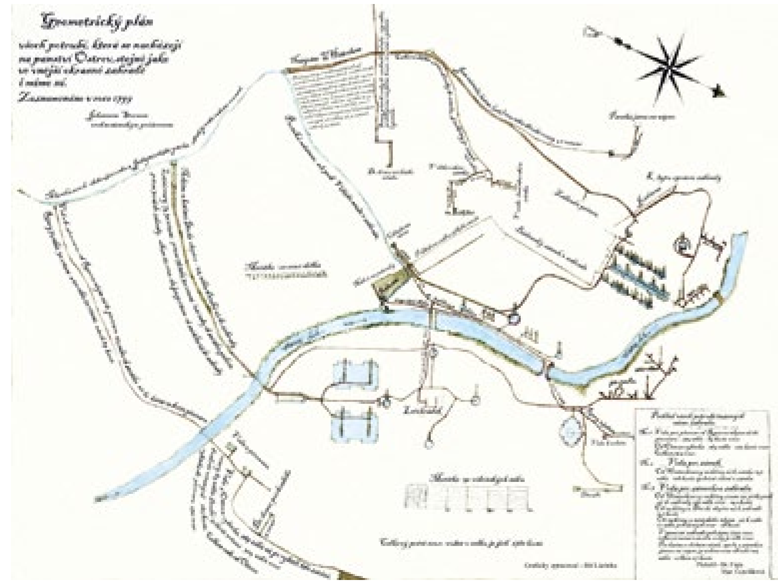

Fig. 14. One of the plans for water distribution in the chateau garden (1799)

Fig. 15. The chateau garden today (August 2024)
Photos pp. 50–53: Z. Řehořová

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Fig. 1. The regional round director Valérie Štylerová launches the 30th year of the Ecological Olympics in the TGM WRI cinema in Prague

Ecological Olympics

It has been 30 years since the first round of the Ecological Olympics competition took place. Over the past three decades, it has gradually spread from Wallachia to the entire country and has become a recognized competition, praised by many universities.

In the 1990s, when the competition was created, ecology and the related environmental protection were already discussed not only in professional circles, but also in the media, and this topic gradually became known to the general public. At that time, Mr. Vlastislav Huška, a professor at Nový Jičín grammar school, decided to organize the first round of a science competition, which he called the Ecological Olympics. Ecology was not yet a commonly taught subject then, so this competition became part of the promotion of education in the field of environmental protection.

Miroslav Janík, a member of the basic organization of the Czech Union for Nature Conservation (ČSOP Kosenka), who sat in the jury at the time, also participated in the organization of the first year. The competition enthused him so much that the following year, ČSOP Kosenka organized it in Valašské Klobouky. In the following years, there were several rounds until the Ecological Olympics gradually became a nationwide competition.

Since its first year, the Olympics has been unique in its team spirit. There are not many other knowledge competitions in which three-member teams compete. Another advantage is its direct connection with practice; in each round, students solve a real issue related to environmental protection in a given area, whether it is management of an orchid meadow (the first field task in Valašské Klobouky), or assessing the plan to expand a car park at Jizerka in the most exposed part of the Jizerské Mountains (task in the 21st national round). Students defend their proposed solutions in front of an expert jury, which also tests the competitors' skills in presenting their work.

Since its inception, the Ecological Olympics has also developed in the topics that it focuses on each year. In its early days, each regional and national round focused on its own topic, which was up-to-date in the location of the respective round of the Olympics. At present, every year, a single nationwide theme is announced, and each regional and national organizer adapts to it with their field practical task. This year's theme is Water in the Landscape and Adaptation to Climate Change. Thanks to this unification, students have the opportunity to better prepare for the competition. Since it is rarely a topic that they would find comprehensively presented in regular secondary school textbooks, we organize a summer camp for them every year, and publish a methodology focused on the current year's topic. A similar methodology is also created for organizers to help them navigate issues that may not be so familiar to them.

