VODOHOSPODÁŘSKÉ TECHNICKO-EKONOMICKÉ INFORMACE

(WATER MANAGEMENT TECHNICAL AND ECONOMIC INFORMATION)

VTEI/2024/6

60 years ago in VTEI

RNDr. Václav Zajíček, CSc., from the Water Research Institute in Prague, Podbaba, wrote an information article about the meeting on "Artificial infiltration in water management", which was held at the Institute on 13th December 1963. The aim of the meeting was to acquaint a wide range of water managers with technical and economic advantages of this method of expanding groundwater reserves and collecting them, as well as with the limits of its applicability.

The contributions were peer-reviewed by Ing. Dr. J. Kůrka.

Excerpt from lectures:

1. *V. Zajíček: Characteristics of natural conditions for the design of artificial infiltration*
   Geological and hydrogeological conditions required for the location of an infiltration field with examples from constructions in the Czechoslovak Socialist Republic and abroad. Possibilities of setting up artificial infiltration systems in Quaternary sediments and older rock formations.

2. *V. Hálek: Methodology of theoretical and experimental solution of artificial infiltration*
   Principles of analogue methods suitable for artificial infiltration with examples of water movement in the infiltration field. Solving non-stationary processes on digital computers. Examples from artificial infiltration objects near Tlumačov in the valley of the Morava River and from Polabí.

Generated by artificial intelligence (Midjourney)

3. *V. Zajíček: Balance of groundwater reserves in the infiltration area*
   The importance of evaluating the accumulation capacity of the infiltration field sedimentary formation and the procedure of determining the effective porosity of soils. Practical calculation of groundwater reserves in the infiltration field during intermittent infiltration operation.

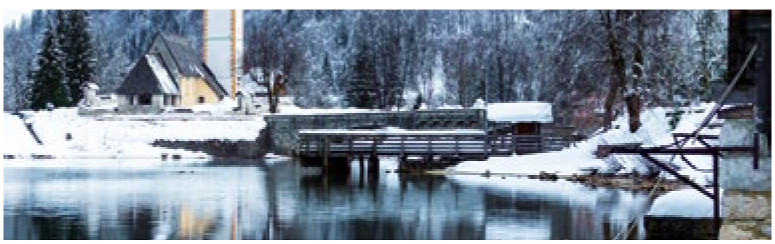
4. *M. Kněžek: Experience from the operation of artificial infiltration with open infiltration ditches*
   Changes in groundwater flow regime in the infiltration field after construction of artificial infiltration and dependence of the width of infiltration reservoirs on boundary conditions; the effect of a filter-less permeable layer formation at the bottom of the reservoir on the flow. The unsuitability of using the so-called specific infiltration (per 1 m^2) without considering the ground plan shape of the infiltration ditch. Findings from Kárané waterworks (at the mouth of the Jizera) and from model tests. Changes in the physical and chemical characteristics of water in the infiltration field from the artificial infiltration object in Kárané.

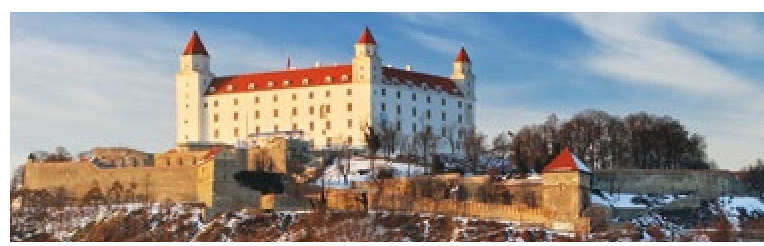
The discussion focused mainly on technical, hygienic, and economic issues of artificial infiltration.

From the TGM WRI archives

VTEI Editorial office

Content



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Dear Readers,

At the beginning of the December issue of VTEI, we are happy to inform you that we successfully completed the evaluation procedure for the acceptance of our journal into the DOAJ – database of open access journals. The VTEI journal also successfully passed the admission process for its inclusion in Elsevier's Scopus database, which is the largest scientific and abstract citation database of peer-reviewed literature in the world. Last but not least, we are preparing documents for applying to the Web of Science database. Thereby we would like to complete the many years of efforts to include VTEI among the important professional periodicals assessed by bibliometric and scientometric tools, forming one of the key bases for the evaluation of scientific results in the Czech Republic.

