VODOHOSPODÁŘSKÉ TECHNICKO-EKONOMICKÉ INFORMACE

(WATER MANAGEMENT TECHNICAL AND ECONOMIC INFORMATION)

VTEI/2023/3

Sixty years ago in VTEI

In its first editions, the VTEI journal also described improvement proposals and inventions.

As we can read in period documents, between 1958 and 1959, the staff department of the First Deputy Minister for Water Management expanded important improvement proposals and inventions through a special collection. The collection was made available to all water management organizations according to their field of expertise, with the obligation to make these materials available to all interested parties, improvers, inventors, innovators, etc.

On 1st December 1958, the staff department of the First Deputy Minister for Water Management issued a list of topics for inventors, improvers, and innovators for 1959. The list contained 14 of the most serious water management issues, with a deadline of 30th June 1959 for their submission. By this deadline, 116 proposals had been received. The archives further state that "all proposals will be discussed and field trials conducted as necessary."

Below is a short list of some improvement proposals for the assigned topics:

- adjusting *steel needles against their opening and against damage to the wooden beams at their bases;*
- *dimensioning of reinforced concrete structures for safety against cracks;*
- *improvement of work procedure in examination of concrete of dam bodies by dynamic ultrasound method;*
- *the use of germanium baffles for electric braking of hydro alternators;*
- *prefabricated valve chambers;*
- *prefabricated* biological filter, etc.

From the TGM WRI archive.

VTEI Editorial office

Photo: Tomáš Hrdinka

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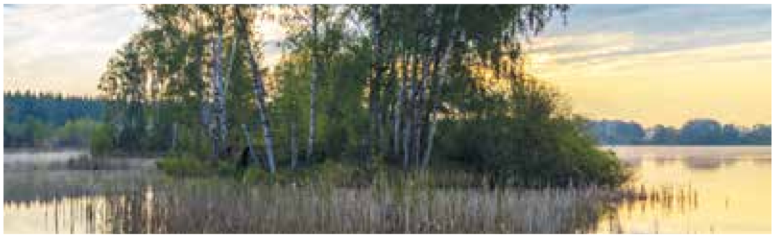

Photo: 123rf.com

Dear readers,

It is with great pleasure that we bring you the June issue of our VTEI journal. This month, we have prepared eight interesting articles for you, which focus on various aspects of water management and ecology of aquatic ecosystems.

In the expert part, we will deal with the development of ponds in the Polabí landscape in Pardubice region, which can show the way forward for other areas with similar natural conditions. Another very interesting article is focused on the issue of juvenile fish community as a suitable tool for monitoring ecological status, which will bring new knowledge about the state of aquatic ecosystems and their protection. Other articles in the expert part cover current trends in water pollution, as well as factors affecting the cost of drinking water production.

The second half of the articles is of an informative nature and will offer readers various points of interest in the field of water management, including the exhibition *"Technical Heritage of the Elbe-Vltava Waterway"*, and an article on getting familiar with artificial intelligence. We also have an interview with Mgr. Petr Hladík, the current Minister of the Environment, who will show our readers his point of view on water management.

In this issue, we will also find some information we wrote about in VTEI 60 years ago; this time we will look at several improvement proposals and inventions from our field from the 1960s.

Overall, you can look forward to a very varied and interesting issue about water management and the ecology of aquatic ecosystems. We believe that our June VTEI will bring you a lot of new knowledge and inspiration and that you will continue reading it. Have a good read!

VTEI Editorial office

Assessment of trends in concentrations of chemical and physico-chemical indicators of the status of surface water bodies

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Keywords: chemical and physico-chemical indicators — surface water — assessment of trends — Water Framework Directive

ABSTRACT

This article presents the results of trend assessment of selected chemical and physicochemical indicators of surface water status. The assessment approach is based on a similar procedure for assessing significant upward trends of pollutants and trend reversals in groundwater bodies. The procedure is based on measured concentrations from 2010 to 2018 and estimates concentrations at the end of 2021, 2024, and 2027. For the trend assessment, data from Czech river basin state enterprises were used to assess the ecological status/potential and the chemical status of surface water bodies. However, only part of the profiles with measured concentrations met the time series requirements. The assessment of trends towards the end of 2024 and 2027 shows that some indicators (polyaromatic hydrocarbons, adsorbable organically bound halogens – AOX, and nitrate nitrogen) are projected to improve compared to the status as of 2018. On the other hand, a slight deterioration is predicted for biochemical oxygen demand, dissolved nickel, and ammonia nitrogen.

INTRODUCTION

For groundwater, an assessment of pollutant trends [1] is required when assessing chemical status, so that cases where the pollutant still meets the limit of good status, although its concentration rises significantly, can be detected in time. However, in the case of surface waters, no method has yet been established in the Czech Republic that would indicate in advance the imminent deterioration of ecological or chemical status of surface waters. For this reason, a procedure for assessing trends in surface water pollutant concentrations was developed. It is based on the methodology for assessing significant upward trends in groundwater pollution concentrations, which was already used in the second cycle of plans and which is based on the recommendations of the Groundwater group for the joint implementation of the Water Framework Directive [2]. Since there are a large number of profiles and indicators, it was necessary to use a relatively simple statistical procedure and create a program that would make the work more efficient and enable the assessment of a large amount of data.

Statistical methods were used as the basic tool – a linear trend using linear regression and a "two-section" model, which makes it possible to statistically detect any break in the trend. By extending the trend, predicted pollutant concentrations were calculated in three time periods – three, six, and nine years from the end of the measured concentrations [3].

For this methodological procedure, to assess long-term trends, individual measured concentrations were used of selected indicators found within the implementation of surface water surveillance and operational monitoring at monitoring sites representative for the assessment of the status/potential of surface water bodies. The results of the trend assessment are therefore related to a specific given indicator and monitoring site (profile).

METHODOLOGY AND DATA USED

For the trend assessment, a time series of data from the monitoring of the assessment of status of surface water bodies from 2010 to 2018 was used, according to documents provided by the river basin state enterprises for the status assessment. Based on the methodology (above), the most relevant indicators were first determined, and then the profiles that meet the conditions which are listed below. Data from selected profiles and indicators were then modified and assessed by software for trend assessment prepared by TGM WRI. The results of the status assessment for selected indicators were also used. Assessment of surface water status is carried out every three-year period (the last one was for 2016–2018).

Selection of indicators, time series requirements and data modification

Selection of indicators and surface water monitoring sites was determined by the results of ecological and chemical status assessment primarily for the last three-year period and time series from 2010 to the end of 2018.

Criteria for general selection of indicators for which the long-term trend of concentrations in water matrix should be analysed were as follows:

- it is a chemical or physico-chemical indicator for assessment of chemical status or ecological status/potential of surface water bodies;
- for the indicator, the environmental quality standard (EQS) or the limit between good and medium ecological status/potential is determined by a characteristic value expressed as an average or median [4–6] and, at the same time, these are not given by a range of values (i.e., indicators are not assessed where the characteristic value is maximum and/or minimum);
- the indicator is not subject to decay or transformation into other substances over time;

- the indicator is not expressed as the sum of several substances with different limits of quantification;
- the indicator is monitored annually within the Czech Republic in a water matrix at a minimum of 5 % of representative monitoring sites for assessing status/potential of surface water bodies;
- for most years, the indicator has a lower amount of data, below the limit of quantification of 75 % within monitoring throughout the Czech Republic;
- the indicator comes out as non-compliant in more than five surface water bodies in the latest three status/potential assessments in the Czech Republic;
- the concentration of the indicator is demonstrably increased anthropogenically, and measures can be proposed to reduce it.

Based on these criteria, 15 indicators were selected for assessment *(Tab. 1)*.

Tab. 1. Summary of assessed quality indicators

Quality indicator	**Quality indicator title**
AOX	adsorbable organically bound halogens
As	arsenic
B-A-ANTHRACENE	benzo[a]anthracene
B-A-PYRENE	benzo[a]pyrene
BOD-5	biochemical oxygen demand in 5 days
C10-C40	C10-C40 hydrocarbons
EDTA	ethylenediaminetetraacetic acid
PHENANTHRENE	phenanthrene
FLUORANTHENE	fluoranthene
NI-R	nickel and its compounds – dissolved
N-NH4	ammonium nitrogen
N-NO3	nitrogen nitrate
P-PO4	phosphorus phosphate
P-V	total phosphorus
PYRENE	pyrene

As part of testing, some indicators were excluded that met the requirements, but which, for various reasons, were not relevant for assessing the trend – manganese, iron (anthropogenic origin of increased concentrations cannot be proven), water temperature and transparency (these are not pollution indicators, but other indicators). Pesticides and their metabolites were also excluded, as well as indicators that are part of the total sum of a given group of chemical indicators, including their decay and reaction products or metabolites (e.g., trichlorobenzenes).

Since there is a requirement for nickel in the chemical status assessment to be considered as dissolved, all measurements were also excluded where total nickel was analysed, which, for the status assessment needs, was subsequently recalculated using a derived constant.

When selecting profiles, the following requirements were made within the time series:

- the minimum length of a continuous time series had to be six years, with the last year having to be 2018;
- in each year there had to be at least six measurements for general physico-chemical indicators and priority substances, and at least four measurements for specific pollutants;
- of these minimum six or four measurements, at least 50 % had to be above the limit of quantification each year;
- if the maximum limit of quantification value for an indicator and a profile was greater than twice the minimum limit of quantification value, this profile and indicator were excluded from the trend assessment.

The final stage of data preparation was the replacement of results below the limit of quantification. If the limits of quantification were the same for the profile and indicator for the entire period, they were replaced by half the value; in the case of different limits, they were replaced by half the value of the smallest limit of quantification for the profile and indicator.

It is obvious that in the case of such strict requirements for time series, a significant part of the measurements had to be excluded. The most profiles to be excluded were for C10-C40 hydrocarbons, nickel, and arsenic. In contrast, the most profiles which remained were for phenanthrene, nitrate nitrogen, fluoranthene, adsorbable organically bound halogens (AOX) and ethylenediaminetetraacetic acid (EDTA) – around 80 % of all monitored profiles in the last three years.

Trend calculation, software used

The trend assessment procedure is based on two calculation methods.

The first procedure is the use of a linear trend with the help of linear regression consisting of approximation of the measured data with a straight line. For a simple linear regression of the model, the slope and the constant indicating the displacement on the y axis must be calculated for the basic equation of the line in the general form y = a x + b. In this case, the indicator concentration in a water matrix is dependent on time. The least squares method is used to estimate the slope and the constant.

$$a = \frac{n\,\Sigma x_i\,y_i - \Sigma x_i\,\Sigma y_i}{n\,\Sigma x_i^2 - (\Sigma x_i)^2}$$

$$b = \frac{\Sigma x_i^2\,\Sigma y_i - \Sigma x_i\,\Sigma x_i y_i}{n\,\Sigma x_i^2 - (\Sigma x_i)^2}$$

where	a	is slope of the straight line
	b	constant
	x_i	date of the measurement
	y_i	pollutant concentration
	n	number of measurements

From the derived equation of the straight line, based on data from the time series 2010–2018, a prediction of the indicator concentration is calculated after three, six, and nine years from the end of the measurement. Therefore, in the case of these trends, the prediction is at the end of 2021, 2024, and 2027.

The second method assumes that the trend may have changed over a longer period of measurement. The basic principle – linear regression – remains the same; however, the program finds one breaking point where the line of the first linear regression transitions at a common point to the second linear regression. As with simple linear regression, the optimal breaking point is found using the method of least squares for the entire analysed time series of measurements, i.e., the variant with the smallest deviations of the measured concentrations from both linear regression lines is used. As a result of this two-section model, the course of the measured concentrations thus has two straight lines with different slope and shift constant. Here, based on the second straight line, the expected concentration in three, six, and nine years is also calculated. Subsequently, the result of the simple linear regression is compared with the two-section model using the F-test (which again uses the results of the least squares method to assess the deviations of the measured concentrations from the interleaved lines of both the simple linear regression and the two-section model in order to refute or confirm the null hypothesis that in the given period of time there is no breaking point) and the model that demonstrates greater reliability is selected.

When calculating trends, there is an option to exclude outliers or extremes, but this was not used (see below).

To assess trends and calculate statistical characteristics, the "lim" application was used, or more precisely, its current version lim38 (TGM WRI, January 2023). It is a continuously developed, modified, and modernized application implemented in the Microsoft Office environment. The application uses the Microsoft Excel environment (version 2016) and was implemented using the integrated programming language VBA (Visual Basic for Applications). The application loads the data entered in the form of a time series of the quality indicator values in the specified profiles *(Fig. 1)*. For each profile and indicator, a trend is assessed (alternatively as a linear one-section and two-section model) and the basic statistical characteristics of the original time series and the assessed trend are calculated and recorded. The application also enables the automatic generation of graphs displaying interleaved trend curves. The resulting data are written both for each profile/indicator separately (in the format of separate notebooks/xlsx files) and also in the form of a summary table used for their further processing and assessment *(Tab. 2)*. A result sheet is also generated for all profiles and indicators entering the data processing and trend calculation process.

Tab. 2. Characteristic values calculated by lim38 software

Last measured value	0.059
Lower confidence limit (20 %)	0.018
Upper confidence limit (80 %)	0.084
Slope of the straight line (trend)	0.000002
Line displacement constant	-0.023
The breaking point of the two-section model	7. 9. 2011
Slope of the straight line 1 of the two-section model	0.000056
Slope of the straight line 2 of the two-section model	-0.000004
Number of straight line 1 measurements of the two-section model	21
Number of straight line 2 measurements of the two-section model	85
Line 1 displacement constant of the two-section model	-2.18
Line 2 displacement constant of the two-section model	0.22
Total number of measurements	105
First measurement	13. 1. 2010
Last measurement	10. 12. 2018
Minimum	0.01
Maximum	0.15
Average	0.048
Median	0.041
Year with minimum occurrence	2010
Year with maximum occurrence	2011
Standard deviation	0.025
Number of values under the limit of quantification	6
Used limit of quantification	0.01
Number of years (from/to) 2010 to 2018	9
Linear versus two-section model (F-test)	a two-section model is more suitable than a linear one

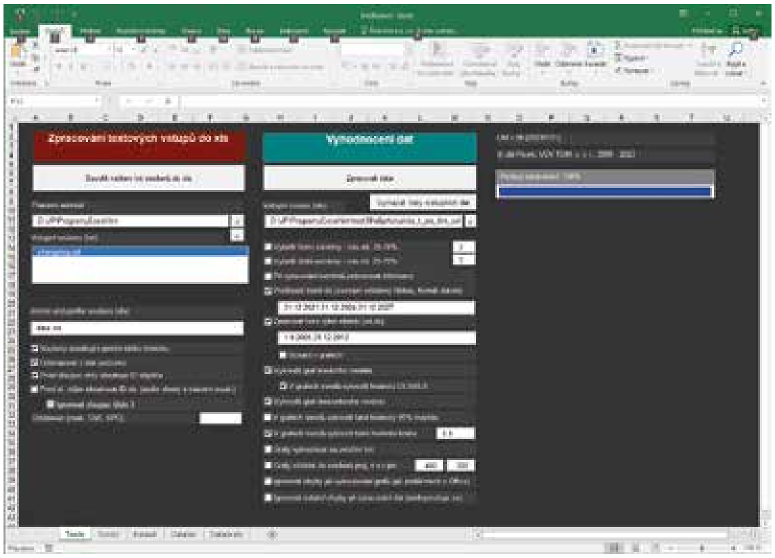

Fig. 1. Example of the lim user interface; the extent and method of data processing can be adjusted by selecting the appropriate options in the main application window

PROCESSING RESULTS

The results of the latest, currently implemented assessment of the ecological and chemical status and the limit of good status (in this case, for the three-year period 2016–2018) are added to the result sheet with the results of the calculation of trends and predicted values, which contain both a linear and a two-section trend.

According to the selected model, corresponding values predicted for the end of 2021, 2024, and 2027 are then assigned to each assessed object and indicator. The predicted value is obtained by extending the trend – in the case of a two-section trend model, the second line. These are then compared with the value of the limit between good and non-compliant chemical status for the given indicator and receptor. It is assessed only with limits expressed as a median (for general physico-chemical indicators) or a mean (for priority and specific pollutants). If the maximum is also used as a limit (which applies to nitrate nitrogen for the selected indicators), the comparison is not carried out. In the case of priority and specific pollutants, the status assessment is carried out for each year separately and the worst result is used [4]; for general physico-chemical indicators, the entire three-year period is assessed together [4].

For each profile and indicator, we thus know the assessment result for the three-year period 2016–2018 (i.e., compliant or non-compliant) – which we can understand as the present – and, depending on the limit of good status, the result for the end of 2021, 2024, and 2027.

Examples of the selected profile assessment are given below.

Ammonia nitrogen on the Loučná – Tržek profile *(Fig. 2)* was assessed as non-compliant in the past three-year period – the limit of good status is 0.1 mg/l. According to the trend assessment, both the linear and the two-section trends are decreasing; however, according to the two-section trend, the decreasing trend has been significantly faster since May 2015. Accordingly, the ammonia nitrogen content could already be in good status at the end of 2021. At the same time, according to the F-test, the two-section model is more reliable.

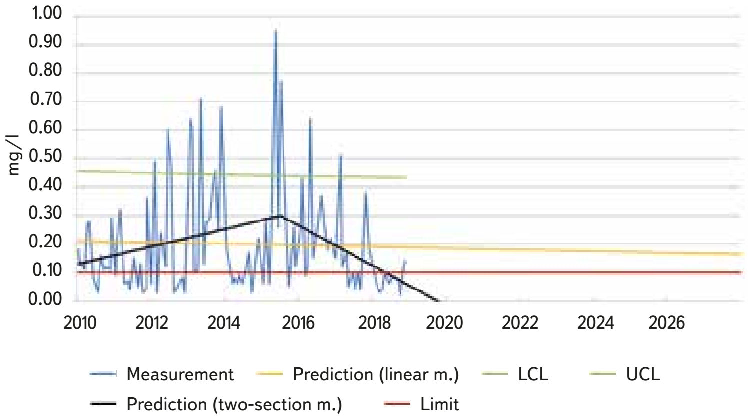

Fig. 2. Calculation of ammonia nitrogen trend in monitoring the Tržek profile, Loučná river
UCL: Upper confidence limit (80 %), LCL: Lower confidence limit (20 %)
Limit: The boundary between good and medium status or environmental quality standard

Data source: Povodí Labe, State Enterprise

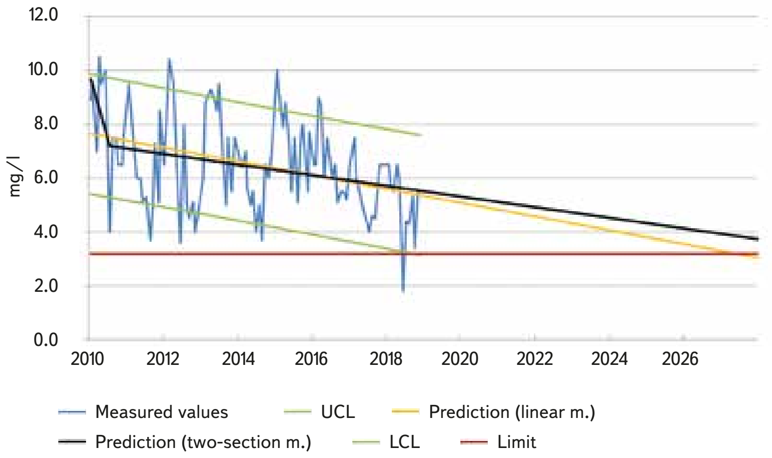

Fig. 3. Calculation of nitrate nitrogen trend in monitoring the Tržek profile, Loučná river
UCL: Upper confidence limit (80 %), LCL: Lower confidence limit (20 %)
Limit: The boundary between good and medium status or environmental quality standard

Data source: Povodí Labe, State Enterprise

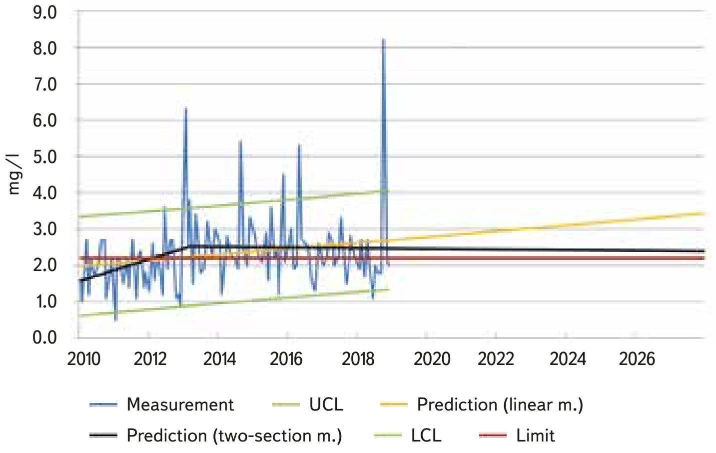

Fig. 4. Calculation of BOD_5 trend in monitoring the Tržek profile, Loučná river for all measurements
UCL: Upper confidence limit (80 %), LCL: Lower confidence limit (20 %)
Limit: The boundary between good and medium status or environmental quality standard

Data source: Povodí Labe, State Enterprise

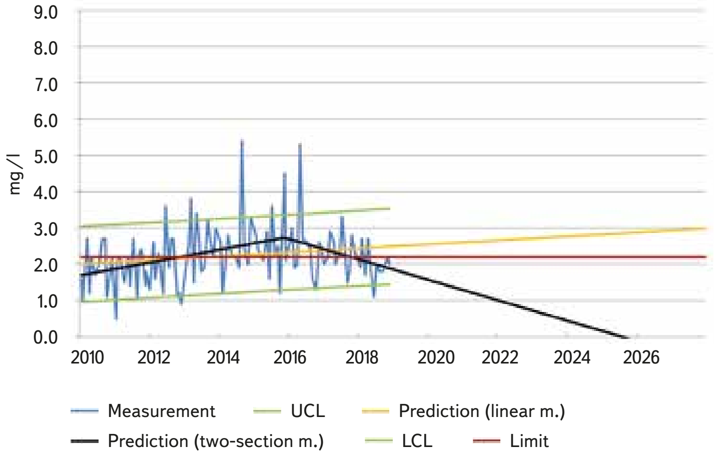

Fig. 5. Calculation of BOD_5 trend in monitoring the Tržek profile, Loučná river; measurements without outliers
UCL: Upper confidence limit (80 %), LCL: Lower confidence limit (20 %)
Limit: The boundary between good and medium status or environmental quality standard

Data source: Povodí Labe, State Enterprise

Nitrate nitrogen was also assessed in the same profile *(Fig. 3)*. It was also classified as non-compliant for the three-year period 2016–2018; the limit of good status is 3.2 mg/l. In this case, the results of the linear and two-section models are comparable, the concentrations decrease similarly, and good status should be reached around 2027. Since the linear model came out as more reliable, if this trend continues, good status will be reached just before the end of 2027.