In addition to the practical field task, the competing teams also compare their knowledge in theoretical areas within a given topic, such as identifying natural objects or in a test. In some regional rounds, teams also have "homework" to bring to the competition, or they participate in a so-called mini-graduation exam, during which they discuss a topic with an expert jury. Most regional rounds last two to three days, so there is plenty of time for an accompanying programme, such as excursions, lectures, discussions, but also dance evenings or theatre performance prepared by the participants themselves. The of the regional round winners meet in the national round, which takes place for three to four days in June of the given school year, each time in a different region. Its programme is similar to that of the regional rounds.

This year's regional Prague round took place on 20–21st March 2025 and was hosted by TGM WRI in Prague. A total of 52 students participated. The winning

Fig. 2. The juror Ing. Jan Moravec with students

Fig. 3. Students in three-member teams solve the botanical part the "identification" task

Fig. 4. It included identifying the sounds of our birds and frogs

Fig. 5. On the second day of the competition, the students defended their field practical task…

Fig. 6. ... which was designing the restoration of the Únětický stream

Fig. 7. The three best teams of the Prague regional round; the winning team (in the middle) advance to the national round

team was from Gymnázium Jana Keplera consisting of students Naxerová, Hromas, Koucký, which received 128.5 points out of a possible 160. Second place was taken by the team of Arachne, z. s., with 116 points, and the "bronze" medal was taken by the second team of Arachne, z. s. with 111 points.

Over the years, the Ecological Olympics' popularity has grown, reaching a steady level of approximately 400 students taking part in it each school year. Information about the competition is also published annually in the Informative List of Competitions (formerly the Bulletin) published by the Ministry of Education, Youth and Sports. The high level of the competition expertise has also attracted the attention of many universities, which take Olympics participation into account for those interested in studying in the admissions procedure for related fields.

We are currently working towards organizing the Ecological Olympics at a school round level. Over the past few years, there have also been discussions about the possibility of expanding the competition to neighbouring countries and organizing an international competition.

This year, we will have four regional rounds and one national round, which will be organized in the Central Bohemian Region by ČSOP Vlašim.

The organizer of the Ecological Olympics is the Czech Union for Nature Conservation (ČSOP), the implementer is the SMOP ČSOP, and the co-announcer is the Ministry of Education, Youth and Sports.

Details can be found on the national website of the competition www.ekolympiada.cz, information directly related to the Prague regional round at: http://praha.ekolympiada.cz/