And now for the content of the December issue. The first peer-reviewed article "HYMOD-KZ database and deficit areas" of the author's team led by Adam Vizina presents the results of hydrological modelling and analysis of the hydrological balance of a basin for current and future climate conditions and presents the readers with current information on the possible impacts of climate change on hydrological balance characteristics. Using HYMOD-KZ database, experts and the general public have a tool that provides outputs in the spatial resolution of water bodies, while the graphical display of the results facilitates understanding of complex hydrological phenomena and supports decision-making in the field of water management planning.

The peer-reviewed article "The issue of antimicrobial resistance in the aquatic environment of the Czech Republic" by Hana Zvěřinová Mlejnková, Kateřina Sovová, Štěpánka Šabacká and Adam Šmída is focused on the topic of antimicrobial resistance, i.e. the ability of bacteria to resist the effect of antibiotics, which is a consequence of their long-term improper use in both human and veterinary practice. The study demonstrated not only resistance to selected antibiotics, but also pointed to the fundamental problem of the presence of antibiotics and their metabolites in the environment, which continues to worsen the whole situation. This issue has so far been neglected in the Czech Republic and it is necessary to pay increased attention to it.

The third peer-reviewed article "Tools for risk assessment of catchment areas for abstraction points of water intended for human consumption" by Lucie Jašíková and the author's team will introduce you to the issue of processing risk analyses for parts of catchments intended for water abstractions, the aim of which is to ensure the comprehensive protection of water resources in the natural environment, i.e. before the water is abstracted. The obligation to perform risk analyses of parts of catchment areas results from the new European Drinking Water Directive.

The last peer-reviewed article, by Jiří Dlabal and collaborators, presents the results of the sub-objective of the project "Future water demand scenarios to 2050: Sectoral analyses and forecasts", which is part of TA CR project No. SS02030027 *"Water systems and water management in the Czech Republic and conditions of climate change (Water Centre)"*. Its authors deal with the projection of future water needs until 2050 through sectoral analyses and forecasts. The implementation uses different scenarios that consider factors such as population growth, economic development, climate change, technological progress, and political decisions; it is aimed at predicting water needs for the following sectors: agriculture, industry, power engineering, and households. Part of the output is an evaluation of the potential impacts of individual scenarios on the availability of water resources. The results show that in some regions (depending on the scenario considered) there may be a significant increase in water demand, which could lead to water shortages and thus require the implementation of new strategies for efficient water management.

Our usual interview is conducted with the current water section director general of the Ministry of the Environment of the Slovak Republic, Ing. Vladimír Novák, who for this year is also the president of the International Commission for the Protection of the Danube River. Details about the Slovak Republic chairing this year's Commission are part of a separate article authored by him.

The December issue closes with an article by Barbora Sedlářová about the 17th conference *"Radionuclides and ionizing radiation in water management"*, which took place in České Budějovice.

Finally, dear readers, let us wish you a beautiful and peaceful Christmas holiday with your family and good health and many professional and personal successes in the new year.

VTEI Editorial Office

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HYMOD-KZ database and deficit areas

ADAM VIZINA, IRINA GEORGIEVOVÁ, PETR VYSKOČ, EVA MELIŠOVÁ, MARTIN HANEL, MIROSLAV TRNKA, PETR PAVLÍK, MILAN FISCHER

Keywords: water resources — water scarcity — water balance — climate change — deficit areas

ABSTRACT

This article describes the HYMOD-KZ database, available at https://shiny.vuv.cz/HYMOD-KZ/. The database provides detailed results of hydrological modelling and hydrological balance analysis of catchments (water bodies) for current and future climate conditions; it also includes updated deficit areas, the description of which is part of this article. This tool can serve as a foundation for water management experts, academia, and the broader professional community as it provides outputs at the spatial resolution of water bodies. The graphical representation of results facilitates understanding of complex hydrological phenomena and supports decision-making in water management planning.