When processing trends, the exclusion of outliers and extremes was considered, since mainly occasional high values significantly affect the final assessment. This is typical for the course of a time series of biochemical oxygen demand (BOD). The software allows these outliers to be excluded. Again, trends for BOD_5 were calculated on the Loučná – Tržek profile, both for all values and with the exclusion of extremes (defined as three times the 25–75 % interval); see *Figs. 4* and 5. BOD_5 was non-compliant in the ecological status assessment; the limit of good status is 2.2 mg/l. There are a total of four measurements above 5 mg/l in the time series, with the two highest values excluded when discarding outliers. While maintaining all values, a linear trend, which is rising, was assessed as more reliable; after removing outliers, a two-section model was recommended, where a significant break occurs in December 2015 and the trend is decreasing. The time data of the breaking point is also different for both variants – when maintaining all values, it is much earlier – in April 2013, and after that date the trend is also decreasing, but the decline is much slower.

RESULTS AND DISCUSSION

Based on the results of the trend assessment, a table of individual indicators was prepared for all assessed profiles together, where there is always a proportion of compliant and non-compliant profiles based on the latest status assessment (i.e., as of 2018) and then the same proportions at the end of 2024 and 2027 (*Tabs. 3* and *4*). The prediction was also prepared for the end of 2021 but it was not used due to the fact that the preparation of the status assessment for the three-year period 2019–2021 is currently underway. Nevertheless, it will be interesting to compare the results of this assessment with the calculated trends.

The table shows the proportion of compliant and non-compliant profiles for 2018 which, however, does not correspond to the results for the entire Czech Republic. The main reason is that these are only profiles that have met the requirements for the length and completeness of the time series and for the proportion of measurements below the limit of quantification. Also, neither the limit of good status, set as a maximum (which is the case for nitrate nitrogen), nor the results of a matrix other than water (assessment of benzo[a]pyrene in fingerling) are taken into account here. However, most of the differences are below 10 %. More significant differences are for EDTA, phenanthrene, fluoranthene, and pyrene, where the situation is more favourable in all profiles (e.g., fluoranthene is non-compliant in all profiles only for 54.7 %, while in selected profiles 89.7 %), and for nitrogen nitrate, where, on the other hand, there are non-compliant profiles in all profiles and, taking into account the maximum values, 49.7 % (only 39.5 % for selected profiles).

Based on these statistics, it can be stated that, according to predictions, a significant improvement should occur for AOX, benzo[a]pyrene, fluoranthene and pyrene, and a slight improvement is expected for phenanthrene and nitrogen nitrate. In contrast, for BOD_5, nickel and ammonium nitrogen, the model found a slight deterioration. For the other indicators, the results in subsequent years are practically the same; from the reliability point of view, differences of up to 5 % are negligible. However, it should be noted here that the model can only work with a linear trend, possibly with a single breaking point, and the concentrations of pollutants in surface waters show significant fluctuations. For BOD_5 (and possibly for some other indicators as well), the result is strongly influenced by occasional significantly increased values, which can worsen the results of the trends, as was seen in the example of the Loučná – Tržek profile. When deciding whether to keep the original results or use only measurements without outliers, we took into account two factors: firstly, that these are not measurement errors, but actual measured values that will probably be repeated in the future; secondly, the fact that that the assessment for this indicator is carried out by comparing the limit, which is set as the median, so outliers will not be reflected in it. In the end, an assessment with all values was used, but with the knowledge that it is probably a worse result than what will be reflected in the status assessment.

Tab. 3. Environmental quality standards (NEK) and good status boundaries for the indicators assessed

	Units	**EQS (average)**	**EQS (maximum)**	**Good status boundary (median)**	**Good status boundary (maximum)**
AOX	µg/l	25	–	–	–
arsenic	µg/l	11	–	–	–
benzo[a] anthracene	µg/l	0.03	–	–	–
benzo[a]pyrene	µg/l	0.00017	0.27	–	–
biochemical oxygen demand	mg/l	–	–	1.5–3	–
C10-C40 hydrocarbons	mg/l	0.1	–	–	–
EDTA	µg/l	5	–	–	–
phenanthrene	µg/l	0.03	–	–	–
fluoranthene	µg/l	0.0063	0.12	–	–
nickel	µg/l	4	34	–	–
ammonia nitrogen	mg/l	–	–	0.08–0.15	–
nitrogen nitrate	mg/l	–	–	1–3.8	1.4–5.6
phosphorus phosphate	mg/l	–	–	0.02–0.05	–
total phosphorus	mg/l	–	–	0.03–0.07	–
pyrene	µg/l	0.024	–	–	–

Tab. 4. Proportions of compliant and non-compliant profiles at present (2018) and at the end of 2024 and 2027
Zdroj dat: státní podniky Povodí

		2018		2024		2027		
	Total number of profiles	**Compliant profiles**	**Non-compliant**	**Compliant profiles**	**Non-compliant**	**Compliant profiles**	**Non-compliant**	**Trend**
AOX	245	60.80 %	39.20 %	83.30 %	16.70 %	84.10 %	15.90 %	improvement
arsenic	159	95.60 %	4.40 %	94.30 %	5.70 %	95.00 %	5.00 %	stable
benzo[a]anthracene	99	96.00 %	4.00 %	96.00 %	4.00 %	94.90 %	5.10 %	stable
benzo[a]pyrene	92	0.00 %	100.00 %	27.20 %	72.80 %	38.00 %	62.00 %	improvement
biochemical oxygen demand	596	55.50 %	44.50 %	47.50 %	52.50 %	48.00 %	52.00 %	slight deterioration
C10-C40 hydrocarbons	30	93.30 %	6.70 %	93.30 %	6.70 %	90.00 %	10.00 %	stable
EDTA	64	45.30 %	54.70 %	50.00 %	50.00 %	50.00 %	50.00 %	stable
phenanthrene	151	82.10 %	17.90 %	96.00 %	4.00 %	96.00 %	4.00 %	slight improvement
fluoranthene	146	10.30 %	89.70 %	55.50 %	44.50 %	58.20 %	41.80 %	improvement
nickel	37	100.00 %	0.00 %	83.80 %	16.20 %	81.10 %	18.90 %	slight deterioration
ammonium nitrogen	542	60.50 %	39.50 %	45.20 %	54.80 %	47.20 %	52.80 %	slight deterioration
nitrogen nitrate	612	67.50 %	32.50 %	75.50 %	24.50 %	77.80 %	22.20 %	slight improvement
phosphorus phosphate	340	32.90 %	67.10 %	35.00 %	65.00 %	35.90 %	64.10 %	stable
total phosphorus	649	15.40 %	84.60 %	14.50 %	85.50 %	15.40 %	84.60 %	stable
pyrene	137	67.90 %	32.10 %	86.10 %	13.90 %	86.10 %	13.90 %	improvement

CONCLUSION

The trend results show that there is an improvement or at least a steady status for the assessed polyaromatic hydrocarbons. However, these predictions may be overtaken by proposed changes at the European level in the assessment of fluoranthene, where the limit is to be significantly tightened, while the limit for benzo[a]pyrene is to be abolished (so this indicator would not be assessed at all). Improvement is also predicted for adsorbable organically bound halogens and nitrate nitrogen. In contrast, a slight deterioration was indicated for BOD_5, nickel and ammonium nitrogen; however, for BOD_5 the deterioration will probably not be reflected in the status assessment, and for nitrate nitrogen it can be assumed that, due to the large increase in the price of industrial fertilizers, the situation will probably improve. The reasons why concentrations should deteriorate for dissolved nickel are not clear, but a stricter environmental quality value has been proposed for it as well.

The weaknesses of this assessment were shown here, as the actual course of the measured concentrations can rarely be sufficiently expressed by a linear or two-section model. The results also show that the statistical assessment of pollutant trends is not a suitable method for individual profiles. In addition to the limitations resulting from linear trends, only a small part of the profiles will meet the requirements for the length of the time series and the number of measurements for most indicators. Therefore, the results cannot be used to identify profiles that currently meet the limit of good status, but are in danger of deteriorating soon. It can be assumed that they are more useful for determining the overall tendencies of individual indicators; however, again only on the assumption that the conditions will not change significantly – be it hydrological or the level of anthropogenic influences. Nevertheless, the trend assessment should be supplemented by other types of analysis: for example, by comparing predicted and actual results of status assessment, the proportion of non-compliant measurements in individual three-year periods, or by comparing three-year averages.

Acknowledgements

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Juvenile fish assemblages – appropriate tool for monitoring of the ecological status

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Keywords: biomonitoring – juvenile fish assemblages – ecological status – water temperature

ABSTRACT

Aquatic organisms have a very good ability to reflect the conditions of the environment they live in and, therefore, they are often used to assess the ecological status of that particular environment. of juvenile fish assemblages (0+) represent an appropriate tool for monitoring the ecological status of watercourses as they show a very rapid response to changes in environmental conditions. The goal of this study was to assess assemblages of juvenile fish (0+) at 22 sites across the Czech Republic between 2019 and 2021. Electrofishing gear (battery – backpack unit) was used to sample the juvenile fish assemblages in shallow parts of rivers along riverbanks. The juvenile fish assemblages (0+) were relatively diverse; overall, a total of 36 species were found, with a minimum of four and a maximum of 15 species per site (average of nine species per site). Significant differences were observed in the assemblages of juvenile fish (0+) across the different sites and during the various years. The ecological status was assessed using the Czech multi-metric index (CZI). Significant differences in ecological status were observed – four sites showed a significant degradation of the ecological status, while four sites showed an improvement. The rest of the sites represented a stable ecological status (there was no significant improvement or degradation). Sites that showed the best ecological status, where juvenile fish assemblages corresponded to the natural character of rivers, were Orlice in Nepasice (Hradec Králové region) and Olše in Věřňovice (Moravian-Silesian region). In contrast, the lowest CZI values were detected at Ohře – Želina (Ústí nad Labem region), Dyje – Podhradí n. Dyjí, Dyje – Jevišovka (South Moravian region), and Cidlina – Sány (Central Bohemian region), suggesting a degraded ecological status. It was found that the degradation of the ecological status was caused neither by a significant change in suitable habitats for juvenile fish nor habitat loss, but instead generally by the presence of non-native species that significantly reduce the CZI value. Based on this research it can thus be concluded that significant changes in juvenile fish assemblages at a particular site can occur even within a very short time period (one year). Year-to-year changes in juvenile fish assemblages can be very significant, and for this reason it is important to perform monitoring every year.

INTRODUCTION

Many river systems are heavily altered or damaged by human activity [1], such as inappropriate hydromorphological modifications and manipulations at hydro-electric power stations [2, 3], introduction of invasive species, excessive input of nutrients, and pollution by hazardoussubstances [3]. These multi-stressors significantly affect entire aquatic ecosystems [1]. Water and its quality play an important role in terms of its usability as an irreplaceable raw material for countless sectors of human activity [4]. The same applies for the environment, to which a large number of organisms are bound in part or through their entire life cycle. The use of aquatic organisms (biota) as an indicator of ecological status has a justified significance [5]. Their physiological tolerance and ecological preferences are closely related to the environmental conditions in which they live, and they are able to quickly reflect environmental changes [6, 7]. Bioindicators are widely used to provide useful information about environmental changes or pollution and reflect long-term effects/stressors that do not act on organisms separately, but simultaneously [8]. Assessment methods are mostly based on the taxonomic composition of the community, which provides information on biological interactions, the internal formation of the community, as well as the functioning of the given ecosystem [9]. The assemblage of juvenile fish (i.e. 0+, where 0 means no experienced winter and + means an experienced vegetation season) therefore represents a suitable tool for monitoring the ecological status of watercourses, especially because most Bohemian and Moravian watercourses are stocked, i.e. subadult and adult fish are released [6]. Juvenile fish (0+) immediately reflect reproductive success or failure in the last spawning period and show a significantly faster response to changing environmental conditions than adult fish [6, 10]. In addition to the reproductive success of adult fish, the assemblage of juvenile fish (0+) is influenced by the survival of their early stages, which are very closely linked to the occurrence of suitable micro- to mesohabitats [11], such as shallow areas with sufficient food and shelter, so-called "fish nurseries" [10, 11]. The assemblage of juvenile fish (0+) is also shaped by seasonal and inter-seasonal changes in habitats as well as hydrological [12] and temperature regimes, which have a significant effect on the overall diversity and abundance of individual species [13, 14]. Environmental changes can be monitored through diversity on a local scale, based on species in a given assemblage (α diversity) or on a wider scale, between individual assemblages (β diversity, [15, 16]). The aim of this study was to assess the assemblage of juvenile fish (0+) and the ecological status of watercourses according to the Czech multi-metric index (CZI) within individual basins between 2019 and 2021 at 22 sites that represent closing profiles and important trunk streams in the Czech Republic.

METHODOLOGY

The biological assessment of the monitored watercourses was carried out using the natural fish assemblage, i.e., juvenile fish (0+). The methodology was compiled in such a way that it was possible to use it to carry out the catch, basic processing and assessment of fish samples (0+) [17, 18]. The chosen methodology represents the current status of the watercourses [19] where only fish that are a maximum of few months old are sampled. The ichthyological survey took place at 22 sites (*Fig. 1*), which were selected on the basis of previous findings from water quality monitoring carried out by the Czech Hydrometeorological Institute [19]. The monitored sites were located in the closing profiles and on the trunk streams of the Czech Republic *(Fig. 1)*. Sampling sites for catching juvenile fish (0+) were located below municipalities and adjacent agglomerations due to possible influence by technical modifications, weir manipulations, discharge of waste water, and surface sources of pollution, especially in important agricultural areas. Thanks to the given sampling design, it was possible to objectively determine the influence of human activity on the assemblage of juvenile fish (0+) between individual basins, as well as across the Czech Republic.

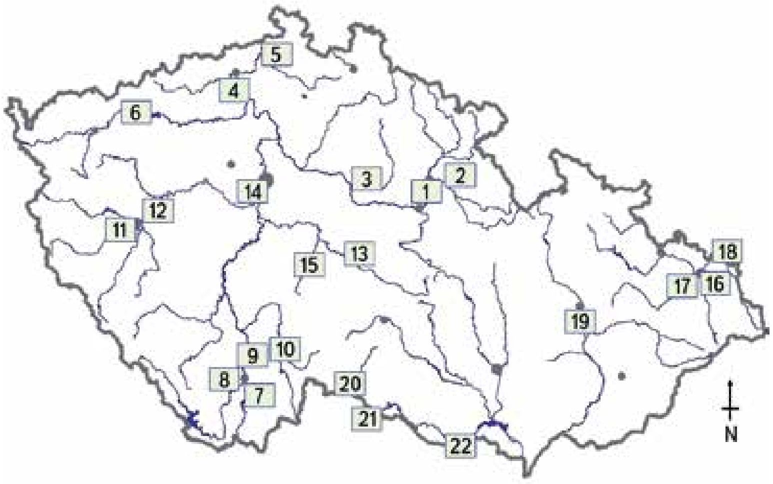


Fig. 1. Monitored watercourses with marked profiles where juvenile fish (0+) were caught: **1)** Labe – Hradec Králové, **2**) Orlice – Nepasice, **3**) Cidlina – Sány, **4**) Labe – Litoměřice, **5**) Ploučnice – Děčín (Březiny), **6**) Ohře – Želina, **7**) Malše – Roudné, **8**) Vltava – Boršov, **9**) Vltava – Hluboká nad Vltavou, **10**) Lužnice – Veselí nad Lužnicí, **11**) Mže – Plzeň, **12**) Berounka – Plzeň, **13**) Sázava – Zruč nad Sázavou, **14**) Vltava – Praha (Vrané), **15**) Želivka – Poříčí, **16**) Ostravice – Ostrava, **17**) Odra – Ostrava (Svinov), **18**) Olše – Věřňovice, **19**) Morava – Blatec, **20**) Moravská Dyje – Písečné, **21**) Dyje – Podhradí, **22**) Dyje – Jevišovka

Catching the fish

Fish catches (0+) were carried out from the second half of August to the second half of September. Late summer is a suitable period to sample juvenile fish (0+) due to relatively low and stable flows. The abundance of juvenile fish (0+) is already relatively stable compared to the high mortality that occurs during the first weeks to months after hatching [10]. During this period, juvenile fish (0+) still stay in the shallow sections along the banks and do not yet move to the deeper parts of the watercourses (to the wintering grounds), which usually happens during the autumn months [10]. In this period, juvenile fish (0+) are already sufficiently mature, their identification features are similar to adults, and their identification can be carried out directly in the field [17, 20].

Catching the fish was carried out along the banks of a watercourse *(Fig. 2)* with a battery-powered electric unit (type SEN and LENA from the Bednář company) with an output frequency of 50–95 Hz [10, 21]. The fish were caught using a direct pulsed current, which is not dangerous for the fish's health in the given frequency range [17, 20]. The length of the fished section depended on the amount of mesohabitats (shallow stream sections, dead wood, aquatic and flooded terrestrial vegetation, standing water) and ranged from 50 m to 200 m (median 100 m). The monitored section was divided into several sub-sections in order to capture a significant part of the environmental variability and the total assemblage of juvenile fish (0+). Following the catch, the fish were identified directly at a given site *(Fig. 3)*.

Fig 2. Juvenile fish assemblages sampling in shallow sections along the riverbank

Fig. 3. Determination of juvenile fish

DATA PROCESSING

The ecological status assessment of the monitored watercourses was carried out using the Czech multi-metric index (CZI), which combines several metrics, whose results are combined into a multi-metric output and include several attributes of the assemblage. Metrics that describe and assess environmental conditions include altitude, watercourse order according to Strahler, sea-drainage area, watercourse type (A – mountain streams to G – lowland rivers), and typical taxa for a given type of watercourse, as well as non-native species, which significantly reduce the resulting index value [16]. The multi-metric index was calculated according to the following equation:

$$CZI = \frac{wi1 * EQRTD + wi2 * EQR\,AR + wi3 * EQRND1 + wi4 * EQRND2}{4}$$

where

wi	is the weight of the metric when calculating CPI
TD	number of typical taxa
AR	abundance of rheophiles (current-loving species)
ND1	presence of undesirable species
ND2	– relative representation of undesirable species – takes on values from 0 to 1 (category CZI, 0–0.2 destroyed; > 0.2–0.4 damaged; > 0.4–0.6 medium; > 0.6–0.8 good and > 0.8–1 excellent). The upper and lower limits of the metric values are used to calculate the Ecological Quality Ratio (EQR), i.e., the ratio between the detected and expected (reference) values [16].

Differences in the juvenile fish assemblage were assessed in the R software program ver. 4.2.2 [21] through the PERMANOVA (Permutational Multivariate Analysis of Variance) method and displayed using multiple scaling – NMDS (Non-Metric Multidimensional Scaling). Visualization of the differences in the fish assemblage was shown through the code designation of individual species (**AA** – *Alburnus alburnus*, **AB** – *Abramis brama*, **AN** – *Anguilla anguilla*, **AP** – *Alburnoides bipunctatus*, **AU** – *Leuciscus aspius*, **BB** – *Barbus barbus*, **BJ** – *Blicca bjoerkna*, **CA** – *Carassius gibelio*, **CG** – *Cottus gobio*, **CN** – *Chondrostoma nasus*, **CT** – *Cobitis taenia*, **CY** – *Cyprinus carpio*, **EL** – *Esox lucius*, **GA** – *Gasterosteus aculeatus*, **GC** – *Gymnocephalus cernua*, **GG** – *Gobio gobio*, **GL** – *Romanogobio albipinnatus*, **LC** – *Squalius cephalus*, **LG** – *Lepomis gibbosus*, **LI** – *Leuciscus idus*, **LL** – *Leuciscus Leuciscus*, **LT** – *Lota lota*, **NB** – *Barbatula barbatula*, **NM** – *Neogobius melanostomus*, **PF** – *Perca fluviatilis*, **PM** – *Proterorhinus semilunaris*, **PP** – *Phoxinus phoxinus*, **PR** – *Pseudorasbora parva*, **RR** – *Rutilus rutilus*, **RS** – *Rhodeus amarus*, **SE** – *Scardinius erythrophthalmus*, **SG** – *Silurus glanis*, **SL** – *Sander lucioperca*, **ST** – *Salmo trutta m. fario*, **TT** – *Tinca tinca*, **VV** – *Vimba vimba*). Comparison of differences in the juvenile fish assemblage between individual years (2019–2021) was performed using the Euclidean distance (Jaccard index). The Cao index [22] was used to assess (beta) diversity of the assemblage between individual sites in the monitored period.