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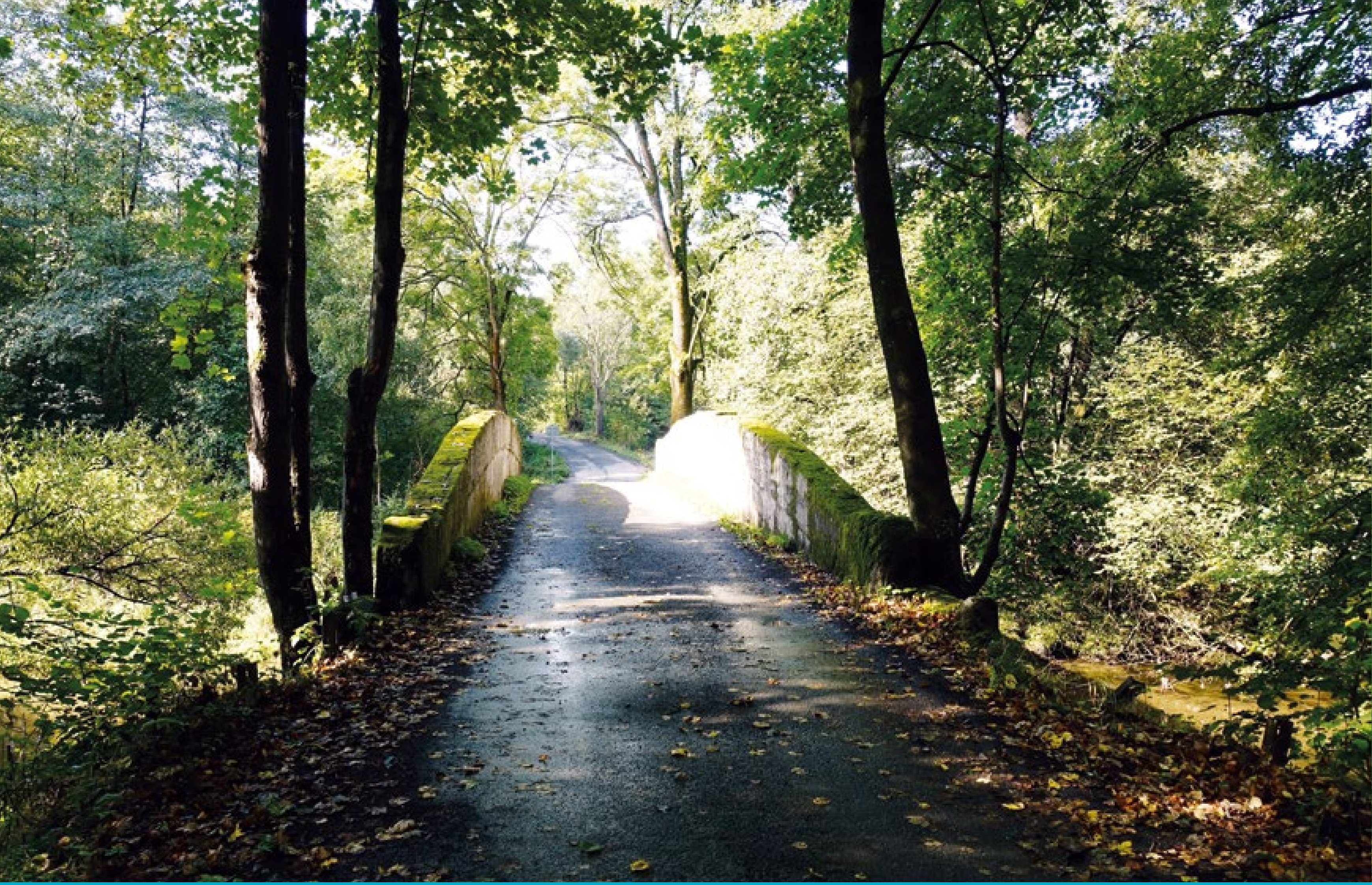

WHERE SPRING DOES NOT HASTE

While in April, spring has usually arrived in the lowlands and mid-altitude areas, it is usually taking its time in the mountains. It is no different in the Jeseníky Mountains, including the Nízký Jeseník Mountains. A specific area of this part of the mountain range in terms of natural conditions and the history is Libavá military district, which, with an area of 235 km^2, is located in the Oder Hills on the northern edge of the Olomouc Region and once extended into the Moravian-Silesian Region. There are many disappeared slate mines and villages, of which only ruins of buildings and uneven terrain and scree remain, such as Barnov, Jestřabí, Keprtovice, Ranošov, and Zigartice. The history of these and other villages can be found in Jiří Glonek's book *Zaniklé obce vojenského újezdu Libavá* (*Disappeared villages of Libavá military district*; 2007). In addition to the often turbulent history, many interesting natural and non-natural features can be found in the accessible places of this area. Wildlife is represented, for example, by the regular occurrence of golden eagle (*Aquila chrysaetos*) and white-tailed eagle (*Haliaeetus albicilla*), which also occurs in other parts of the Nízký Jeseník Mountains. And along with the ruins of villages, we can find the remains of water and hammer mills, along with the remains of flumes and reservoirs. We can mention Novooldřůvský (Madrův) or Barnovský mill, which stood near the preserved Barnovský bridge (see photo). And from the hydrological point of view, one of the most important European rivers – the Odra/Oder – originates here.

This captivating landscape inspired a team of authors from the Czech Hydrometeorological Institute to write the book *O krajině a přírodě Červené hory a okolí* (*On the landscape and nature of Červená hora and surrounding areas*; 2022). It can be downloaded at the following address: https://www.chmi.cz/files/portal/docs/reditel/SIS/nakladatelstvi/assets/cervena.pdf

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