INTRODUCTION

Climate change represents one of the most significant environmental challenges, fundamentally affecting the availability and quality of water resources [1, 2]. In the Czech Republic, climate change manifests itself mainly through an increase in air temperatures, changes in precipitation distribution, increased frequency and intensity of drought and, conversely, short-term extreme precipitation events that can lead to floods [3, 4]. These changes disrupt the hydrological balance of the landscape, affect water balance, and contribute to the reduced availability of groundwater and surface water supplies, which are key for supplying the population, agriculture [5], and industry.

In some areas of the Czech Republic, which are already classified as deficient in terms of water regime, climate change impacts are deepening. The lack of water manifests itself both in the dry season, when river levels drop and the availability of water for various purposes decreases, and in the winter months, when reduced water reserves via snow cover contribute to low flows in the spring season. These issues are exacerbated by rising air temperatures, which increase evaporation and thus further reduce water availability in the landscape.

The HYMOD-KZ database is a tool that shows the results of hydrological modelling and water balance analysis for current and future climate conditions in the Czech Republic. This tool uses advanced hydrological modelling methods that include both spatial interpolation of meteorological data and simulations of water regime changes based on different climate scenarios. The database provides spatially explicit information on water balance, which enables a detailed assessment of the impacts of climate change on individual basins and water bodies.

Within the HYMOD-KZ database, so-called deficit areas are also identified, where the climatological water balance is significantly negative, which indicates risks for sustainable management of water resources. This information is key for planning water management measures, such as building new retention reservoirs, optimizing the use of water resources, or implementing adaptation strategies aimed at improving the landscape's storage capacity. The database is therefore a tool (base) for experts in water management, who can use the data to support decision-making and create long-term strategies to mitigate the impacts of climate change.

METHODOLOGY AND DATA

Current climate conditions

Climate data for 1961–2020 was used for the actual assessment of current conditions, namely a time series of air temperatures and precipitation totals. Since long time series contain measurement errors, inhomogeneities caused by moving the station, changing instruments or observers, or measurement failures, it is necessary to clean the data series from these influences. For this purpose, the data underwent a quality control within the CLIDATA database at CHMI. All data were tested for inhomogeneities in the series and these were corrected using the proprietary DAP method. Any missing data from 1961–2020 were added based on interpolation methods. Station data processed in this way were subsequently interpolated into a grid network with a spatial resolution of 500 m. For each day, the dependence on terrain parameters (altitude, slope, roughness) was determined as well as on latitude and longitude. The basis for spatial interpolation is a terrain map with a resolution of 500 × 500 m. The result of spatial interpolation are layers (GeoTIFF) of meteorological variables in a daily time step, which were used to derive time series for the studied area (to the centre of individual surface water bodies). The period 1991–2020, which corresponds to the current reference period, was used for the assessment itself.

Climate change scenarios in water management

Climate models are mathematical representations of the physical processes that take place in the atmosphere, oceans, ice sheets, and land. They are used to simulate past, present, and future climate on Earth. Global climate models (GCMs) work with a coarse spatial resolution, which means that smaller geographical areas, such as the Czech Republic, are not accurately represented in these models. Therefore, regional climate models (RCMs) are used at the regional level, spatially refining the GCM outputs. Both GCM and RCM have their advantages and disadvantages [6].

The most recent CMIP6 GCM [7, 8] simulations include models with different spatial resolutions, mostly around 100 or 250 km. However, some models with a resolution of 50 km end the simulations in the mid-21st century. The models differ in complexity of the climate system description and parameterization of smaller scales, which leads to differences between simulated climate and reality. For Central Europe, GCMs that best simulate its climate were selected, ensuring that this selection was representative of the entire original set of models. Six models with a resolution of up to 100 km were selected that cover all emission scenarios and take into account basic meteorological elements.