RESULTS

The assemblage of juvenile fish was relatively rich, with 36 species recorded at 22 sites. There were significant differences in the composition of the species community between individual sites; at least four species were recorded per site (Cidlina – Sány in 2019); the most species (15) were caught in 2021 at the Labe – Hradec Králové site (the section was fished below the weir near the village of Vysoká nad Labem). In the monitored period, an average of 9 species were caught at the sites (an average of 7.1 species per site was recorded in 2019, 8.7 in 2020, and 9.7 in 2021). Among the species with the highest abundance were European chub (*Squalius cephalus* ∑6156 ind. [individuum], *Fig. 4*, *Tab. 1*), gudgeon (*Gobio gobio* ∑2976 ind., *Fig. 4*, *Tab. 1*), European bitterling (*Rhodeus amarus* ∑2518 ind., *Fig. 4*, *Tab. 1*), common bleak (*Alburnus alburnus* ∑2447 ind., *Fig. 4*, *Tab. 1*), common roach (*Rutilus rutilus* ∑2007 ind., *Fig. 4*, *Tab. 1*), and barbel (*Barbus barbus* ∑1434 ind., *Fig. 4*, *Tab. 1*). The Catch Per Unit Effort (CPUE) fluctuated significantly between individual years and sites; the minimum value o CPUE was recorded in 2019 at the Berounka in Pilsen (Bukovec) – 0.3 ind.m^{-1} *(Fig. 5)*, and the maximum was 25.4 ind.m^{-1} at Olše in Věřňovice in 2021 *(Fig. 5)*. The average value of CPUE between sites and years was 3.3 ind.m^{-1}. A medium and higher CPUE value was recorded in 23 cases during the monitored period

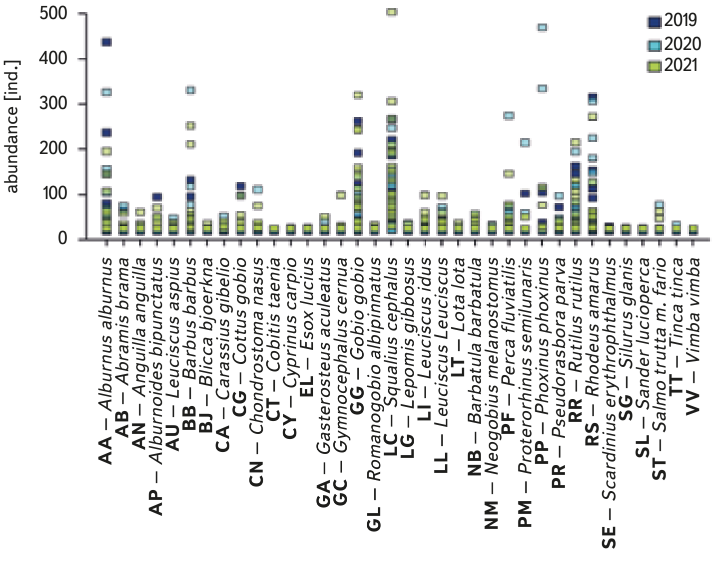


Fig. 4. The results of juvenile fish survey, abundance of fish species, 2019–2021

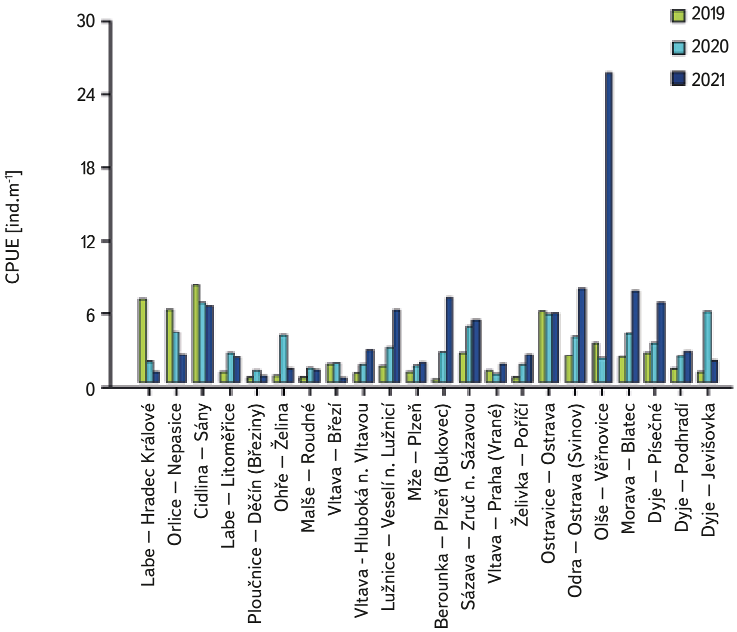


Fig. 5. The results of catch per unit effort (CPUE) at monitored sites, 2019–2021

(in 2019 at five sites, and in 2020 and 2021 at nine sites). Similar to CPUE, fish biomass showed high variability between years and sites. The lowest values of 0.4 g.m^{-1} were recorded in 2019 on the Vltava in Prague (Vrané, *Fig. 6*), while the highest values of 5.0 g.m^{-1} were recorded in 2021 on the Odra in Ostrava (Svinov, *Fig. 6*). The average value of biomass between sites in the monitored period reached 1.8 g.m^{-1}. The medium and higher value of biomass was recorded in 27 cases (in 2019 it was found at seven sites, in 2020 at eight sites, and in 2021 at 12 sites). The ecological status assessment according to the Czech multi-metric index (CZI) showed significant changes in the monitored sites that occurred during 2019–2021. Degradation of the status was recorded at four monitored sites compared to previous years (Labe – Hradec Králové, Ploučnice – Děčín/Březiny, Mže – Plzeň, Dyje – Podhradí, *Fig. 7*). The lowest CZI values, and thus the worst ecological status (i.e., destroyed and damaged), were recorded at the following sites: Ohře – Želina (0.200, *Fig. 7*), Dyje – Jevišovka (0.295, *Fig. 7*), Cidlina – Sány (0.305, *Fig. 7*), and Dyje – Podhradí (0.344, *Fig. 7*). At the Ohře in Želina, the population was mainly dominated by European perch (*Perca fluviatilis*), with a minor proportion of common roach and three-spined stickleback (*Gasterosteus aculeatus*). In the community on the Dyje in Jevišovka, the majority consisted of western tubenose goby (*Proterorhinus semilunaris*), European bitterling, and common roach. On the Cidlina in Sány, the majority share of the community was formed by European bitterling, gudgeon, common roach, and topmouth gudgeon (*Pseudorasbora parva*). On the Dyje in Podhradí, European chub, common roach, and European perch dominated the fish community. An improvement in ecological status was detected in a total of nine sites *(Fig. 7)*. The most significant improvement during the monitored period was recorded at four sites, i.e., on the Labe in Litoměřice, Lužnice in Veselí nad Lužnicí, Vltava in Prague (Vrané), and Dyje in Písečné. At the sites of the Orlice in Nepasice and the Olše in Věřňovice, the ecological status reached first class (i.e., excellent). At the remaining sites, the situation was rather stable – there was neither significant improvement nor degradation *(Fig. 7)*. Multivariate analyses showed significant differences in the juvenile fish assemblage in 2019–2021 (P = 0.011, *Fig. 8a*), but no differences in community diversity across the monitored sites were proven (P = 0.086, *Fig. 8b*).

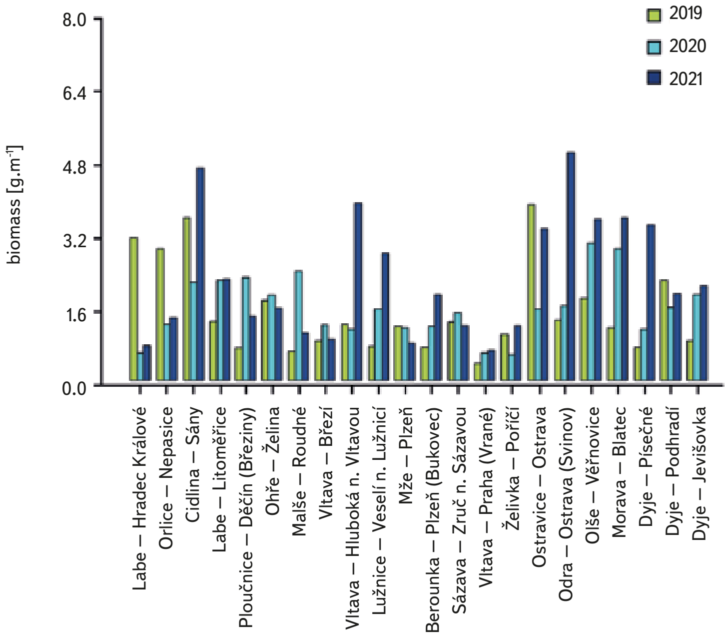


Fig. 6. Biomass of juvenile fish at monitored sites, 2019–2021

DISCUSSION

The study was conducted across the Czech Republic. Individual watercourses and sites differed significantly not only in terms of water bearing, geomorphology, but also in the technical modifications of the riverbed. At all 22 monitored sites, the assemblage of juvenile fish was very diverse. Species diversity varied across individual years and sites; a total of 36 species were recorded (a minimum of four and a maximum of 15 species per site). CPUE values showed a relatively high variability between sites and monitored years *(Fig. 5)*. The lowest CPUE values (0.3 ind.m^{-1}, *Fig. 5*) were recorded on the Berounka in Pilsen in 2019; however, in 2021, CPUE values of 6.8 ind.m^{-1} were recorded *(Fig. 5)*. The highest CPUE values were 25.4 ind.m^{-1} in Olše in Věřňovice in 2021; however, significantly lower abundances were recorded in previous years (4.5 and 2.1 ind.m^{-1}, *Fig. 5*). Similarly, the biomass also showed great variability in the monitored period between sites and years; the lowest values were found on the Vltava in Prague (0.4 g.m^{-1}, *Fig. 6*) in 2019, but in 2021 the biomass reached almost double the values *(Fig. 6)*. The highest values of 5.0 g.m^{-1} were in 2021 on the Odra in Ostrava (the Svinov district, *Fig. 6*); however, more than three times lower biomass values were recorded in previous years *(Fig. 6)*. Significant differences in biomass and CPUE between individual years within the same site may be related to interannual differences, temperature fluctuations or water level fluctuations (floods, drought), which have a significant effect on the reproductive potential of fish and their entire community [6, 24, 25]. Differences in both abundance and biomass can also be influenced by interannual biological cycles, such as the sizes of individual cohorts entering breeding [6, 10], which can vary significantly between individual years. They can also be caused by the fluctuation of available food, i.e., a change in the community of micro and macrozoobenthos, which represents an important source of food for juvenile fish [24, 26, 27]. Among other things, even significant temperature fluctuations have a noticeable effect on fish reproduction [13, 28], because higher water temperatures can

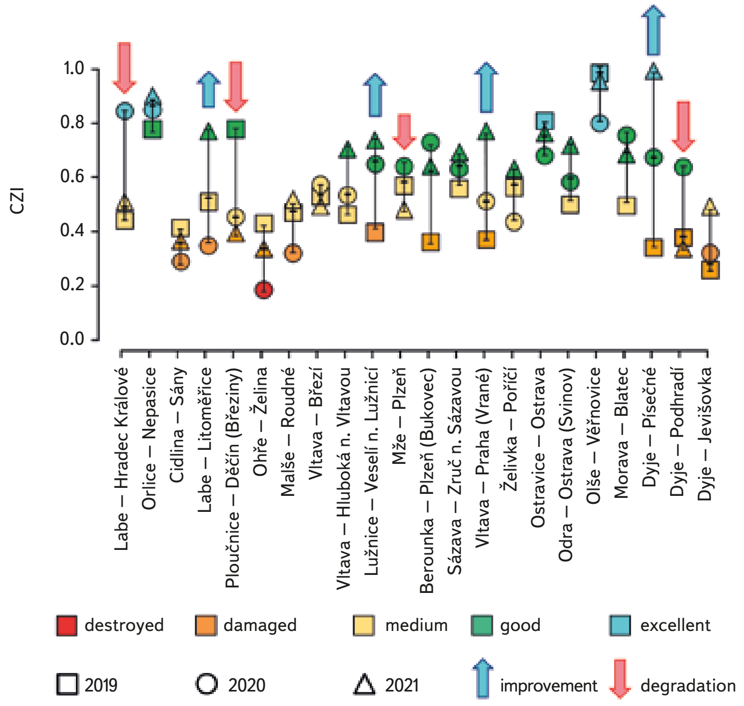


Fig. 7. Ecological status assessment using Czech multi-metric index (CZI) at monitored sites, 2019–2021

Tab 1. Summary of juvenile fish (0+) caught at monitored sites, 2019–2021

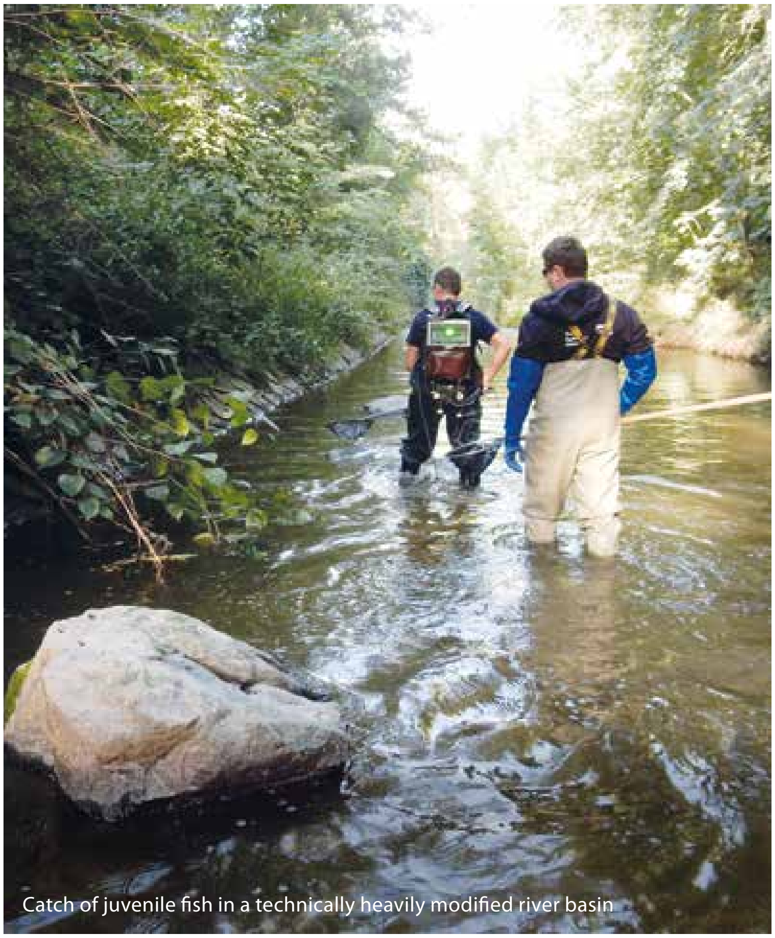
		common bleak *Alburnus alburnus*	**common bream** *Abramis brama*	**asp** *Leuciscus aspius*	**European eel** *Anguilla anguilla*	**barbel** *Barbus barbus*	**white bream** *Blicca bjoerkna*	**Prussian carp** *Carassius gibelio*	**nase** *Chondrostoma nasus*	**spined loach** *Cobitis taenia*	**mirror carp** *Cyprinus carpio*	**northern pike** *Esox lucius*	**three-spined stickleback** *Gasterosteus aculeatus*	**Eurasian ruffe** *Gymnocephalus cernua*	**gudgeon** *Gobio gobio*	**white-finned gudgeon** *Romanogobio albipinnatus*	**European chub** *Squalius cephalus*
Code		AA	AB	AU	AN	BB	BJ	CA	CN	CT	CY	EL	GA	GC	GG	GL	LC
Labe – Hradec Králové	**2019**	226	1			1											19
	2020	315				100			3						15		68
	2021	40	2	1	37		1							3	92	8	44
Orlice – Nepasice	**2019**	8				117			11						108		106
	2020	48		2		320			93					1	50		55
	2021	31	2			40			52						139		25
Cidlina – Sány	**2019**														252		20
	2020	1													37		12
	2021														45		30
Labe – Litoměřice	**2019**	6	5												18		90
	2020																36
	2021			5					1					2	3		110
Ploučnice – Děčín (Březiny)	**2019**					80			1						10		76
	2020					6		6	5						1	1	2
	2021			1		2		15			2	3			4		39
Ohře – Želina	**2019**						1						1		2		18
	2020											1	21				
	2021											2	26	5			5
Malše – Roudné	**2019**					33									4		113
	2020	1													8		16
	2021					10								2	70		77
Vltava – Březí	**2019**	1				11									59		173
	2020														19		140
	2021					12						1			14		37
Vltava – Hluboká n. Vltavou	**2019**	46		1			2								2		6
	2020	85	1	27													32
	2021	15		13													5

orfe *Leuciscus idus*	**dace** *Leuciscus leuciscus*	**pumpkinseed sunfish** *Lepomis gibbosus*	**burbot** *Lota lota*	**stone loach** *Barbatula barbatula*	**round goby** *Neogobius melanostomus*	**European perch** *Perca fluviatilis*	**western tubenose goby** *Proterorhinus semilunaris*	**topmouth gudgeon** *Pseudorasbora parva*	**common roach#** *Rutilus rutilus*	**European bitterling** *Rhodeus amarus*	**common rudd** *Scardinius erythrophthalmus*	**wels catfish** *Silurus glanis*	**zander / pike perch** *Sander lucioperca*	**brown trout** *Salmo trutta m. fario*	**tench** *Tinca tinca*	**vimba bream** *Vimba vimba*	**spirlin** *Alburnoides bipunctatus*	**European minnow** *Phoxinus phoxinus*	**European bullhead** *Cottus gobio*	**Total [ind.]**
LI	LL	LG	LT	NB	NM	PF	PM	PR	RR	RS	SE	SG	SL	ST	TT	VV	AP	PP	CG	
										98										345
	1			3					23	1										529
	19	9	3			6			13	3										281
	12																			362
	6			4		2			4											585
	12					1			3											305
								55		76										403
						5		78	99	295										527
						8		89	110	106										388
									8							4				131
						15			179	18										248
36	5					4		1	6	40										213
	2																	96	82	347
1	6				11	38			7	1										85
17					5	1		2	31		1	2								125
2						32			56											112
						262			105						3					392
	2					125			10											175
	26			3				1	2										103	285
	2					27		19	13											86
	15			10		10		5	10										18	227
	10			2				26	19											301
	17	15				51													1	243
	9	2		1		27													30	133
						27			131											216
20						41			3											209
76						17			10				1							137

		common bleak *Alburnus alburnus*	**common bream** *Abramis brama*	**asp** *Leuciscus aspius*	**European eel** *Anguilla anguilla*	**barbel** *Barbus barbus*	**white bream** *Blicca bjoerkna*	**Prussian carp** *Carassius gibelio*	**nase** *Chondrostoma nasus*	**spined loach** *Cobitis taenia*	**mirror carp** *Cyprinus carpio*	**northern pike** *Esox lucius*	**three-spined stickleback** *Gasterosteus aculeatus*	**Eurasian ruffe** *Gymnocephalus cernua*	**gudgeon** *Gobio gobio*	**white-finned gudgeon** *Romanogobio albipinnatus*	**European chub** *Squalius cephalus*
Code		AA	AB	AU	AN	BB	BJ	CA	CN	CT	CY	EL	GA	GC	GG	GL	LC
Lužnice – Veselí n. Lužnicí	**2019**	15	48				6	1							33		209
	2020	36	55							2					123		127
	2021	85	35	1			1								130		72
Mže – Plzeň	**2019**								1						19		82
	2020								2						8		123
	2021				6										15		50
Berounka – Plzeň (Bukovec)	**2019**					1		2							78		30
	2020			5	7	8		11			1			2	83		72
	2021					18			11						305		141
Sázava – Zruč nad Sázavou	**2019**					6			2						22		113
	2020				2	13			4			1			18		234
	2021					30			3			2			228		250
Vltava – Praha (Vrané)	**2019**	433	1												15		60
	2020	29			5	3	2							2			103
	2021	124	1	12	10	1									2		290
Želivka – Poříčí	**2019**														4		97
	2020				2												195
	2021														5		192
Ostravice – Ostrava	**2019**	131		3		27									13		256
	2020	3				4											82
	2021	14				3		6	2					76			173
Odra – Ostrava (Svinov)	**2019**	25	1			21	2								16		184
	2020	140				4		2	1						8		103
	2021					235									50		80
Olše – Věřňovice	**2019**	131				34									17		74
	2020	4				58			5						1		66
	2021	176				193									226		495
Morava – Blatec	**2019**	20	6					1							179		44
	2020	4				5									22		72
	2021	38				22									120	1	131