Climate change scenarios (Shared Socioeconomic Pathways: SSP [9]) reflect different possible future global trajectories in terms of emissions and socio-economic development:
— SSP1–2.6: sustainable development
— SSP2–4.5: middle path with deterioration of environmental systems
— SSP3–7.0: regional rivalry and limited economic development
— SSP5–8.5: development based on fossil fuels

The selection of GCM models was carried out according to the methodology [10] and ensures reliable climate simulations of Central Europe. Furthermore, the ALADIN-CLIMATE/CZ regional model, which is characterized by high spatial resolution, was included. The ALADIN-CLIMATE/CZ model calculation area includes almost all of Europe with the Czech Republic in its centre, which is important for the actual modelling of the future climate; however, it is no longer needed for further processing of the results, so it was reduced [11]. The resulting set of used simulations is shown in *Tab. 1.*

Tab. 1. Selected GCM models from CMIP6 and ALADIN-CLIMATE/CZ simulations, their spatial resolution, and available SSP scenarios

Model GCM	Selected SSP scenarios	Model spatial resolution in [km]
CMCC-ESM2	SSP126, SSP245, SSP370, SSP585	100 × 90
EC-EARTH3	SSP126, SSP245, SSP370, SSP585	80
GFDL-ESM4	SSP126, SSP245, SSP370, SSP585	100
MPI-ESM1–2-HR	SSP126, SSP245, SSP370, SSP585	50
MRI-ESM2–0	SSP126, SSP245, SSP370, SSP585	60
TAIESM1	SSP126, SSP245, SSP370, SSP585	100
ALADIN-CLIMATE/CZ	SSP245, SSP585	2.3

For the creation of SSP scenarios in the context of estimating changes in the hydrological balance, the so-called incremental method is used as standard in the Czech Republic, especially for studies in monthly step. This method consists in transforming the observed data so that changes in transformed quantities correspond to changes derived from climate model simulations. In the monthly step, changes in average monthly precipitation totals and average monthly temperature are normally considered. In the daily step, it is also necessary to consider changes in the variability of quantities. Therefore, the *Advanced Delta Change* (ADC) incremental method was used to create SSP scenarios. The incremental method is based on transforming the observed data in a way that guarantees that the changes between the transformed and the original series are the same as the changes derived from the regional climate model. For precipitation and temperature (especially in the daily step) it is desirable that the considered transformations take into account changes in both average and variability. This simply means that the extremes can change in a different way than the average. When deriving precipitation changes from the climate model, the ADC method also considers systematic simulation errors. Since the temperature is transformed linearly, systematic error has no effect on the resulting temperature transformation [12]. For individual water bodies, selected [13] Global Circulation Models (GCM) and ALADIN-CLIMATE/CZ Regional Circulation Model were transformed by the selected method.

Hydrological balance modelling

To calculate hydrological balance, the BILAN conceptual model was used, which has been developed for more than 20 years in TGM WRI Department of Hydrology. The model calculates the chronological hydrological balance of the basin or area in daily and monthly time steps. It expresses the basic balance relationships on the surface of the catchment area, in the aerated zone (which also includes the basin vegetation cover), and in the groundwater zone. Air temperature is used as an indicator of energy balance, which significantly affects hydrological balance. Using the calculation, the potential evapotranspiration, land evaporation, infiltration into the aerated zone, seepage through this zone, water supply in snow, water supply in soil, and groundwater supply is modelled. Runoff is modelled as the sum of three components: two components of direct runoff (including subsurface runoff) and base runoff [15–18]. The daily version of the model, which is controlled by six parameters, was used to model the hydrological balance. The model uses linear and non-linear reservoirs to transform precipitation into runoff. The main inputs of the model are precipitation and air temperature (also measured runoff for calibration), the output is the modelled runoff from the basin and other hydrological balance components.

The calibrated BILAN hydrological model within the HAMR system [19] was used for the actual simulations.

Hydrological modelling of climate change

The procedure for modelling the climate change impact on the hydrological regime can be briefly summarized as follows:

1. The selected hydrological model is calibrated for the selected catchment area using observed data. A hydrological model should be based on physics to guarantee that it will provide acceptable results even for unobserved conditions.
2. The input variables from the global or regional climate model are converted to time series of scenarios for individual basins, in this case by subsequent processing of the climate model output, i.e. using the incremental method or correction of systematic errors. It is often necessary to use spatial interpolation to relate the data from the calculation cells of the climate model to the centre of the given basin. For the correct use of the methods, it is necessary to have the observed data available.
3. Using a calibrated hydrological model and time series of scenarios, hydrological balance for the corresponding period is simulated.

The procedures are described in more detail in [15–19].

Deficit areas

Within the database, deficit areas of landscape water regime are displayed from a climatological point of view, without the water management aspect. Based on the analyses of the input variables, a simple interpretation of deficit areas was chosen based on the so-called climatological water balance, which is expressed by the following equation

$$B = P - PET,$$

where:

B	is	climatological water balance
P		precipitation total
PET		potential evapotranspiration

The balance was calculated for current and future conditions based on the aforementioned simulations, aggregated and divided into categories:

1. Problem-free area: B > 0 mm
2. Risk area: 0 mm > B > -100 mm
3. Threatened area: -100 mm > B > -200 mm
4. Critical area: B < -200 mm.

HYMOD-KZ database: Specialized public database

Based on the outputs (dealing with modelling climate change impacts on water regime) of TA CR projects ("*Water Centre*" and "*PERUN*"), the HYMOD-KZ database was created; it is available at https://shiny.vuv.cz/HYMOD- KZ/. The database runs on the equipment of TGM WRI in Prague. The aim of the database is to provide users with comprehensive information on water availability (natural water regime) for current and future conditions with an emphasis on individual climate model simulations.

Technical specification

The HYMOD-KZ database was created in the R programming language (version 4.3.1). The application's interactive web interface is provided through an open-source superstructure in the form of Shiny packages (version 1.7.5.1) and flexdashboard (version 0.6.2), where Shiny provides the functionality of the user interface (i.e. contains all functions and calculations as well as instructions necessary for layout and appearance), while flexdashboard allows linking all Shiny components in the form of a single RMarkdown document. Furthermore, the application uses tools in the form of packages, such as tidyr (version 1.3.0) and dplyr (version 1.1.2), used for editing and transforming data, sf (version 1.0–13) enabling work with the OpenGIS geographic data standard, Simple Features, and Leaflet (version 2.2.0), enabling the display of spatial data in the form of interactive maps.

Home page

The main menu for the database is via the opening page (*Fig. 1*), which shows:

1. Logo and project name, and database logo.
2. Public Database Section: Contains links to sections such as "Hydrological Balance" and "Deficit areas" that provide users with access to relevant information and data.
3. Contact information: On the right, the contact information for the researchers, including their institutions and locations, is listed.
4. Project summary.

Fig. 1. Main menu of the HYMOD-KZ database home page

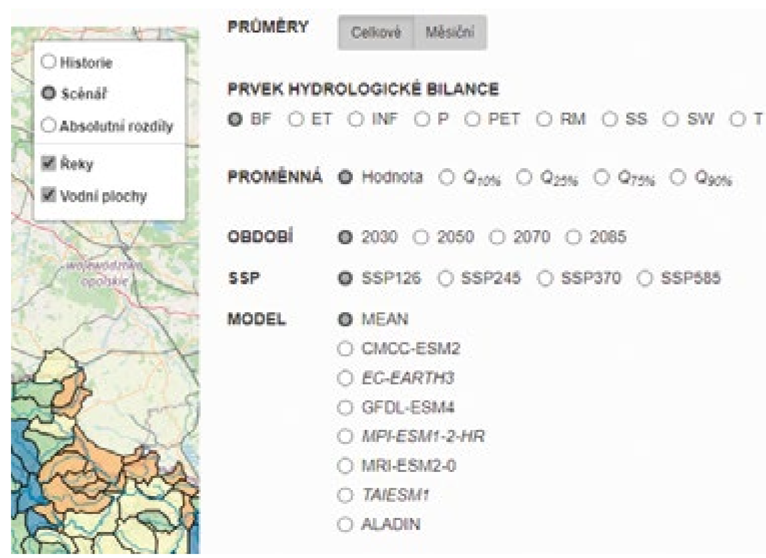

Fig. 2. HYMOD-KZ database main menu: options for selecting variables and time period in the "Hydrological balance" component