orfe *Leuciscus idus*	**dace** *Leuciscus leuciscus*	**pumpkinseed sunfish** *Lepomis gibbosus*	**burbot** *Lota lota*	**stone loach** *Barbatula barbatula*	**round goby** *Neogobius melanostomus*	**European perch** *Perca fluviatilis*	**western tubenose goby** *Proterorhinus semilunaris*	**topmouth gudgeon** *Pseudorasbora parva*	**common roach#** *Rutilus rutilus*	**European bitterling** *Rhodeus amarus*	**common rudd** *Scardinius erythrophthalmus*	**wels catfish** *Silurus glanis*	**zander / pike perch** *Sander lucioperca*	**brown trout** *Salmo trutta m. fario*	**tench** *Tinca tinca*	**vimba bream** *Vimba vimba*	**spirlin** *Alburnoides bipunctatus*	**European minnow** *Phoxinus phoxinus*	**European bullhead** *Cottus gobio*	**Total [ind.]**
LI	LL	LG	LT	NB	NM	PF	PM	PR	RR	RS	SE	SG	SL	ST	TT	VV	AP	PP	CG	
	3					1		19	149		11									495
1		1				3		5	27							2				382
25	35					6		5	196	5										596
	14																			116
	52								3											188
	15		12	22		10		2	10					40					75	256
	12			1				1	2											127
12	43			36				6	101			4			11	2			6	410
21	75		4	17				15	85										11	703
										307										450
	3							27	42	211					1					556
				2				2		256										773
									7											516
2	1								64		5									216
1	12					2		1	15	1										472
3	2			1		1			20					8				91		227
						31			4					57				324		613
	6					3			73		2			23				53		357
				1				1		3								120		555
	1							8			3							464		565
	1							2	1	2								6		286
	1							4		140										394
						7		4	53	31							28			381
										7		2					12			386
	6			1													78	89		430
				1		15		8		2								5		165
				33					5								47	94		1269
	6							19	14	36										325
8									23	109										243
				7		1		1	5	26							26			378

		common bleak *Alburnus alburnus*	**common bream** *Abramis brama*	**asp** *Leuciscus aspius*	**European eel** *Anguilla anguilla*	**barbel** *Barbus barbus*	**white bream** *Blicca bjoerkna*	**Prussian carp** *Carassius gibelio*	**nase** *Chondrostoma nasus*	**spined loach** *Cobitis taenia*	**mirror carp** *Cyprinus carpio*	**northern pike** *Esox lucius*	**three-spined stickleback** *Gasterosteus aculeatus*	**Eurasian ruffe** *Gymnocephalus cernua*	**gudgeon** *Gobio gobio*	**white-finned gudgeon** *Romanogobio albipinnatus*	**European chub** *Squalius cephalus*
Code		AA	AB	AU	AN	BB	BJ	CA	CN	CT	CY	EL	GA	GC	GG	GL	LC
Dyje – Písečné	**2019**	33													106		19
	2020	9							1						96		174
	2021					1			11						55		179
Dyje – Podhradí	**2019**	11	10			1	3										7
	2020	49	1			1	3		2			1			10		55
	2021		10			3	10	1						5			63
Dyje – Jevišovka	**2019**	64						6								2	5
	2020	50						31		1							40
	2021					10		15							17	3	60



Catch of juvenile fish in a technically heavily modified river basin

The Ohře river near the Želinský meander

orfe *Leuciscus idus*	**dace** *Leuciscus leuciscus*	**pumpkinseed sunfish** *Lepomis gibbosus*	**burbot** *Lota lota*	**stone loach** *Barbatula barbatula*	**round goby** *Neogobius melanostomus*	**European perch** *Perca fluviatilis*	**western tubenose goby** *Proterorhinus semilunaris*	**topmouth gudgeon** *Pseudorasbora parva*	**common roach#** *Rutilus rutilus*	**European bitterling** *Rhodeus amarus*	**common rudd** *Scardinius erythrophthalmus*	**wels catfish** *Silurus glanis*	**zander / pike perch** *Sander lucioperca*	**brown trout** *Salmo trutta m. fario*	**tench** *Tinca tinca*	**vimba bream** *Vimba vimba*	**spirlin** *Alburnoides bipunctatus*	**European minnow** *Phoxinus phoxinus*	**European bullhead** *Cottus gobio*	**Total [ind.]**
LI	LL	LG	LT	NB	NM	PF	PM	PR	RR	RS	SE	SG	SL	ST	TT	VV	AP	PP	CG	
								2	10	307										477
								5	6	165	2						1			459
				26		3			6	30							20			331
						57	6		27			1								123
						6	39		43	9						1				220
						54	27	3	61	25										261
							86			42										205
							200	19	103	131			3			2				580
4	2						27	2	10	35										185

Selection of an appropriate flow section depending on the variability of the environment

After determination, the fish were gently released back into the river

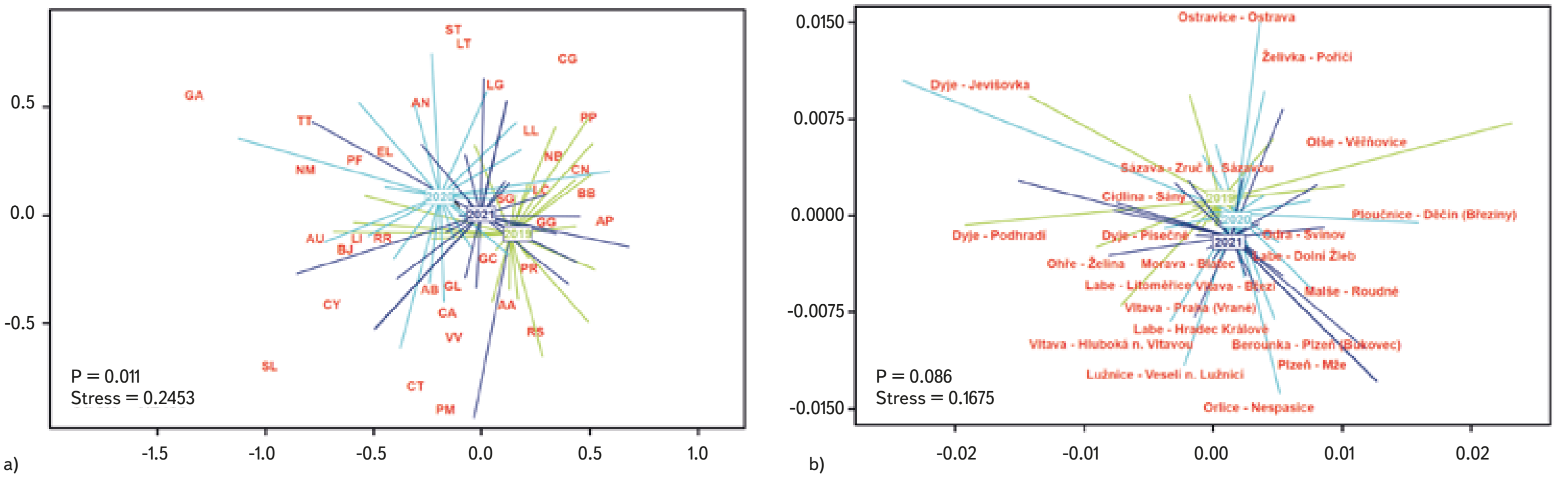


Fig. 8. Similarities between monitored sites based on juvenile fish assemblages, a) the results of nonmetric multidimensional scaling of juvenile fish assemblages between 2019–2021, b) differences in juvenile fish assemblages between sites, 2019–2021

contribute to an earlier spawning time, while a sudden drop can slow down or delay fish spawning [13, 29]. It can be assumed that a significant drop in temperature in the spring season can also cause the absence of a cohort, especially in fish with batch spawning, such as European chub and common nase. In 2020, February and March were significantly above average in temperature, while May was very cold (with a deviation of -2.1 °C from normal, [31]). In a number of sites, a missing cohort was recorded in a number of sites this year during fish catches, or the size spectrum ranged only in two categories (about 20–30 mm and 40–50 mm of body length), and the middle category of 30–40 mm was almost absent (this mainly concerned European chub and common nase). Despite significant differences in the abundance of individual species *(Fig. 4)* and significant variability in species diversity *(Fig. 8a)*, and due to significant differences between a number of sites *(Fig. 8b)*, no statistically significant differences were found in the assemblage of juvenile fish between the monitored sites (P = 0.086, *Fig. 8b*); however, this value is quite close to the significance level (P = 0.05). In contract, significant differences in the assemblage were recorded in 2019–2021 (P = 0.011, *Fig. 8a*), when the species variability changed noticeably during the monitored years *(Fig. 8a)*. Inconclusive differences in the assemblage of juvenile fish between sites could be caused by a significant representation of eurytopic species, as the monitored sites are more probably to be found in the lower parts of watercourses, and therefore the communities between sites could be quite similar. In contrast, significant differences in the fish community between monitored years may point to fundamental changes that take place during individual years, or reflections of normal interannual fluctuations of an otherwise stable community may have been captured [25]. According to the Czech multi-metric index, two sites almost consistently showed the best composition of the juvenile fish assemblages, i.e. excellent ecological status (0.863–1.0 CZI, *Fig. 7*). These were Orlice in Nepasice and Olše in Věřňovice. The banks and riverbed were made of medium coarse gravel to sand. There was a considerable amount of mesohabitats that were suitable both for reproduction and for the growth and survival of the spawning community [32], i.e., river shallows with a low current speed and a significant amount of dead wood, which formed a suitable habitat with enough food and shelter [10, 33]. In contrast, the lowest CZI values (0.200, 0.296, 0.305, 0.344, *Fig. 7*), which represent the "worst" state (destroyed to damaged), were found on the Ohře in Želina, the Dyje in Jevišovka, the Cidlina in Sány and the Dyje in Podhradí. The Ohře and Dyje were influenced by the adjacent water reservoirs (Nechranická, Vranovská, and Novomlýnská reservoirs), into which they form the main tributaries. Simultaneously, the reservoirs also influence the resulting assemblage of juvenile fish (e.g., by the height of the swelling and reproduction of part of the reservoir stock in tributaries). In the monitored sections, the riverbed was relatively shallow, stony to sandy and only in places overgrown with algal growths and aquatic macrophytes. On the Ohře, the species community was relatively poor, with the predominance of European perch in particular, with a smaller occurrence of common roach and three-spined stickleback. In the spring, part of the stock travels from the dam to the tributaries, where it reproduces [34, 35]. In the early spring months, perch [35] and then roach [36] reproduce. European perch is able to actively hunt smaller juvenile fish at a size of 25–30 mm. It normally grows to this size during July and August [37–39]. Its great abundance, together with its enormous predatory potential, allows it to prevail in the assemblage of juvenile fish, where it subsequently forms a dominant share. The low values of the Czech multi-metric index on the Dyje in Podhradí and Jevišovka were caused by the relatively low abundance of rheophilic species, higher abundance of eurytopic species such as common roach and European bitterling, and especially the presence of non-native species such as western tubenose goby, topmouth gudgeon, and Prussian carp (Carassius gibelio). On the Cidlina in Sány, the abundance of gudgeon decreased in the fish community in the given period, and common roach and topmouth gudgeon gradually began to dominate. The community was influenced by the proximity of the Žehuňský pond, which had an effect on the flow conditions and temperature regime and can also serve as a reservoir for non-native species, such as topmouth gudgeon. According to the CZI, the degradation of the ecological status during the monitored three-year period was recorded at four sites (Labe – Hradec Králové, Ploučnice – Děčín/Březiny, Mže – Plzeň, and Dyje – Podhradí, *Fig. 4*). In the given period, no significant change of mesohabitats was recorded at the monitored sites (e.g., technical modifications of the riverbed or excessive overgrowth of the riverbed with macrophytes due to low flows). The deterioration was mainly caused by the presence of non-native species, which significantly reduce the value of the CZI. These species already expand further from newly colonized areas or are intentionally or unintentionally expanded with fish stocks [40, 41], or escape from ponds and other water bodies (fish production, ornamental ponds and lakes), which are situated in the upper parts of the basin [42]. In contrast, an improvement in the status during 2019–2021 was recorded at four sites (Vltava – Hluboká nad Vltavou, Vltava – Vrané nad Vltavou, Želivka – Poříčí, Dyje – Písečné, *Fig. 4*). The improvement may be related to the creation of suitable mesohabitats for fingerling survival, which arose as a result of more significant hydrological events (i.e., increased water levels), which were recorded mainly in the spring and autumn months of 2020 (Czech Hydrometeorological Institute, unpublished data). Significant fluctuations in water levels can result in hydromorphological changes in riverbeds [43, 44], especially cleaning of the riverbeds from fine inorganic and organic material (detritus), which can contribute to the creation of a number of mesohabitats [11]. These can subsequently be used for individual stages of juvenile fish (0+) [32, 45, 46].

CONCLUSION

The study results point to the fact that the assemblage of juvenile fish (0+) represents a suitable indicator of the ecological status of our watercourses and is directly and indirectly influenced by the natural conditions in a given year. The improvement of the ecological status in many sites was probably caused primarily by increased water levels, which act as an important channel-forming element and which caused the removal of sediments and the creation of suitable mesohabitats for the reproduction and subsequent survival of the first stages of juvenile fish (0+), especially in rheophilic species. However, degradation of the ecological status was not caused by a significant change in suitable habitats or their sudden decline, but mainly by the presence of non-native species, which significantly reduce the CZI index value. The conclusions of our survey point to the fact that significant changes in the assemblage of juvenile fish can occur at the same site even in a very short period of time (one year). Interannual changes can be very significant, so it is important to carry out monitoring every year in order to be able to separate "normal" fluctuations from fundamental changes taking place in the assemblage of juvenile fish (0+).

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Factors affecting the cost of drinking water production

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Keywords: drinking water — groundwater — drinking water treatment costs

ABSTRACT

The article summarizes the findings of a statistical analysis of the cost of drinking water production in the Czech Republic in 2018. Understanding the factors that influence the cost of drinking water production is important for choosing a cost-effective public drinking water supply system. We present the first study analysing the factors affecting the cost of drinking water production in the Czech Republic. We tested the following factors for their influence on the production costs of drinking water: the quantity of drinking water produced, the type of raw water (surface vs. groundwater), electricity consumption, and the treatment technologies and chemicals applied. The results suggested that drinking water production from groundwater was cheaper than from surface water. At the same time, some water treatment technologies and usage of some treatment technologies and chemicals increase production costs. The use of sodium hypochlorite, chlorine and demanganisation have the greatest impact on production costs. We have also confirmed economies of scale in the production of drinking water.

INTRODUCTION

The cost of drinking water treatment depends on the quality of raw water, treatment technologies, legal regulations, used energy sources, and the amount of treated water [1]. Regarding technological processes for water treatment, the use of gravity filtration and chlorine application has the greatest impact on costs. The cost of drinking water production is also influenced by the distance over which the water is distributed from the producer to the customer, and the method of this transport [1].

One of the most important factors affecting the cost of drinking water production is the quality of raw water. Numerous studies have found that improving source water quality reduces its treatment costs [2]. Due to greater natural purification, groundwater is usually considered cleaner than surface water [3], and the cost of treating it is lower than that of surface water [4].

Natural water purification is one of the most frequently mentioned benefits that nature provides to people, so-called ecosystem services [5]. Although the demand for valuing water-related ecosystem services is growing [6], research in this area is still scarce [7]. Valuation of the ecosystem service of groundwater purification has so far only been carried out in the Netherlands, using the replacement cost method [4]. Using this method, the value of groundwater purification can be calculated as the difference between surface and groundwater treatment costs. To use this method, it is therefore necessary to know how the costs of producing drinking water from surface water and groundwater sources differ. However, this issue has not yet been investigated in the Czech Republic.

Previous research into factors affecting drinking water production costs has focused primarily on North America and Western Europe. Therefore, we focused on Central Europe and analysed the costs of drinking water production in the Czech Republic. According to our information, this is the first study to examine parameters affecting the costs of drinking water production in Central Europe.

DATA

The data was obtained by combining the data that owners and operators of water supply and sewerage systems must report annually to the relevant water authorities (selected data from property records and selected data from operational records of water supply and sewerage systems, so-called VÚME and VÚPE data). This data was supplemented with other data, e.g. rates of charges for water abstraction. We performed the analysis on data for 2018.

We excluded observations from the database which had too low water production as well as those with too low or too high unit production costs. We assumed that these observations were entered incorrectly. We also excluded three abstraction points where more than 50 % of water production was technological water. In addition, we also excluded locations where infiltration is used. After cleaning the data, 3,253 observations remained (the total number of observations before cleaning was 3,566).

METHODOLOGY

In the short term, the costs of companies using environmental inputs are determined by the volume of production, company characteristics, costs of non-environmental inputs, costs of fixed factors, and characteristics of the natural capital used (non-environmental input) [5, 8].

Since we were not interested in the effects on total costs but on unit production costs, we used the following function based on previous research:

$$JNBP = \alpha + \beta 1 \ln VV + \beta 2\, EL + \beta 3\, PDV\_d + b1\, TECH1 + b2\, TECH2 + \ldots + b30\, TECH30 + e \quad (1)$$

where $JNBP$ are unit production costs without water abstraction charges
VV is amount of water produced

Tab. 1. Descriptive statistics

Variable	Description	Number of observations	Average	Standard deviation	Min.	Max.
JNBP	Unit production costs without raw water abstraction charges (CZK/m^3)	3 253	12.73	9.77	0.52	49.9
VV	Amount of drinking water produced (km3/year)	3 253	176.1	1.82	0.02	87.16
EL	Unit consumption of electrical energy (kWh/m3 of drinking water produced)	3 253	0.71	1.36	0	43.64
PDV_d	Binary variable = 1 if the proportion of groundwater was >= 0.5 in the total water production at a given abstraction point	3 253	0.96	0.2	0	1
NoSludgeTreat	Binary variable = 1 if no sludge treatment was used	3 253	0.36	0.48	0	1
NoTreatment	Binary variable = 1 if according to VÚME, there was no water treatment technology category	3 253	0.55	0.5	0	1
Deacidification	Binary variable = 1 if deacidification by filtration, aeration was used	3 253	0.1	0.3	0	1
Demanganisation	Binary variable = 1 if demanganisation was used	3 253	0.11	0.31	0	1
Filtration	Binary variable = 1 if filtration was used	3 253	0.17	0.37	0	1
ChemDisinfection	Binary variable = 1 if chemical disinfection was used	3 253	0.38	0.49	0	1
Chlorine	Binary variable = 1 if chlorine was used	3 253	0.11	0.31	0	1
IronRemoval	Binary variable = 1 if iron removal was used	3 253	0.12	0.32	0	1
OtherAggregation	Binary variable = 1 if other aggregation agent according to VÚME was used	3 253	0.08	0.26	0	1
OtherTechnology	Binary variable = 1 if other technology according to VÚME was used	3 253	0.07	0.26	0	1
PotassiumPermanganate	Binary variable = 1 if potassium permanganate was used	3 253	0.06	0.24	0	1
RadonRemoval	Binary variable = 1 if radon was removed	3 253	0.08	0.27	0	1
SodiumHypochlorite	Binary variable = 1 if sodium hypochlorite was used	3 253	0.87	0.33	0	1

EL	*unit consumption of electrical energy (kWh/m^3 of water produced)*
PDV_d	binary variable characterizing the type of raw water
proměnné TECH 1–30	are binary variables characterizing the technologies and chemicals used in water treatment
a	is constant
β1–β3, b1–b30	are regression coefficients
e	is an error term

Since there is often a non-linear relationship between costs and the amount of produced water [1], we used natural logarithm of production volume (ln VV). The PDV_d variable was equal to 1 if the proportion of groundwater in the total water production at a given abstraction point was equal to or greater than 50 %. We had information on 17 technologies and 13 chemicals used in water treatment. However, some of these technologies and chemicals are not used very often, or their use is not frequent according to the VÚME database for the analysed year (2018). For the statistical analysis, we used only the following 13 technologies and chemicals with 5 % or more use in the year under review:

- deacidification,
- demanganisation,
- filtration,
- chemical disinfection,
- chlorine application,
- iron removal,
- without sludge treatment,
- without treatment (category according to VÚME database: without treatment, 1-stage and 2-stage treatment and infiltration)
- other aggregating agent,
- other technologies,
- potassium permanganate,
- radon removal,
- sodium hypochlorite.

Descriptive statistics for all variables are presented in *Tab. 1*

Since the costs of water production include charges paid for raw water abstraction, we first calculated the unit costs without charges. We calculated the unit costs without charges for an abstraction point a (JNBPa) as follows:

$$JNBPa = \frac{(CNa - PVVa * SPVa - PDVa * SPD)}{VVa} \qquad (2)$$

where	*CNa*	are total production costs at the abstraction point *a*
	PVVa	is amount of surface water abstracted at the point *a*
	SPVa	rate of charges for the abstraction of surface water at the point *a*

Tab. 2. Regression results. Dependent variable: JNBP (unit costs without charges)

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
lnVV	-1.15***	-1.14***	-1.15***	-1.14***	-1.14***	-1.14***	-1.14***	-1.13***	-1.12***
	(-0.11)	(-0.11)	(-0.11)	(-0.11)	(-0.11)	(-0.11)	(-0.11)	(-0.11)	(-0.11)
PDV_d	-2.06**	-2.09**	-2.13**	-2.15**	-2.32***	-2.37***	-2.47***	-2.45***	-2.24**
	(-0.95)	(-0.94)	(-0.94)	(-0.93)	(-0.90)	-0.90)	(-0.89)	(-0.89)	(-0.88)
EL	0.49**	0.49**	0.49**	0.49**	0.49**	0.49**	0.49**	0.50**	0.52**
	(-0.23)	(-0.23)	(-0.23)	(-0.23)	(-0.23)	(-0.23)	(-0.23)	(-0.24)	(-0.24)
Deacidification	-0.74	-0.711	-0.73	-0.75	-0.73	-0.74			
	(-0.64)	(-0.63)	(-0.62)	(-0.62)	(-0.62)	(-0.62)			
Demanganisation	2.70***	2.71***	2.70***	2.85***	2.93***	2.87***	2.91***	2.94***	3.96***
	(-0.92)	(-0.92)	(-0.92)	(-0.86)	(-0.85)	(-0.86)	(-0.85)	(-0.85)	(-0.61)
Filtration	0.43	0.45	0.45	0.46					
	(-0.64)	(-0.64)	(-0.64)	(-0.63)					
Chem. Disinfection	1.39**	1.47***	1.41***	1.42***	1.49***	1.40***	1.28***	1.38***	1.50***
	(-0.61)	(-0.51)	(-0.45)	(-0.45)	(-0.44)	(-0.43)	(-0.41)	(-0.40)	(-0.40)
Chlorine	4.79***	4.82***	4.87***	4.88***	4.87***	4.89***	4.93***	4.96***	4.94***
	(-0.99)	(-0.97)	(-0.93)	(-0.93)	(-0.93)	(-0.94)	(-0.94)	(-0.94)	(-0.94)
Iron Removal	1.08	1.1	1.11	1.12	1.28	1.31	1.33	1.34	
	(-0.86)	(-0.86)	(-0.86)	(-0.86)	(-0.82)	(-0.82)	(-0.82)	(-0.82)	
No Sludge Treat	-0.14	-0.12							
	(-0.45)	(-0.44)							
No Treatment	-0.15								
	(-0.61)								
Other Aggregation	1.94**	1.94**	1.95**	1.96**	1.94**	1.94**	1.67**	1.86**	1.82**
	(-0.78)	(-0.78)	(-0.78)	(-0.78)	(-0.78)	(-0.78)	(-0.74)	(-0.73)	(-0.73)
Other Technology	0.75	0.76	0.77	0.76	0.84	0.86	0.88		
	(-0.69)	(-0.69)	(-0.69)	(-0.69)	(-0.67)	(-0.67)	(-0.67)		
Potassium Permanganate	0.33	0.33	0.33						
	(-0.9)	(-0.9)	(-0.9)						
Radon Removal	-0.52	-0.49	-0.51	-0.52	-0.54				
	(-0.68)	(-0.66)	(-0.66)	(-0.66)	(-0.66)				
Sodium Hypochlorite	4.73***	4.74***	4.8***	4.79***	4.77***	4.77***	4.78***	4.8***	4.8***
	(-0.87)	(-0.87)	(-0.83)	(-0.83)	(-0.83)	(-0.83)	(-0.83)	(-0.84)	(-0.84)
Constant	11.98***	11.85***	11.81***	11.84***	12.01***	12.04***	12.11***	12.07***	11.82***
	(-1.46)	(-1.33)	(-1.31)	(-1.31)	(-1.29)	(-1.29)	(-1.28)	(-1.28)	(-1.26)
Number of observations	3 253	3 253	3 253	3 253	3 253	3 253	3 253	3 253	3 253
R2	0.08	0.08	0.08	0.08	0.082	0.082	0.081	0.081	0.08

Robust standard errors are given in parentheses *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

PDVa the amount of groundwater abstracted at the point *a*
SPD rate of charges for the abstraction of groundwater
VVa the amount of drinking water produced at the point *a*

Since CNa were not included in the database, we calculated them as:

$$CNa = JNa*VVa \tag{3}$$

where *JNa* are unit production costs (CZK/m3) listed in VÚPE database.

RESULTS

First, we estimated the full model including all explanatory variables, i.e., ln *VV*, *EL*, *PDV_d*, and *TECH 1–30*. As heteroskedasticity was detected (Breusch-Pagan test: F(16.32) = 5.35, Prob > F = 0.00), robust standard errors were calculated for all specifications.

The coefficients were statistically significant for ln *VV*, *EL*, *PDV_d* and some *TECH* (demanganisation, chemical disinfection, chlorine, other technologies, and sodium hypochlorite). To simplify the model, we successively dropped the variables with the lowest absolute value of the t-statistic. We proceeded in this way until only statistically significant variables remained. The variables were successively dropped in the following order: No Treatment, No Sludge Treat, Potassium Permanganate, Filtration, Radon Removal, Deacidification, Other Technology, and Iron Removal. A total of nine model specifications were tested and the results of all these specifications are shown in *Tab. 2, columns 1–9*. The same variables were statistically significant in all tested model specifications.

The results show that companies that produce drinking water mainly from groundwater have significantly lower production costs compared to companies that produce drinking water mainly from surface water. The size of this effect depends on model specification and ranges from 2.06 to 2.47. Furthermore, we confirmed economies of scale, as unit costs drop significantly with the logarithm of the amount of water produced. This finding was significant at the 1 % significance level in all specifications tested. It was also found that unit production costs increase slightly with unit consumption of electricity (by 0.5 CZK/m^3). Last but not least, we found that some water treatment technologies and the use of certain chemicals increase production costs. The biggest impact is the use of sodium hypochlorite (Sodium Hypochlorite), chlorine (Chlorine), and demanganisation (Demanganisation), which increase unit costs by 4.7–4.8 CZK, 4.8–4.96 CZK, and 2.7–3.96 CZK.

CONCLUSION AND DISCUSSION

In order to design cost-effective public water supply systems, it is essential to understand the factors affecting drinking water treatment costs. This article contributes to the existing literature by analysing the factors affecting drinking water production costs in the Czech Republic in 2018. The results showed that production of drinking water from groundwater is cheaper than production from surface water sources. However, some technologies increase drinking water treatment costs, so producing drinking water from groundwater can be more expensive than from surface water. Furthermore, we have confirmed economies of scale in drinking water production, which means that centralized water treatment is more cost-effective. A similar result (i.e. decreasing costs with the logarithm of the amount of drinking water produced) was also shown by previous studies [1, 9]. In further research, economies of scale could be further tested using different specifications of the cost model, e.g., translog or Cobb-Douglas function, as studied in previous studies [9].

The estimated cost function is based on the general cost function. However, data for some explanatory variables were not available, e.g., data on company characteristics and fixed production factors. We also had limited data on the costs of non-environmental inputs, e.g., missing data on the number of employees, ownership structure, and number of customers supplied. However, local specific factors have the greatest influence on drinking water production costs [1]; therefore, the lack of these data probably caused the low value of determination coefficient R2. The problem of these missing data could be overcome by using panel data, as fixed effects control for time-constant characteristics [10]. Using panel data will allow to take into account the heterogeneity between companies. When using a fixed-effects model, it is possible to distinguish the influence of time-invariant characteristics, such as company size and managerial characteristics, and time-varying characteristics, such as raw water quality and technologies used. Furthermore, although the database does contain raw water quality data, it was not possible to use this index as this data was missing or misreported in many observations.

In all estimated models, the R2 value was quite low (0.08). However, there is no assumption about the minimum R2 value in linear regression models. A low R2 value means that only a small part of the variability of the dependent variable is explained by the explanatory variables used [11]. In our case, the low R2 value was caused by site-specific factors that most influence drinking water production costs [1] and which were not included in the estimated cost function due to missing data. In subsequent further research, it is possible to supplement these data together with data on raw water quality and use them to estimate the cost function.

The results show that producing drinking water from groundwater is cheaper than production from surface water. This is due to the usually better quality of groundwater compared to surface water [3, 12] thanks to natural purification of groundwater, the so-called regulating ecosystem service of water purification. Despite the great importance of ecosystem services associated with groundwater, these services are often neglected in decision-making, which is mainly due to the fact that the value of these ecosystem services is difficult to express in monetary units [13]. The results of the presented study can be used to calculate the monetary value of purification of groundwater which is used to produce drinking water. The replacement cost method, which has already been used to value groundwater purification in the Netherlands [4, 14] and surface water [15], is suitable for valuation. To use this valuation method, it is necessary to know the difference in the production costs of drinking water from surface and groundwater sources, which was the content of this research.

In follow-up research, it would be appropriate to use panel data, which would alleviate the shortcomings caused by the absence of some variables affecting the costs of companies, such as the characteristics of water management companies. Furthermore, it is necessary to focus on research into the relationship between the production costs of drinking water and the characteristics of the catchment area of raw water abstraction points, such as the ratio of the representation of different ecosystems in a catchment area. The influence of ecosystems on the production costs of drinking water has already been addressed in numerous studies outside Central Europe, e.g. [8, 16, 17]. According to these studies, raw water is cleaner when abstracted from places whose catchment areas are dominated by forests. The costs of treating this water are lower compared to water that is abstracted from catchment areas where populated areas and agriculture predominate.

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Development of pond locations in the Polabí lowland since the mid-19th century – part 1 – Pardubice region

PAVEL RICHTER

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

ABSTRACT

This article focuses on mapping the development of the lowland landscape over the last 180 years, related to pressures to use lowland areas for economic purposes, including transformation of wetland habitats (specifically ponds) into arable land. The Polabí lowland was chosen as the study area because it is currently affected by a lack of water and there is an occurrence of seasonal drying up of small watercourses. This issue will probably be of greater significance in the future, particularly in the context of the expected continued extreme climatic phenomena. Within the Polabí lowland, the results from the Pardubice region (where the biggest change in pond locations occur) are presented here. The area of all types of ponds (according to their stability) makes up 6.83 % of the study area. According to their occurrence from the Second Military Mapping (1836–1852) up to 2022, the ponds were divided into disappeared, continuous, and new. Disappeared ponds have the largest representation – about two-thirds of the total pond area according to stability. They are followed by continuous ponds, and the smallest area is represented by new ponds. The historical, or more precisely, disappeared ponds were more robust than the present ones, i.e., they had a larger average size. Analyses show that almost half of the disappeared ponds have been replaced by arable land.

INTRODUCTION

The main goal of this article was the mapping of ponds in Pardubice region in the 19th century and at present. In addition to newly created ponds, continuously used preserved ponds and sites of disappeared ponds were found by comparing their occurrence, including their current land use. These results should be a suitable basis for the potential restoration of wetlands, or for the construction of small water reservoirs at suitable locations in the study area.

The first mentions of ponds on the area of the current Czech Republic date back to the 12th century. The ponds occupied the largest area at the end of the 16th century (180,000 ha); at the end of the 18th century it was only 79,000 ha, and in 1850 it was 35,000 ha, which is the lowest recorded area of ponds. After that, their area increased slightly and since 1956 it has been around 50,000 ha. However, the change in the amount of fish production per hectare is striking, increasing more than tenfold from the Middle Ages to the present [1] *(Tab. 1)*.

In the past, there was a more extensive and complex system of ponds in the Polabí lowland – especially in the Pardubice region – than in the Třeboň region. While in the Třeboň region the majority of ponds have been preserved, in the Polabí lowland the ponds were largely landfilled in order to grow agricultural crops [2]. In the second half of the 19th century, sugar beet was the main crop grown in the lowlands; in addition to Polabí, also especially in the Morava and Dyje basins in South Moravia [3]. The reason was that sugar beet achieves the highest yields in the warm and slightly humid climate of the region on certain soil types, namely black earths, brown earths, and fluvisols. This combination is usually found in the lowlands [4], which was due to the fact that the development of beet cultivation increased the demand for heavy, wet soils. As a result, there was large-scale loss of ponds in wider flat floodplains. At that time, ponds remained only in colder production areas, in narrow valleys, and in extremely wet places [3, 5]. Since the mid-19th century, sugar industry became the most important branch of food industry in both Bohemia and Moravia [6], where the Kyjovka, Prušánka, and Trkmanka basins in the Hodonín district were similar to Polabí in terms of sugar beet cultivation and the presence of sugar factories [3]. In Polabí, after 1870, the sugar beet crop area was increased the most in the judicial districts of Kolín, Poděbrady, Pardubice, Chlumec nad Cidlinou, Nový Bydžov, Kutná Hora, and Holice [7].

Tab. 1. The development of ponds in the Czech Republic. Data source: Přikryl 2004 [1]

Period / year	Pond area (1 000 ha)	Fish production (kg/ha)
12th century	First mention	–
End of 14th century	75	40
End of 16th century	180	40
End of 18th century	79	30
1850	35	25
1924	44	81
1956	50	137
1965	50	210
1975	51	328
1985	52	393
1995	52	423

In the course of the 20th century, there was a gradual reduction in the area planted with sugar beet and, in connection with this, sugar mills were also closed down. In Polabí lowland, several dozen sugar factories (e.g., in Pardubice, Hrochův Týnec, Čáslav, Kolín, Ratboř, Pečky,Velim) that were built there in connection with sugar beet cultivation [7–9] were closed down relatively recently. Currently, the cultivation of cereals, maize, and rapeseed dominates the Polabí lowland.

STUDY AREA

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

The area of the Polabí lowland is not completely defined in any available source. From the many known definitions of the Polabí lowland, the area from Jaroměř to the confluence of the Labe and the Vltava near Mělník was chosen. The area of interest was determined by the boundaries of 4th order hydrological basins [10] in combination with the typology of the current landscape of the Czech Republic [11]. Only the 4th order hydrological basins in the warm landscape of the lowlands (according to the mentioned typology) were taken into account. The selected area of the Polabí lowland consists of 512 fourth order hydrological basins with a total area of 424,613.78 ha *(Fig. 1)*.

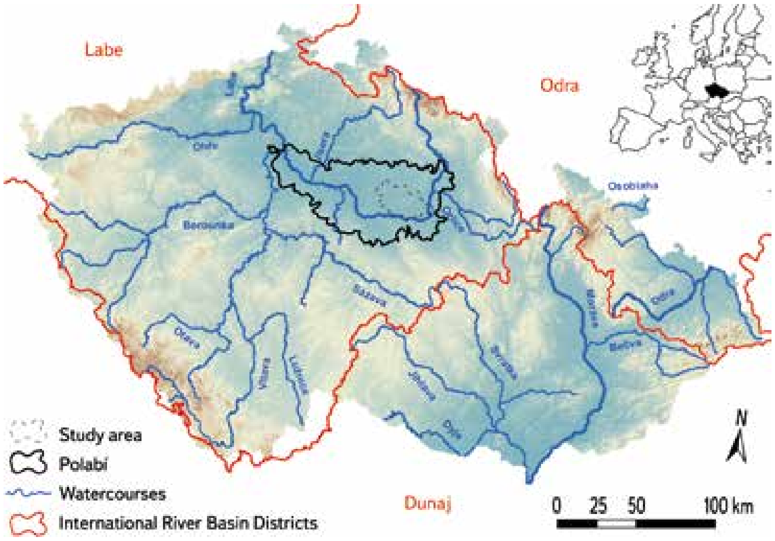

Fig. 1. The study area in the Pardubice region within Polabí lowland

The areas of Pardubice and Poděbrady were identified as sites with the largest representation of historical, or of current ponds, within the Polabí lowland. This article presents the results for the Pardubice region; Poděbrady region will be presented in a follow-up article in the next issue of VTEI journal.

The study area of Pardubice region is located on the outskirts of Pardubice and includes the surroundings of Lázně Bohdaneč and Chlumec nad Cidlinou. The defined area of Pardubice region *(Fig. 1)* consists of 56 fourth order hydrological basins with a total area of 50,104.5 ha, i.e., it occupies approximately one eighth of the Polabí lowland. These 4th order basins belong to the following 3rd order basins: 1-03-01 Labe from Orlice up to Loučná, 1-03-04 Labe from Chrudimka up to Doubrava, 1-04-02 Cidlina up to Bystřice, 1-04-03 Bystřice, 1-04-04 Cidlina from Bystřice up to the mouth and Labe from Cidlina up to Mrlina, and 1-04-05 Mrlina and Labe from Mrlina up to Výrovka [10].

METHODOLOGY

The first step was the selection and subsequent comparison of the current and historical state of new, continuous, and disappeared ponds in Polabí based on map interpretation.

The map of Second Military Mapping was selected for the primary detection of the occurrence of ponds. The current Basic Map of the Czech Republic 1 : 10,000 (BM 10) and the current orthophoto map of the Czech Republic were primarily used to show the current state of ponds and other water bodies.

The next step was a field survey of sites with the largest proportion of historical and current ponds to verify their current condition, or the state of the sites of disappeared ponds.

MAPS USED

The basic document for the creation of a vector layer for the analysis of the development of ponds in the study area was the map of Second Military Mapping (showing the state of the area between 1836 and 1852 on a scale of 1 : 28,800), available on the CENIA Geoportal as a WMS service [12] to show the historical state of the area. To approximate the state of the landscape before the Second Military Mapping, the map of First Military Mapping was used (showing the state of the area from the 1860s to 1880s on a scale of 1 : 28,800), which can be found in the map browser on the Arcanum Maps – The Historical Map Portal [13] website. Müller's map of Bohemia from 1720 is the easiest to find in the map browser of the Land Surveying Office archive [14]. Both mappings do not yet have precise geodetic foundations; however, water bodies are shown to identify their historical occurrence.

For the analysis of the current state, the orthophoto map of the Czech Republic (showing the state from 2021), ZABAGED®, and the Basic Map of the Czech Republic 1 : 10,000 (BM 10) were used, all available on the ČÚZK Geoportal [15] as a WMS service.

As part of processing these map and tabular outputs, the results regarding the change in area and location of ponds are presented here. According to stability, the ponds were classified as continuous, disappeared, and new. In the event that a historical pond was preserved on a smaller area, the preserved area of this pond was classified as a continuous pond, and the replaced (disappeared) area of the same pond was classified as a disappeared pond. A similar procedure was followed in the event that the pond area was larger than in the past. For all analyses, only polygons with a minimum size of 0.01 ha were used to minimize spatial imprecision.

As part of the analysis of landscape changes, only ponds were taken into account; other water bodies were not included, such as drinking water tanks, swimming pools, fire tanks, water bodies in former quarries, and water bodies created by sand or brick clay mining, etc.

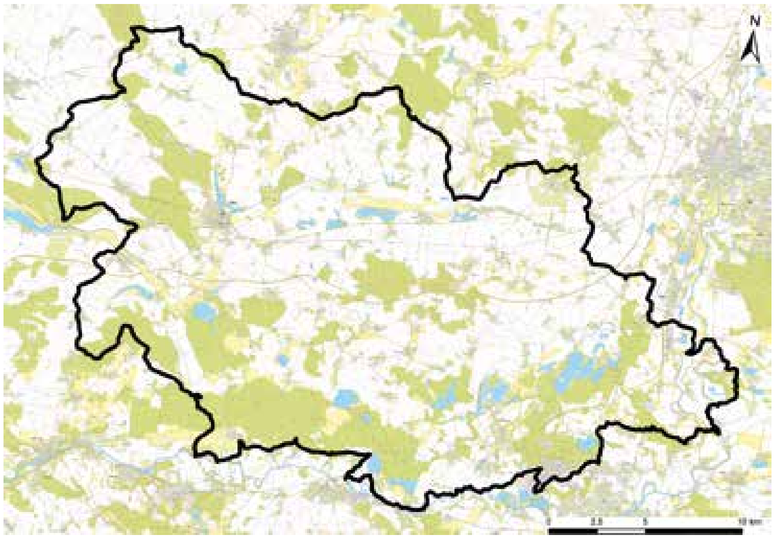

Fig. 2. The researched area in the Pardubice region on current BM 10

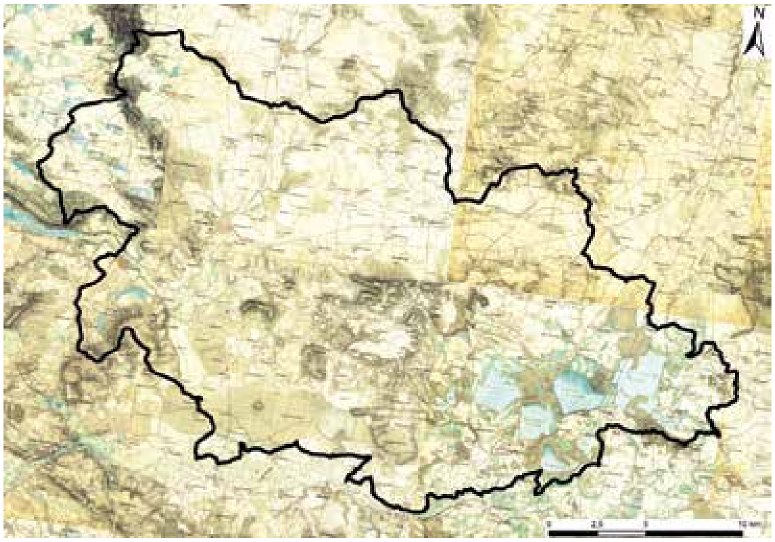

Fig. 3. The researched area in the Pardubice region on a map of the Second military mapping

Fig. 5. The researched area in the Pardubice region on the base of Müller's mapping

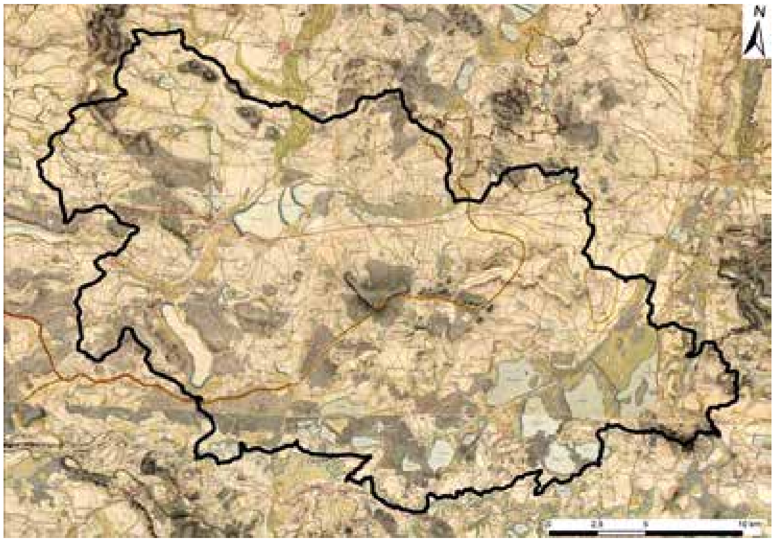

Fig. 4. The researched area in the Pardubice region on a map of the First military mapping

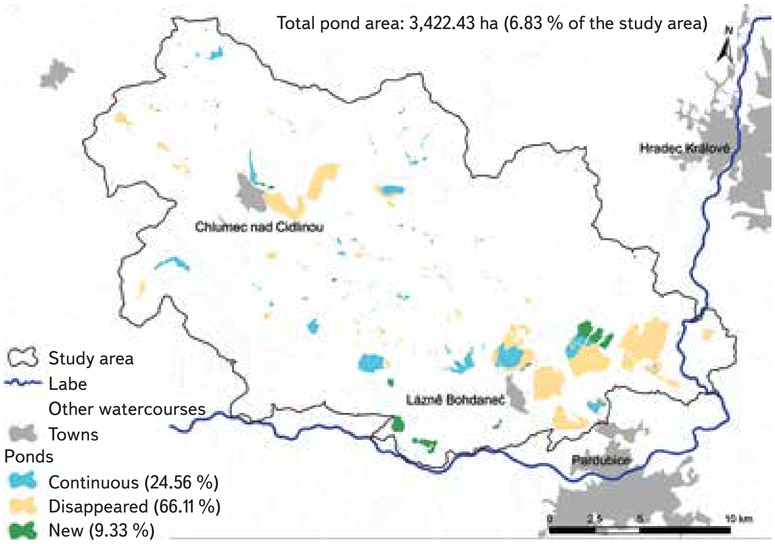

Fig. 6. Development of pond location in the Pardubice region

RESULTS

During the initial visual detection and subsequent analysis of changes in the location of ponds in the Polabí lowland using the Second Military Mapping maps and current maps (BM 10 and orthophoto map), two areas with the largest proportion of historical and current ponds were selected, namely in the Pardubice and Poděbrady regions.

Results for the Pardubice region are presented here. When looking at the study area on the map of Second Military Mapping and the current BM 10, it is clear that there has been a decrease in the area of ponds and, in particular, the disappearance or reduction of large pond areas *(Figs. 2 and 3)*. Müller's mapping and the First Military Mapping show that in the Pardubice region there was a greater representation of ponds during the 18th century than in the mid-19th century. The robust Rutvas pond near Chlumec nad Cidlinou is worth mentioning, which is no longer found on the map of Second Military Mapping *(Figs. 4 and 5)*.

The area of all types of ponds according to stability makes up 6.83 % of the study area in the Pardubice region. Disappeared ponds have the largest representation – 66.11 % of the area of all ponds according to stability (2,262.63 ha). Continuous ponds follow with 24.56 % (840.51 ha) and new ponds represent the smallest area with 9.33 % (319.29 ha) (*Fig. 6*, *Tab. 2*). The average area of disappeared ponds is 23.82 ha, continuous ponds 11.68 ha, and new ponds only 4.91 ha. The minimum size of the area of continuous and new ponds is identical to the minimum size that was considered during the data analysis, for disappeared ponds it is 0.5 ha. For the maximum size of the area, it also applies that the most robust were the disappeared ponds, the least robust are the new ponds *(Tab. 2)*.

Tab. 2. Landscape-ecological characteristics of pond development according to stability in Pardubice region

Pardubice region (50 104.5 ha)			
Ponds 1836/1852–2022	**disappeared**	**continuous**	**new**
Area [ha]	2 262.63	840.51	319.29
Number of plots [pcs]	95	72	78
Minimum plot size [ha]	0.50	0.01	0.01
Maximum plot size [ha]	520.45	145.34	63.84
Average plot size [ha]	23.82	11.68	4.91
Share of the total area of ponds in the study area [%]	66.11	24.56	9.33
Ratio to the total area of the study area [%]	4.52	1.68	0.63

Arable land currently covers 49.31 % of the area of disappeared ponds, and the share of forest land and permanent grassland (27.96 % and 12.12 %, respectively) is also significant. Swamps and marshes replaced 3.85 % of the area of the disappeared ponds, while built-up areas accounted for 4.51 % of their area. Other land use types at the sites of disappeared ponds do not exceed 1 % of their total area *(Tab. 3)*.

Although almost half of the area of disappeared ponds is occupied by arable land, there is a large proportion of their replacement by forest land. The most extensive of them is the area of the disappeared ponds Oplatil, Rozkoš, and Velká Čeperka between Pardubice, Lázně Bohdaneč, and Opatovice nad Labem *(Fig. 7)*.

Tab. 3. Current land use types at sites of disappeared ponds in Pardubice region

Land use	**ha**	**%**
arable land	1 115.80	49.31
forest	632.56	27.96
permanent grassland	274.33	12.12
swamps, marshes	87.12	3.85
built-up area	102.12	4.51
orchards, parks and gardens	20.08	0.89
shrubs	21.72	0.96
watercourses	4.06	0.18
quarries, landfills and other areas	4.90	0.22

The current state of part of this territory, or the state in August 2022 (at the time of field surveys in Pardubice region in the area of disappeared ponds), is shown in *Figs. 8–11*. These are the current ponds Oplatil I and II and Malá Čeperka. While the Oplatil I and II ponds are located partly on the site of the historical Oplatil pond and partly on the site of historical marshes and wet meadows, Malá Čeperka pond is entirely located on the site of historical marshes and wet meadows in the vicinity of the site where the Velká Čeperka pond was located. On the site, there are currently several water bodies created by gravel-sand mining, and there is also a cottage settlement. Today, this site is used both for recreation and gravel-sand mining. The historical pond Rozkoš is now almost entirely afforested.

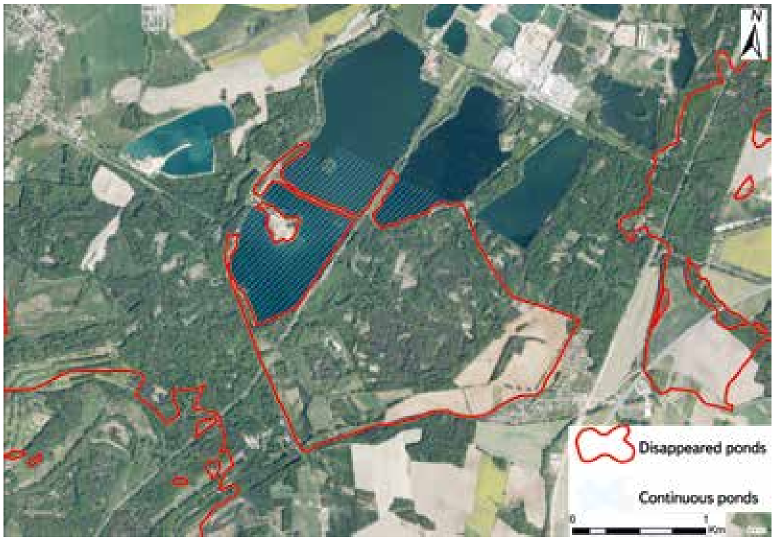

Fig. 7. Sites of historical ponds Oplatil, Rozkoš, and Velká Čeperka based on the current orthophoto map of the Czech Republic

Fig. 8. Oplatil I. pond (August 2022)

Fig. 9. Recreational use near the Machač water reservoir, created by gravel-sand mining (August 2022)

Fig. 10. Malá Čeperka pond (August 2022)

Fig. 11. One of the access roads to the Malá Čeperka cottage settlement (August 2022)

Fig. 12. Sites of disappeared ponds in the Chlumec nad Cidlinou area based on the current orthophoto map of the Czech Republic

Fig. 14. The current state of the landscape on the site of the disappeared Chlumecký pond near Chlumec nad Cidlinou (March 2023)

Fig. 13. The current state of the landscape on the site of the disappeared Chlumecký pond near Nové Město (March 2023)

Fig. 15. Waterlogged arable land on the site of the disappeared Chlumecký pond near Chlumec nad Cidlinou (March 2023)

One of the most extensive sites where ponds have been replaced mainly by arable land is the landscape to the east of Chlumec nad Cidlinou, where the Second Military Mapping map recorded Chlumecký, Písecký, and Kosický pond. In these areas, on arable land (but also on permanent grassland), there are visible signs of seasonal waterlogging both at the site of disappeared ponds and in their vicinity, at the site of the historical occurrence of swamps and wet meadows *(Fig. 12)*. The current state of the landscape at the site of the disappeared Chlumecký pond, or in March 2023, is shown in *Figs. 13–15*. It is a permanent grassland showing signs of waterlogging, partly with reeds, near Nové Město. Furthermore, the current state of the landscape used as arable land near Chlumec nad Cidlinou is shown, where waterlogged sites are also partially covered with reeds.

DISCUSSION

While in the past all man-made water bodies equipped with a dam or excavated by human activity were considered ponds [2], nowadays there are a large number of types of water bodies according to use and no official database is known to distinguish ponds from other water bodies. Even in the mid-19th century, the difference between a reservoir (fire, household, etc.) and a pond (i.e., a water body intended exclusively for fish breeding) was not yet clearly defined. For this reason, we can consider all water bodies drawn on maps of the Second Military Mapping as ponds [2, 3].

The results from the Pardubice region regarding the area of ponds according to stability do not correspond to the data for the whole of the Czech Republic, which are presented in *Tab 1*. In Pardubice region, from the mid-19th century to the present, disappeared ponds have the largest representation – 66.11 % of the area of all ponds according to stability, followed by continuous ponds with 36.56 %, and new ponds represent the smallest area with 13.4 %; however, for the entire Czech Republic it is stated that the smallest area of ponds was in the mid-19th century and has been increasing slightly since then. This difference is probably due to the fact that, in the lowlands, there was generally pressure for further removal of ponds only in the second half of the 19th century in connection with the sugar beet cultivation [2–7]. Two thirds of the sugar beet production in Bohemia was grown in Polabí. For this reason, ponds disappeared in the second half of the 19th century, although a large number of them had already disappeared [2, 16], which is evident, for example, from the maps of the First Military Mapping and Müller's mapping. In *Figs. 3–5*, this trend is also confirmed for the Pardubice region.

The methodology used in landscape ecology (e.g., in the study by Skaloš et al. [17]) was chosen for the categorization of ponds according to stability into disappeared, continuous, and new. In the event that a historical pond was preserved on a smaller area, the preserved area of this pond was classified as a continuous pond, and the disappeared area of the same pond was classified as a disappeared pond. And similarly, if the area of a pond was larger compared to the past, this area was classified as a new pond. On the other hand, in the project dealing with historical ponds of the Czech Republic, the area and location of a specific historical pond recorded on the Second Military Mapping was considered a starting point, and for present interpretation, it was assigned the attribute of a continuous pond (in approximately the same extent / in a significantly smaller extent / in significantly larger extent) or a disappeared pond (completely disappeared / currently only very small / currently a different type of water body) [2, 18]. The given data show that new ponds were not considered and that the area of a specific historical pond was in no case divided into a continuous and disappeared part. However, this project has initial comprehensive information about the location of historical ponds.

CONCLUSION

The area of all types of ponds (according to stability) makes up 6.83 % of the defined area of Pardubice region. Disappeared ponds have the largest representation – a total of 66.11 % of the pond area according to stability (2,262.57 ha). Continuous ponds follow with 36.56 % (840.51 ha) and new ponds have the smallest area with 13.4 % (319.29 ha). The average area of disappeared ponds is 23.82 ha; for continuous ponds it is 11.68 ha, and for new ponds only 4.91 ha. Arable land currently covers 49.31 % of the area of disappeared ponds, the share of forest land and permanent grassland is also significant (27.96 % and 12.12 %, respectively). Swamps and marshes replaced 3.85 % of the area of the disappeared ponds, while built-up areas make up 4.51 % of their area. Other land use categories occupy only small areas in the places of disappeared ponds.

The results presented here contribute to the understanding of the dynamics of changes in ponds at the landscape level and are important for basic research in landscape ecology. From a practical point of view, the presented results can be a source of inspiration for those who decide on the management of ponds in a landscape context. The use of this study for the restoration of ponds in the places of their historical occurrence (disappeared ponds) is very specific. It can therefore be reasonably assumed that such sites are optimal in terms of functional landscape parameters and management of ponds as one of the wetland types. In the past, there have been major changes in terms of the use of the landscape in this area, mainly caused by intensive agricultural activity and the associated modifications of watercourses and land reclamation. Therefore, there is significant scope for designing landscape changes in the catchment area in order to retain water in the landscape. One of the possibilities offered is the restoration of ponds, i.e., one of the types of wetland habitats as one of several ways of combating drought.

Acknowledgements

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Optimization network model of water management systems

PETR VYSKOČ, JIŘÍ PICEK

Keywords: water resources — water supply — water management system — software

ABSTRACT

The article describes software aimed at analysing water management infrastructure and identifying critical points for water supply and assessing possible measures aimed at optimising the water supply function of the water management system. The computational procedures integrate the evaluation of hydrological characteristics of an area, parameters of water management and water supply systems, and water supply requirements. The solution uses graph theory and network flow optimization (out-of-kilter algorithm is applied). The program is implemented as a PC application and equipped with a user interface.

INTRODUCTION

In the Czech Republic, like elsewhere in the world, we are increasingly encountering local and regional water shortages. The reason is both the changing demands (of the population, industry, power engineering, agriculture, etc.) for water supply, and in particular changes in the availability of water resources, caused primarily by changes in climatic conditions. Possible future negative impacts of drought can be mitigated or eliminated by a number of preventive measures. The measures under consideration are still mainly oriented towards increasing the capacity of water resources as such; however, much less attention is paid to the possibility of optimizing the use of these resources. These measures also include optimization of the storage function of water management and water supply systems (WS), including their interconnection or modification of their technical parameters.

The risks of the climate change impact on water resources and their use have been the subject of a number of research projects and studies in the last 15 years, in which T. G. Masaryk Water Research Institute (TGM WRI) has also significantly participated. These studies were mainly focused on the assessment of possible future risks in securing water supply requirements and they mainly used hydrological and water management balance modelling methods, including simulation models of the storage function of water management systems. The need to focus also on the assessment of possible mitigating measures at risk locations aimed at streamlining the management of water resources in this context led to the need to supplement these already existing and used tools with another tool aimed at optimizing the WS parameters and water distribution from water resources, especially water reservoirs, to consumption areas. When creating this tool, the significant methodological background was used which was created at TGM WRI (Václav Zeman, Břetislav Lank et al.) at the turn of the 1980s and 1990s, when the Model system for designing water management systems was designed and implemented [1]. Part of these models was also the Network model of water management system [2]. At the beginning of 1990s, this model was experimentally verified in a pilot catchment area. However, the then state of information technology development significantly limited its application. According to the solution principles of this model, the software *"Optimization network model of water management and water supply systems"* (system designation VSTOOLS.OPTIM) was developed as part of the project *"Water management and water supply systems and preventive measures to reduce risks in the supply of drinking water"* (project no. VI20192022159), financed by the Ministry of the Interior as part of Security Research of the Czech Republic in 2019–2022. The software is designed to analyze water management infrastructure and determine critical points to ensure water supply and assess possible measures to optimize the storage function. The application thus functionally complements existing tools for solving the climate change impact on water management systems and water supply with an optimization element.

METHODOLOGY

Software implementation of the optimization network model is based on the concept of the so-called "Network model of the water management system", defined and described in detail in [2]. This concept is based on the system concept (a system as a set of elements that have certain mutual relationships between them), from graph theory (vertices on the graph represent elements of the system and the edges of the graph represent links between the elements), and methods of network flow optimization. In this sense, the water management system is therefore considered as a set of elements that have certain relationships with each other, creating a purposeful whole.

According to [2], the water management system (WS) can be described as follows:

$$WS = [P, k, m, u, t, A, g, d, h, c]$$

where

P is the set of WS elements
k function which assigns an integer $k(p)$ to each element p of the set P, which is an identifier of the time period
m function which assigns an integer $m(p)$ to each element p of the set P, which is an identifier of the water circulation subsystem
u function which assigns an integer $u(p)$ to each element p of the set P, which is an identifier of the position of WS profiles
t function which assigns an integer $t(p)$ to each element p of the set P, which is an identifier of the type of the WS element
A the set of activities of WS elements

g	mapping of set A to set P2, where P2 is the set of all ordered pairs of elements belonging to P
d	function which assigns a positive real number d(a)to each activity a of the set A, called the lower bound of the activity capacity (edges of the graph)
h	function which assigns a positive real number h(a) to each activity a of the set A, called the upper limit of the activity capacity (edges of the graph)
c	function which assigns a real number c(a) to each activity from the set A, called the cost of the activity (flow along the edge of the graph)

For activities representing input variables of the system function, d(a) = h(a) applies; for activities representing output variables of the system function, d(a) < h(a) applies.

If the input and output activities are determined in such a way that there is more than one output activity solution for a certain choice of input activities, for complete function identification it is possible, for example, to determine the method of selecting the output activity values by specifying a purpose function. Each activity is assigned its "cost" evaluation c(a).

The method of selecting a solution is that we require that

$$\sum c(a).x(a) = \min$$

where

c(a)	is the "cost" evaluation of activity a
x(a)	value of flow through activity a

On the WS model defined in this way, the optimal values of "activities" or water circulation are assessed. To determine the optimal network flow, the model uses the out-of-kilter algorithm [3].

The water management system model is based on the decomposition of the system in terms of:

- influence of water circulation on environmental subsystems of surface water, groundwater and water use, as well as the types of elements (e.g. water reservoir), which determine what "activities" these elements exhibit (e.g. water accumulation in a reservoir),
- space (WS elements and flow relationships between them),
- time (transfer of water supplies from one period to another through the accumulation of water in water reservoirs).

Among WS subsystems and their elements, the structural model recognizes the following activities:

PZAS	initial water supply in reservoirs
PPPO	natural inflow from inter catchments
AGVY	aggregate water discharges (sum of discharges in an inter catchment)
PPPZ	abundance of groundwater source
KZAS	final water reserves in reservoirs
LOOD	water consumption
AGOD	aggregated water abstractions
VYPA	water vapour
ODTO	the run-offs from the last WS profile
OPPZ	abundance of the groundwater source unused for the abstraction
PRUT	flow in a watercourse between WS profiles
PREV	water transfer between WS profiles
VODO	water supply (transport route in the water use subsystem)
KUPR	water treatment plant capacity
MZAS	interim water reserves in reservoirs
CTOK	total water flow through network

WS element types determine what activity the element exhibits in the water cycle structure. The types considered are:

NAD	water reservoir
POV	surface water abstraction
POD	groundwater abstraction
VYP	discharge to surface water
BPF	balance (control) profile on the river network
SPO	consumption area
UPR	water treatment plant
UZL	transport route junction (in the water use subsystem)

The activities of WS elements are illustrated in *Fig. 1*. Here, ZAC represents the beginning of the system, PVS represents WS elements, and KON the end of the system. The system elements are shown in more detail in *Fig. 2*. PRF represents the profiles on the river network (water reservoirs, points of water abstraction and discharge, and balance profiles), POD represents points of groundwater abstraction, UPR represents water treatment plant, and SPO represents consumption area. (Surface water subsystem elements and activities are shown in blue, groundwater subsystem in green, and water use subsystem in yellow, system elements are shown in grey.)

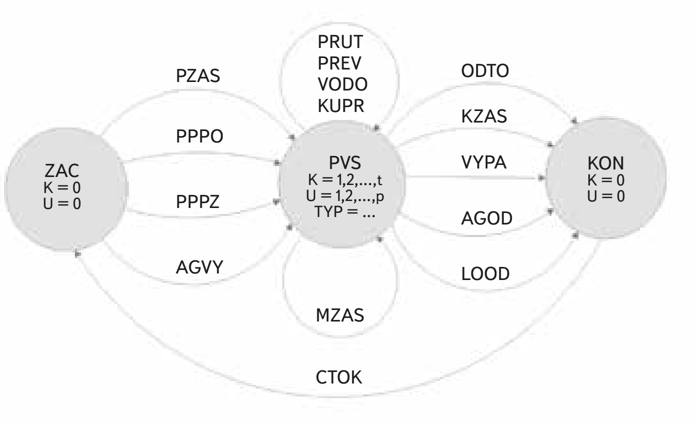

Fig. 1. Water management system model: system element and its activities

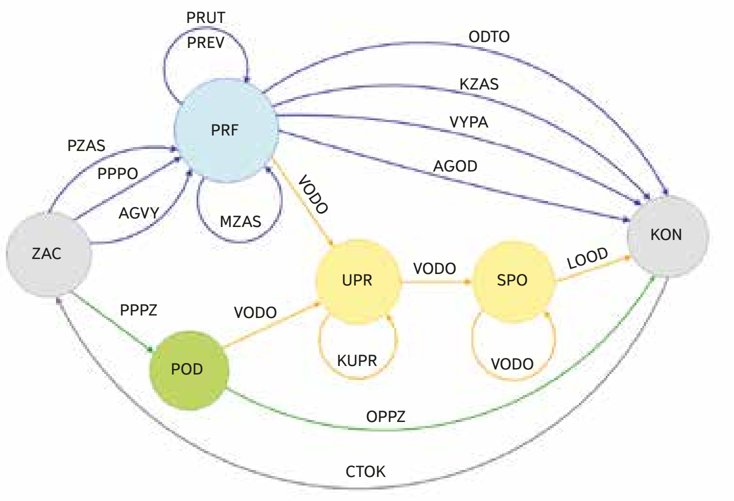

Fig. 2. Water management system model: elements of the surface water, groundwater and water use subsystems

When applying the model, the following modifications can be introduced:

- Aggregation of abstractions and discharges: Since there are a large number of specific elements, especially water abstractions and discharges, and for practical reasons it is not expedient to define them all as WS elements, only decisive objects and profiles are selected that represent the WS in its function. The influence of other elements is aggregated to these objects and profiles.
- Grading of activities: The above-mentioned activities of the system elements can be "graded" for the required determination of the purpose function, i.e., the activity of the element can be divided into several edges of the graph with different cost assessment. This is typically expedient, for example, for the MZAS activity, which can be divided according to the volumes of reservoirs defined by dispatcher graphs, for the LOOD activity in the event that a possible deficit in water supply is required to be distributed over time, or for the PRUT activity for the need to ensure minimum flows.
- Water treatment plant capacity: Since flow capacity can only be assigned to graph edges (not vertices) in the model, it is necessary to represent the water treatment plant with two vertices and to assign the treatment plant capacity to the edge between these vertices.

The model application requires the following input data (in the range given by the WS in question):

- Description of the watercourse network.
- Identification and location of relevant elements (profiles, objects), including the position of profiles on the watercourse network.
- Identification of water transfers and transport routes (water pipes), determination of the initial and final object/profile.
- Time series of natural flows in WS profiles.
- Requirements to maintain minimum flow rates.
- Requirements for water abstractions.
- Data on water discharge.
- Technical parameters of the objects – volumes of water reservoir storage space, capacity of water transfers and transport routes (water pipelines), capacity of water treatment plants.
- Priorities for meeting requirements for water use – water abstractions, maintenance of minimum flows, maintenance of reservoir water volume.

The model application takes place in the following steps and the relevant algorithms:

1. Filling in the model input data (see above).
2. Transformation of WS objects and links between them into the form of an oriented graph in the form of the structural model described above.
3. Filling the lower and upper limits of the capacities of the graph edges, representing the individual activities described above (see the input and output variables of the system functions above).
4. Determination of the objective function through the "valuation" of the edges of the graph. The valuation is based on the specified priorities for fulfilling individual requirements for water use.
5. Calculation of the optimal network flow using the out-of-kilter algorithm.

SOFTWARE

The optimization network model software (VSTOOLS.OPTIM) is designed as an application to run on a user's local computer. The condition for running the application is the latest version of Microsoft Windows operating system with the current version of Microsoft NET Framework platform installed. Hardware requirements are determined only by the requirements of the operating system and the Microsoft NET Framework platform; however, the quality of the hardware equipment determines (in direct dependence on the scope of the processed data) the speed of the calculations performed by the application. The software was implemented using the Microsoft Visual Studio development environment in the Visual Basic programming language. From the point of view of the development and implementation of software applications, it is a proven complex tool used as standard for the development of both simple and very complex applications.

The application structure is made up of individual cooperating program modules, which together form a so-called "assembly". From the functional point of view, it mainly concerns the application administration environment, calculation modules, editor and data viewer, and configuration files of the application and user settings. Part of the application is a purpose-built geodatabase organized on the principle of relational databases. Data sets (input data for calculations and calculation results) are stored in the format of structured text files (txt, semicolon separator, header in the first line of the file). Reference datasets (especially vector map layers) are stored in Esri shapefile (shp) and mif/mid MapInfo formats, and the underlying reference raster data in hrr format. The use of the mentioned data formats was chosen with the aim of maximally simplifying the handling of data even outside the means of the implemented software, so that the users can also access the data from the applications (tools) they normally use.

The application enables the calculations and data evaluation mentioned below in a graphical user interface (GUI). In addition to the calculation functions themselves, the application also offers tools for organization the calculation, the administration of input data, and the display and presentation of the calculation and evaluation results, especially in the form of tables, maps, and graphs. Examples of the user interface are shown in *Figs. 3* and *4*.

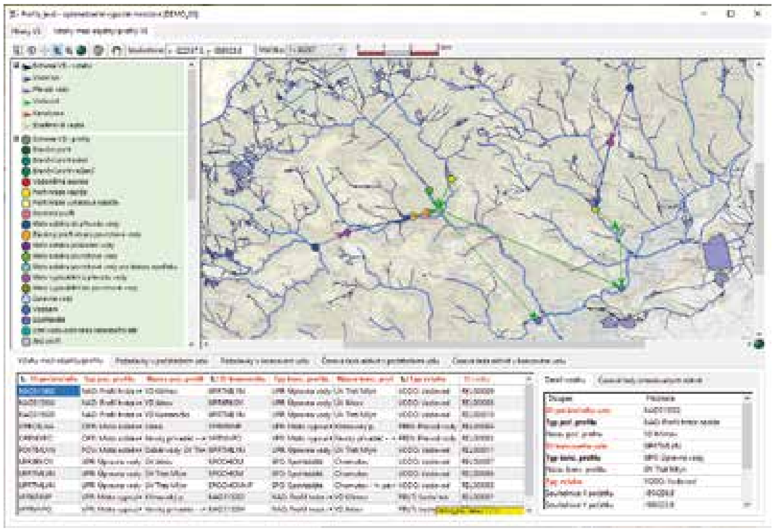

Fig. 3. User interface: model input data

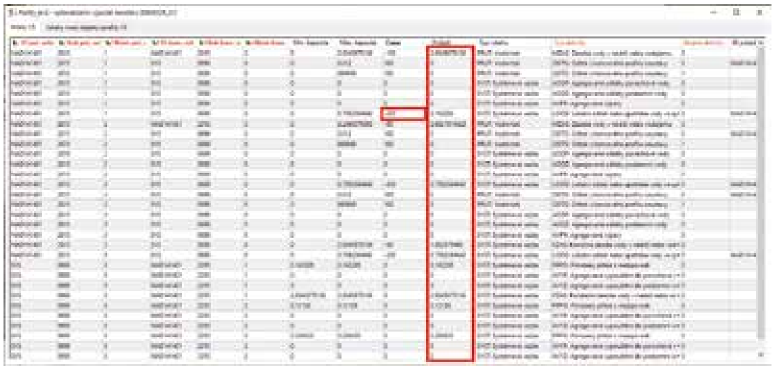

Fig. 4. User interface: model output data

The application was created as part of the "VSTOOLS" group of tools. It is a gradually developed, updated and expanded modular system of tools for performing various types of analyses, calculations and modelling of water management phenomena. The optimization model software is designed in such a way that, through a suitable data interface, it enables communication with the database and other programs used in TGM WRI when solving the storage function of water management systems and water management balances. These are mainly the Simulation model of the storage function of water management systems [4] and the BILAN hydrological balance model [5]. Using this model, time series of flows are modelled using the chronological hydrological balance method, which enter both the simulation and optimization network model of the WS storage function. Relationships between the database and the models are illustrated in a simplified way in *Fig. 5*. The relevant records of ISVS-VODA (Information System for Public Administration in Water Management) [6] can be used as a database, especially the records of water abstractions, discharges and accumulations maintained according to [7] for the purposes of drawing up water balances. To describe the river network structure, it is expedient to use the Structural model of watercourses (i.e., a description of the river network broken down into watercourse sections) maintained as part of the Digital Water Management Database (Digitální báze vodohospodářských dat, DIBAVOD) [8]. The Hydroecological Information System (Hydroekologický informační systém, HEIS VÚV) database [9] is used in TGM WRI as a tool for the integration of input data (i.e., filling in links between individual records).

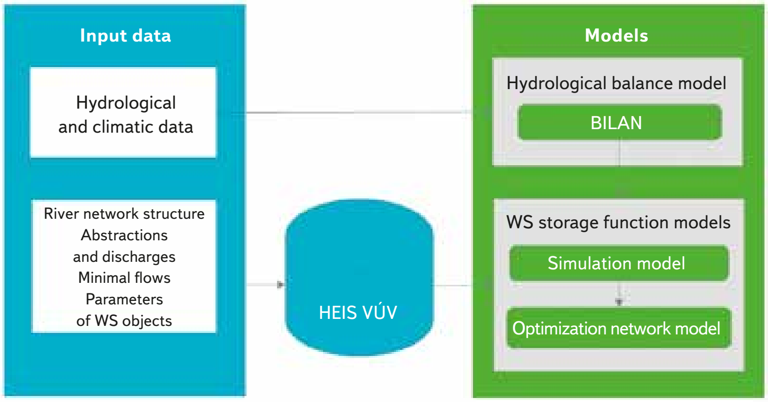

Fig. 5. Tools for dealing with the issue of the storage function of water management systems

CONCLUSION

The WS optimization network model described above is sufficiently universal and can be applied when assessing the storage function of any WS. The use of graph theory ("network" model) and the algorithm for finding the optimal flow of networks makes it possible to assess as a whole more complex structures of water management and water supply systems from the point of view of optimizing the fulfilment of their storage function. Elements of surface water, groundwater, and water use subsystems can be integrated into the model, thus assessing the provision of water distribution from water sources to its consumption in municipalities. The relevant software was developed and its functionality verified as part of the Security Research project of the Czech Republic. The use of the model is expected especially in the TA CR project *"Water systems and water management in the Czech Republic in conditions of climate change" ("Water Centre")*, possibly in other projects and studies focused on the issue of drought and water shortage and the assessment of possible mitigating measures.

Acknowledgements

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Interview with Mgr. Petr Hladík, Minister of the Environment

The Minister of the Environment wants to give people the opportunity to live in harmony with nature, and by that he does not mean just planting trees on city streets. Why does Petr Hladík call the Ministry of the Environment the Ministry of the Future? The use of rainwater, solar panels, and deposit PET bottles no longer have to represent an excessively progressive approach, but a standard for returning to our planet at least the minimum of what we take from it. Grey water subsidies? Why should we want it and what will we actually benefit from it? The new Minister of the Environment, Petr Hladík (KDU-ČSL), answers these questions for VTEI journal.

Mr. Hladík, what do you consider to be your biggest challenge as Minister of the Environment?

There are so many challenges ahead of us this year, it's impossible to choose just one. For example, we will continue with the "Nová zelená úsporám Light" (New Green Savings Light), which is intended for households with lower incomes. It is a subsidy for the insulation of windows, facade, ceiling, and other parts of the house. An applicant can receive up to 100% subsidy from the state, up to 150,000 CZK. Another big challenge is the crisis amendment to the Water Act, which responds to deficiencies in practice and puts them in order. The most famous case that pointed out the shortcomings was the accident on the Bečva river. We also want to focus on deposits for cans and PET bottles, which we would like to introduce in the spring. The closest possible date when it would be possible to have deposit cans and PET bottles in the Czech Republic is 2025. The best waste is the one that is not created. However, if it is already created, it is important to reuse it in production or as a source of electricity or heat. Support for the circular economy is key to creating sustainable development in the Czech Republic. I want the Ministry of the Environment to become a strong and self-confident department that will give people the opportunity to live healthier and in greater harmony with nature.

You mention the crisis amendment to the Water Act; what will it contain?

Among other things, the amendment is intended to ensure that we are able to prevent similar events as best as possible, such as the accident on the Bečva river in 2020. We want to introduce online monitoring of wastewater discharged from industrial operations into rivers at the outlets of significant polluters, where wastewater discharged by them may pose a significant risk in terms of an accident on watercourses. We also added this to the updated government programme statement. Among other things, the amendment clarifies the roles of the entities involved in dealing with accidents and increases the penalties for the illegal discharge of wastewater containing dangerous substances. We expect the amendment to be approved this year. As part of the amendment, we also launched a pilot project for monitoring outlets on a selected section of the Labe – about 30 kilometres between Brandýs nad Labem and Mělník – which is taking place thanks to the Water Research Institute. I see the role of TGM WRI as very important. The data that the Institute brings us can be beneficial not only to water managers and the Ministry, but we also need it because of the changing climate. For example, the Institute can provide field research work. With equipment for sampling and evaluation of water samples, it can measure the pollution of streams. It has been dealing with the assessment of the status of water bodies for a long time and has the necessary technical and professional capacity for these selected areas of water management.

The issue of power engineering is closely linked to the environment. What is your view on this relationship, and what steps are you planning to take to support the use of renewable energy sources?

I already hinted it a little at the beginning of the interview. It is important that power engineering policies are adopted with regard to their environmental impact and are in line with sustainable development goals. I see the solution in a combination of nuclear and renewable energy sources with the aim of reducing dependence on fossil fuels. Therefore, as a government, we try to support the installation of photovoltaics as much as possible. Within two years, we want to have a total of 200,000 panels on roofs, which is double the original programme statement. I believe we can do it with no problem. Last year alone, over 55,000 households applied for a subsidy for a solar power installation for more than 10 billion CZK, which is four times more than in 2021. The received applications represent a total installed power of 380 MWp, and the average power per installation on a family house is around 7.5 kWp. Thanks to this, a household can save over 30,000 CZK a year and, at the same time, cover up to 70 per cent of electricity from its own sources. However, the development of energy communities must also go hand in hand with this.

The Czech Republic is a bit behind in developing energy communities, in other countries they are much further. When will we have it?

The first change in the Energy Law has already occurred. The so-called LEX OZE I has already been published in the collection of laws. Now the second amendment is being discussed, which concerns energy communities. I assume that there will be a settlement of comments and a gradual process towards the government and parliament. The third legislative change will follow, which should bring energy storage, flexibility and aggregation to the Czech Republic. All of this together will bring an absolutely fundamental revolution to Czech power engineering, which is why we mentioned these changes in the revised programme statement. As the Ministry of the Environment, we support the creation of energy communities, which is probably not a surprise. However, we also have a large number of mayors and deputy mayors who want their cities and towns to become energy communities so that they can produce, share and store energy together. As a ministry, we have subsidy titles for this, so what we really need now is the legislation.

Let us talk now about the area of water management. What is your opinion on current water management methods and what changes would you like to see implemented?

It is evident that current water management is aimed at protecting water resources, ensuring the supply of high-quality drinking water, and supporting

Photo: archive of Mr. Hladík

the restoration of riverbeds and natural wetlands. All this cannot be done without measures to eliminate the risk of pollution by dangerous substances, without minimizing the causes of accidents, especially for areas protected not only from the point of view of drinking water sources, but also from the point of view of the protection of water-bound ecosystems.

Although the issue of water management also falls under the responsibility of the Ministry of Agriculture, I would like to improve water management and the protection of water resources together with Minister Zdeněk Nekula, who is also my party colleague. This is where I see the priority of our interdepartmental cooperation, for example in the area of increasing the efficiency of water management.

Speaking of efficient water management, you also focus on the capture of rainwater and its reuse in the previously mentioned New Green Savings subsidy programme. How specifically?

That's right. We offer people a subsidy for collecting and using rain and wastewater. The captured water can be used for watering the garden or as service water. The benefit is saving expenses and drinking water consumption. The subsidy can range from 27,000 to 105,000 CZK. A new tank, ideally located underground, or a cleaned underground cistern or a specially adapted well can be used to accumulate rainwater. In the case of wastewater, the subsidy applies, for example, to the use of grey water – that is, from wash basins, baths, showers, and sinks.

Will you be actively involved in cooperation with neighbouring countries regarding the protection of common water resources?

As someone said, water knows no boundaries and naturally crosses them. Cooperation with neighbouring countries is therefore crucial for a sustainable and effective solution to water management problems. One of the important tools for cooperation is the European Union and its water management policy. We can share experience and information with Member States. It is necessary to maintain working relationships, especially with our neighbouring countries, with whom specific problems often need to be solved. Simultaneously, I will continue to support activities at the level of organizations such as the International Commission for the Protection of the Elbe River (ICPER).

Another big issue is drought. What are your priorities to address drought and water scarcity? Through what adaptation measures in water management can the Czech Republic best prepare for expected climate changes?

Drought and water scarcity can be faced with a whole range of measures. It is mostly a set of complex measures that complement each other. A clear priority is the retention of water in the landscape and the restoration of natural water regime. However, we must not neglect the protection of water sources, which I consider necessary to maintain the availability of water for households, agriculture, industry, power engineering, and others. Moreover, in the government programme statement, we committed ourselves to the constitutional protection of water.

Amending existing laws and adopting more effective legislative tools to protect water and agricultural land will help us fight drought and its effects. Protection and improvement of the landscape via restoration of wetlands, forests, pools, small water reservoirs and floodplains, management of valuable habitats, planting vegetation, improvement of spatial and species composition of forests or restoration of watercourses will help to minimize the effects of drought and improve water quality. Several subsidy programmes are also in progress (not only) to support water retention in the landscape; for example, support for the construction of new sources of drinking water, water pipes, interconnection of water supply systems, rainwater absorption and utilization systems, drinking water treatment technologies, sewerage and wastewater treatment systems. Priority support takes place through the National Recovery Plan and the Operational Programme Environment (OPE). Approximately one billion CZK has been spent so far. However, OPE has a total of more than 14 billion CZK ready for the construction of sewers and wastewater treatment plants. Another total of 10 billion is aimed at the use of rainwater, the creation of pools and small water reservoirs, green roofs, but also the support of environmentally friendly farming on agricultural land and anti-flood measures.

You often refer to the Ministry as the Ministry of the Future. What should the future look like according to the new Minister of the Environment?

I want the Ministry to completely change Czech power engineering through subsidies. So that leaving coal is not a bad move, but a used opportunity. So that we no longer wonder if we are not too progressive, but that this approach is the standard. We must not forget that the Earth was entrusted to our care and we have no other. I will make an effort to ensure that we will pass it on to future generations in good condition. The current government places much greater emphasis on the climate than previous governments. We are experiencing a really big change, and in order to be able to prepare for it, we need to support not only households, but also industry and companies. Also because of what is happening in Ukraine, people and companies are now more willing to decide what kind of energy they will use in the future.

Thank you very much for the interview.

Ing. Josef Nistler

Mgr. Petr Hladík

Mgr. Petr Hladík, born 28 September 1984, graduated from the Faculty of Informatics at Masaryk University, majoring in Service Science, Management and Engineering. He joined the KDU-ČSL in 2010 and was elected to the council of the Brno-north district. In 2016, he became the first deputy mayor of the city of Brno. In 2018, he defended his position and became the first deputy mayor for the environment. In 2022, he was again elected as a representative and continues to work as an ordinary representative of the city of Brno. In 2019, he became vice-chairman of the KDU-ČSL and chairman of the KDU-ČSL expert commission for the environment. Together with Anna Hubáčková (the former Minister of the Environment), he prepared the government programme statement in the field of the environment. From 9th January 2023, he was the Deputy Minister of the Environment. He became the Minister of the Environment on 10th March 2023.

Photo: 123rf.com

AI – our first interview

The idea of interviewing artificial intelligence was brought to us by an article from a completely different field than our water management. However, we also had the idea to test the current level of artificial intelligence on topics that are close to our field. Based on examples of questions and generated answers, you can judge for yourself how useful this tool is in water management. The structure of the questions is built from the simplest to the most complicated in the form of comments on the results of forecasting models, or the effectiveness and efficiency of legal regulations and directives. ChatGPT was chosen for communication. However, if one does not try this tool, one has no idea what it is; it is then up to you to assess the interview itself.

However, before the interview, allow us a few words of introduction. Artificial Intelligence (AI) has become one of the most discussed topics in the field of technology in recent years. AI encompasses a wide range of technologies that allow computers to learn and recognize patterns, predict outcomes, and even simulate human thinking. This technology is used widely, in healthcare and production to financial services and media. One of the biggest benefits of AI is its ability to solve complex issues and process huge amounts of data faster. This enables, for example, doctors to diagnose diseases faster, companies to identify new business opportunities, and authorities to improve citizen safety and protection.

However, the development of artificial intelligence can also be accompanied by several challenges and concerns. One of the most fundamental concerns is the reduction of jobs, as many work activities that were previously done by humans may be replaced by AI. There are also concerns about privacy and data security, as AI has the potential to collect and analyze large amounts of information about people. It is therefore important to ensure that AI is used responsibly and ethically.

Artificial intelligence has huge potential to improve our lives; however, its use needs to be carefully considered. Therefore, it is necessary to ensure that it is used in a way that brings benefits to society while respecting people's privacy and security. It is essential that developers, politicians, and the public work together to define fair and responsible principles for its use.

Now, let us start the interview:

Hello, I would like to talk to you about water management. Is it possible?

Hello! Yes, I would like to talk to you about water management. What specific questions and interests do you have in this area?

What is water and how important is it to life on Earth?

Water is a chemical compound that is made up of two hydrogen atoms and one oxygen atom (H_2O). Water is essential for life on Earth, as it forms the basic component of all living organisms and is a key component of the environment. Water is important for many processes, such as digestion, metabolism, and excretion of waste products.

Water also plays an important role in climate regulation as it helps maintain a constant temperature on Earth and transfers heat energy from one place to another. Water also serves as a source of energy, such as hydroelectric power stations.

Last but not least, water is essential for agriculture and industry, as well as for human activities such as drinking, cooking, and washing. Overall, it can be said that water is an essential element for sustaining life on Earth and is important for the functioning of the entire ecosystem.

Name the areas on Earth that are experiencing water scarcity/lack of drinking water.

Water scarcity and lack of drinking water are huge problems in many areas of the world. Some of the most affected areas are:

- Sahel in Africa,
- Middle East and North Africa, including Syria, Jordan, and Iraq,
- Indian subcontinent, especially northern and western India and Pakistan,
- South and Southeast Asia, including Bangladesh, Thailand, and Vietnam,
- Western United States and California, US,
- South Africa, especially Cape Province and other areas.

These areas are either too dry to meet water needs or suffer from insufficient infrastructure to supply water to the population. These problems are often caused by climate change, excessive water consumption, and excessive water extraction for industrial and agricultural purposes.

You mentioned climate change. How big of an impact does this change have on water security?

Climate change has a major impact on water availability worldwide. As temperatures rise and precipitation patterns change, extreme weather events such as droughts, floods, and storms occur that have a significant impact on water supplies.

Droughts are becoming more frequent and intense in many areas of the world, resulting in a drop in groundwater levels and depletion of water resources. In addition, climate change also affects precipitation, which can lead to water shortages for agriculture and drinking water for residents.

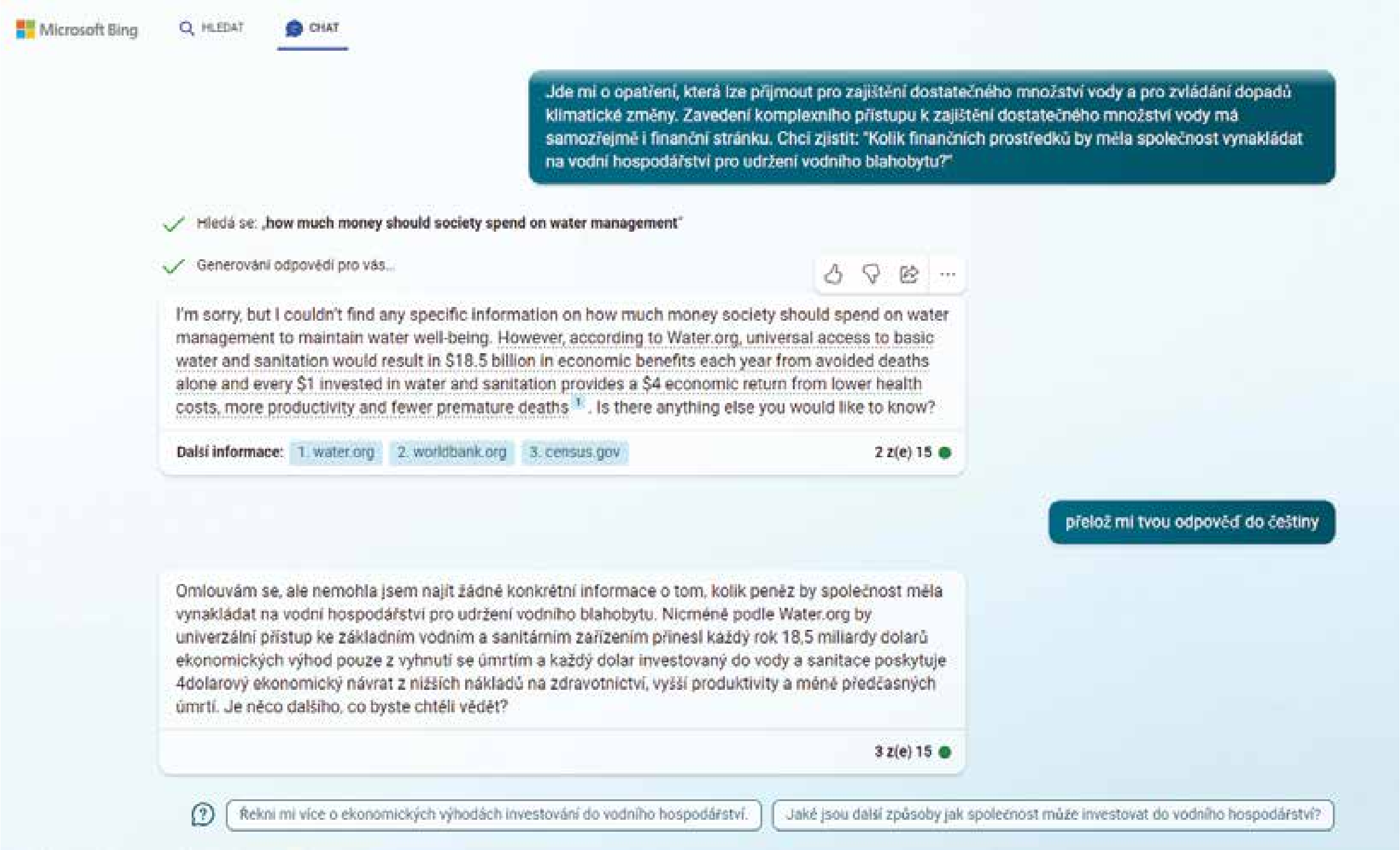
Additionally, rising temperatures can cause increased evaporation of water from sources such as lakes and rivers, which also reduces the availability of water for humans and animals. As a result, it becomes increasingly difficult to secure sufficient water for agriculture, industry, and human needs.

Overall, it can be said that climate change is one of the main factors that cause water scarcity, and that has a great impact on the living conditions of the population.

You mentioned climate change consequences with water. What do you think are the appropriate measures to ensure a sufficient amount of water?

Many measures can be taken to ensure sufficient water and to manage the impacts of climate change. Here are some examples:

- Improving water supply infrastructure – this includes building new dams, reservoirs, canals, and aqueducts to transport water to where it is needed.
- Conservation of natural resources – in this way water losses caused by evaporation and soil erosion can be minimized. Furthermore, it is necessary to protect forests, which play an important role in regulating rainfall and preserving water resources.
- Implementation of water-saving measures – in this way water consumption in households, industry, and agriculture can be reduced. This includes, for example, the installation of energy-saving equipment, irrigating plants using technologies with low water demands_and using recycled water.
- Promoting sustainable agriculture – farming practices such as switching to no-till farming, using organic fertilizers, and drip irrigation can help minimize water loss and maintain soil fertility.



Jde mi o opatření, která lze přijmout pro zajištění dostatečného množství vody a pro zvládání dopadů klimatické změny. Zavedení komplexního přístupu k zajištění dostatečného množství vody má samozřejmě i finanční stránku. Chci zjistit: "Kolik finančních prostředků by měla společnost vynakládat na vodní hospodářství pro udržení vodního blahobytu?"

✓ Hledá se: **„how much money should society spend on water management"**

✓ Generování odpovědí pro vás...

I'm sorry, but I couldn't find any specific information on how much money society should spend on water management to maintain water well-being. However, according to Water.org, universal access to basic water and sanitation would result in $18.5 billion in economic benefits each year from avoided deaths alone and every $1 invested in water and sanitation provides a $4 economic return from lower health costs, more productivity and fewer premature deaths[1]. Is there anything else you would like to know?

Další informace: 1. water.org 2. worldbank.org 3. census.gov **2 z(e) 15** ●

přelož mi tvou odpověď do češtiny

Omlouvám se, ale nemohla jsem najít žádné konkrétní informace o tom, kolik peněz by společnost měla vynakládat na vodní hospodářství pro udržení vodního blahobytu. Nicméně podle Water.org by univerzální přístup ke základním vodním a sanitárním zařízením přinesl každý rok 18,5 miliardy dolarů ekonomických výhod pouze z vyhnutí se úmrtím a každý dolar investovaný do vody a sanitace poskytuje 4dolarový ekonomický návrat z nižších nákladů na zdravotnictví, vyšší produktivity a méně předčasných úmrtí. Je něco dalšího, co byste chtěli vědět?

3 z(e) 15 ●

Bing Chat – questioning AI on-line

— Improving the management and monitoring of water resources – effective management of water resources and monitoring of water quality and quantity can help minimize water losses and ensure sufficient water supplies for future generations.

Overall, a comprehensive approach to water sufficiency needs to be put in place, encompassing all these elements and tailored to local conditions and needs.

The introduction of a comprehensive approach to ensuring a sufficient amount of water also has a financial aspect. How much money should society spend on water management to maintain water well-being?

It is difficult to determine the exact amount that society should spend on water management to maintain water well-being, as it depends on many factors, such as the extent and nature of water problems, the need for infrastructure, economic conditions, etc.

However, a 2019 United Nations report estimated that investment in water infrastructure would need to reach around $1.7 trillion annually over the next decade to ensure a sustainable water supply for all people in the world. This amount includes not only investments in new infrastructures but also the maintenance and modernization of existing equipment and systems.

It is important to note that spending money on water management may seem like a high cost, but it can bring many benefits in the long run. Improving water management not only ensures the sustainability of water supplies for future generations, but also brings benefits in the form of reduced healthcare costs, increased productivity in agriculture and industry, and reduced risk of disasters caused by floods and droughts.

What development can be expected in water management in the next thirty years?

In the next thirty years, water management can be expected to be increasingly affected by climate change and the growing demand for water from various sectors. Here are some of the possible developments in the field of water management:

— Increased demand for water – as population, urbanization, and industry grow, there will be more and more demand for water. This will lead to increasing pressure on its availability and the efficient use of water resources.

— Improved technology and innovation – innovative technologies will be increasingly used to improve the efficiency and sustainability of water management. For example, improved technologies for wastewater recycling, saltwater desalination, and polluted water treatment.

— The increasing importance of restoring water resources – with climate change and more frequent extreme weather conditions, it will be increasingly important to restore water resources and improve water retention in the landscape.

— Greater emphasis on integration – water management will be more integrated with other sectors such as agriculture, power engineering, and industry to better coordinate the use of water resources and minimize conflicts.

- Increased international cooperation – as many water resources cross national borders, it will be increasingly important to improve cooperation and coordination on an international level.
- Greater support for sustainable water management – new approaches to water management will be promoted that will contribute positively to the sustainability of water resources and environmental improvement.

However, the enforcement of the aforementioned must also have its legislative framework, for example. Please name the legislative instruments in the field of water management at the EU level.

At the EU level, there are several legislative instruments in the field of water management. The following list includes some of the main ones:

- Water Framework Directive – this 2000 Directive sets out the framework for the protection of water resources in the EU, including the protection of aquatic ecosystems and ensuring the quality of surface and groundwater. This Directive aims to achieve good water status by 2027.
- Nitrate Directive – this 1991 Directive aims to reduce nitrate pollution of waters by agricultural activities, especially fertilization.
- Urban Waste Water Treatment Directive – this 1991 Directive sets minimum requirements for the treatment of municipal wastewater throughout the EU.
- Bathing Water Directive – this 1976 Directive sets minimum water quality requirements for bathing at public beaches and other swimming areas.
- Drinking Water Directive – this 1998 Directive sets minimum water quality requirements for human consumption, including maximum permitted values for certain pollutants.
- Integrated Pollution Prevention and Control Directive – this 1996 Directive sets minimum requirements for the control of water and air pollution throughout the EU.
- Fisheries Directive – this 2006 Directive sets minimum requirements for the protection of water resources that are used for fishing.

In your list, you mention the Water Framework Directive from 2000. How effective is this more than twenty-year-old legislative instrument?

The Water Framework Directive was originally adopted in 2000 to achieve good water status in Europe by 2015. This deadline was later extended to 2027. While the Directive has had some successes, the target has not been met in many areas, and in some cases, the situation has even worsened.

The main challenge to the successful implementation of this Directive was that it was issued as a framework directive, meaning that it was designed to allow Member States flexibility in its implementation. However, this has led to a large difference in the interpretation of the Directive and how Member States implement it.

The process of evaluating the Water Framework Directive's effectiveness and reviewing some of its provisions is currently underway. Following this review, it is probable that further measures will be taken to improve the effectiveness of this Directive.

Thank you for your answers and a pleasant interview.

You are welcome, it was a pleasure to answer your questions and discuss with you. If you have any other questions, do not hesitate to ask me.

(Editor's note: the answers have not been edited for content, they have only undergone language proofreading. The original interview was in Czech. This has been translated by a real person. When done in English, the responses to the questions are sometimes quite different (e.g., some non-existent EU Directives were mentioned in response to the question about EU legislation).

The purpose of communication in the form of an interview was to find out the level of knowledge of AI (in our case, ChatGPT) and the way of language composition of individual answers. It should be noted that the ChatGPT tool is not connected to the Internet, it draws all its knowledge from its "crammed" memory, which also has outages from time to time. An example can be supplementary and clarifying questions:

Please verify the information "A 2019 United Nations report estimates that investment in water infrastructure should reach about $1.7 trillion annually over the next decade."

Yes, the information is correct. A 2019 United Nations (UN) report titled "World Water Development Report 2019: Leaving No One Behind" estimates that to achieve the Sustainable Development Goals related to water, investments in water infrastructure would need to average around $1.7 trillion annually over the next decade (2019–2030). This investment should ensure that all people in the world have access to drinking water and sanitation and hygiene services, and would also improve water management infrastructure and public water resources around the world.

Unfortunately, I could not find such information. Can you specify the information for me, for example, the page of the document where this information is written?

I apologize for the misunderstanding. The information I provided is not accurate. The figures quoted above do not refer to the UN report but are estimates of total infrastructure needs published by the World Economic Forum in 2018.

The UN's "World Water Development Report 2019: Leaving No One Behind" really focuses on the challenges and needs of water management. Among other things, this UN report states that by 2030, it is estimated that around $114 billion will need to be invested annually in water infrastructure worldwide. This amount applies mainly to improving water management services and infrastructure in lower-income countries.

Again, I apologize for the incorrect information and I hope I can provide you with this information.

It can be seen from the above that in many cases the AI "invents" the answer and can claim complete nonsense. This cannot be taken as an "error", but a result that follows from the principle on which the tool works. If we compare the level of similar tools a few years ago, progress has rocketed. One can only guess to what level the AI tool will move in the next months/few years and how this higher level will respond to the same questions.

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Generated by artificial intelligence (Midjourney)

Photo on this double page: M. Sedláček

Technical Heritage of the Elbe-Vltava Waterway

From 8th November 2022 to 31st January 2023, an exhibition entitled *"Technical Heritage of the Elbe-Vltava Waterway"* took place in the atrium of the Faculty of Civil Engineering of the Czech Technical University in Prague (CTU). The exhibition included exhibition panels, an interactive model of a weir lock, a video projection screen, and a stand with a web application www.lvvc.cz. The exhibition mapped the history and development of this 324 km waterway since the beginning of the 19th century, and it is expected to continue as a travelling exhibition. The exhibition was created under the guidance of doc. Dr. Ing. Pavel Fošumpaur from the Faculty of Civil Engineering of CTU, Department of Hydraulic Structures, as part of the project *"Documentation and presentation of technical cultural heritage on the Elbe-Vltava Waterway"* administered by the programme of the Ministry of Culture to support applied research and experimental development of national and cultural identity 2016–2022 (NAKI II).

The purpose of the exhibition *"Technical Heritage of the Elbe-Vltava Waterway"* is to acquaint visitors with the history and development of the Elbe-Vltava waterway (LVVC). It focuses on the modern history of LVVC modifications since the beginning of the 19th century, when navigation of the Vltava and Elbe rivers was achieved first through regulations. From the end of the 19th century, the implementation of canalization was started with the construction of a continuous cascade of locks. Canalization was decided by the issuance of Imperial Water Act No. 93 of 1869. A systematic approach to the regulation of watercourses and an emphasis on their multi-purpose nature was only put in place in 1896, when the Commission for canalization of the Vltava and Elbe rivers in Bohemia was established. The regulation programme was subsequently laid out in the framework of the Land Waterways Act of 1901. Between 1899 and 1905, the lower Vltava was canalized to Mělník through construction of a cascade of locks. The Vltava in Prague was canalized between 1907 and 1913. The section of the Elbe from Mělník to Lovosice was canalized between 1907 and 1919, and Střekov lock was completed in 1936. The cascade of locks on the middle Elbe was put into operation according to the importance of floodplain protection. Most of the water structures were completed by the middle of the 20th century. A number of historical buildings on the LVVC are classified as important cultural heritage.

The result of these efforts is the Elbe-Vltava Waterway as we know it today. Thanks to the technical erudition of our ancestors, a set of 34 unique water structures was created, which still serve their purpose today. The exhibition documents the Vltava waterway from the Slapy dam to Mělník and the Elbe waterway from Pardubice to the state border with Germany. Although the principal purpose is to ensure navigational conditions on this waterway, according to the original plans, the set of buildings still serves many other purposes, such as flood protection, water supply, use of renewable water energy, and recreation. A number of buildings on the LVVC are part of the national property cultural heritage fund, and some buildings have the status of cultural monuments. The aim of the exhibition is to draw attention to the existence of this extraordinary set of water structures with a unique history and societal significance as well as to deepen interest in technical education, which has a long tradition in our country.

A catalogue was published for the exhibition presenting documented information about locks on the LVVC and its historical development, as well as the main results of the project. The catalogue is also available in an electronic version on the project website. In addition to locks, public ports are also presented in more detail, whose creation is closely related to transport infrastructure

development. One of the project's outputs is also a map with specialized content, presenting historical regulations on the lower Elbe below Střekov in Ústí nad Labem up to the state border with Germany. Attention is also paid to special topics, such as the multi-purpose nature of individual buildings, personalities connected with the development of the waterway, the latest modernizations implemented, and hydropower utilization. The exhibition was supplemented with an interactive model of a lock with a weir, a chamber, a power station, a canoe slalom channel, a model of the planned Děčín barrage, a stand with a web application, and a large screen with a video projection of the spatio-temporal development of the LVVC.

The project also includes the web application "Technical Heritage of the Elbe-Vltava Waterway", which was introduced in 2020. The application documents the existing technical historical objects on this waterway and their construction and technological elements and makes them available to the public. It also offers tips on tourist attractions in the vicinity of the rivers, and in animation it presents the temporal development of modern modifications of the waterway from the end of the 19th century to the present day. It is also equipped with a glossary of technical terms, and history enthusiasts can find a number of digitized historical documents, maps and drawings. The application is available at https://www.lvvc.cz/.

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KRHOVICE – HEVLÍN IRRIGATION SYSTEM

The basic function of the Krhovice – Hevlín canal was to bring irrigation water to the area between Znojmo (Krhovice) and Hrušovany nad Jevišovkou. The motive behind the creation of the irrigation system was to limit the effects of drought and the need for irrigation for sites that were exposed to the warm weather and lacking in rainfall area and without a significant network of streams and channels. For this reason, sprinkler irrigation was chosen. Preparations for the construction of the irrigation system were underway long before the Second World War, but implementation finally took place between 1949 and 1954.

The irrigation system consists of a main irrigation channel, which transports water from the Dyje to individual irrigation pumping stations; in addition, water is pumped by supply stations to other irrigation system sections with storage tanks. The main Krhovice – Hevlín irrigation canal is followed by two supply canals built in 1966, which bolster water distribution. The area of approved irrigated areas was already close to 6,000 ha in 1966, and other large-scale sections followed until the 1980s.

The Krhovice – Hevlín system represents one of the first modern large-scale sprinkler irrigation systems in former Czechoslovakia and was an exemplary project that provided valuable experience for the further development of modern irrigation systems. The actual system is also functionally linked to the water storage facilities in the area – the Vranov and Znojmo waterworks. This generously designed system in the area between Dyje and Jevišovka made the irrigation regime more efficient, which was previously fragmented into small-scale or local distribution. Particularly with regard to the interruption and restriction of irrigation after 1989, this preserved and still functional system is a unique example of industrial heritage.

Text: Ing. Miloš Rozkošný, Ph.D., doc. PhDr. Zbyněk Sviták, CSc., photo: Mgr. Radek Bachan

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