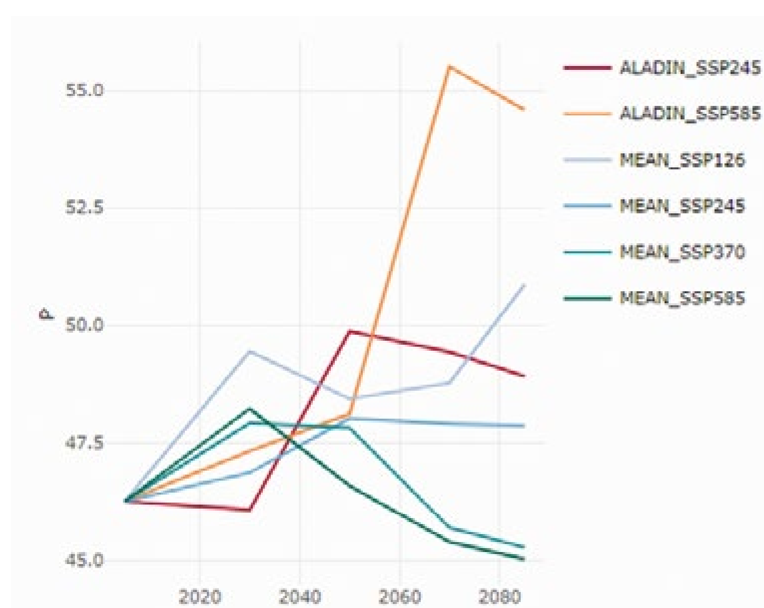

Fig. 3. Development of the selected variable in a specific water body based on individual SSP scenarios and the ALADIN-CLIMATE/CZ model

Hydrological balance

The "Hydrological balance" component displays a summary of basic hydro-climatological parameters for individual water bodies. *Fig. 2* shows the user interface with different selection options. The user can select different variables:

— BF – basic runoff [mm],
— ET – current evapotranspiration [mm],
— INF – infiltration [mm],
— P – precipitation total [mm],
— PET – potential evapotranspiration [mm],
— RM – modelled runoff [mm],
— SS – water supply in snow [mm],
— SW – water supply in soil [mm],
— T – air temperature [°C].

The values are aggregated into monthly ("Monthly" tab) and annual values ("Total" tab) and further derived basic static quantities such as the average ("Value") or partial quantiles (10%, 25%, 75%, and 95%). Within the application, it is also possible to choose between different periods (2030, 2050, 2070, 2085) and different socioeconomic pathways (SSP126, SSP245, SSP370, SSP585), indicating possible future development scenarios.

Ater this choice, climate models such as MEAN (average of all models), CMCC-ESM2, EC-EARTH3, GFDL-ESM4, MPI-ESM1-2-HR, MRI-ESM2-0, TAIESM1, and ALADIN (ALADIN- CLIMATE/CZ) are listed, which represent different climate models used for simulations. It is also possible to display values for the present 1991–2020, "History", scenario values ("Scenario") for the 2030, 2050, 2070, and 2085, and absolute differences between the future and the present for the selected quantity.

The graph (*Fig. 3*) shows development of the selected variable, quantile, and water body according to individual SSP scenarios and simulations by the ALADIN-CLIMATE/CZ model for individual time horizons.

Fig. 4 shows overall output composition, which consists of a map window and graphs based on the selected combination (in this case, absolute values of precipitation total for the variant: outlook to 2050, SSP126, and MEAN – arithmetic mean of all simulations).

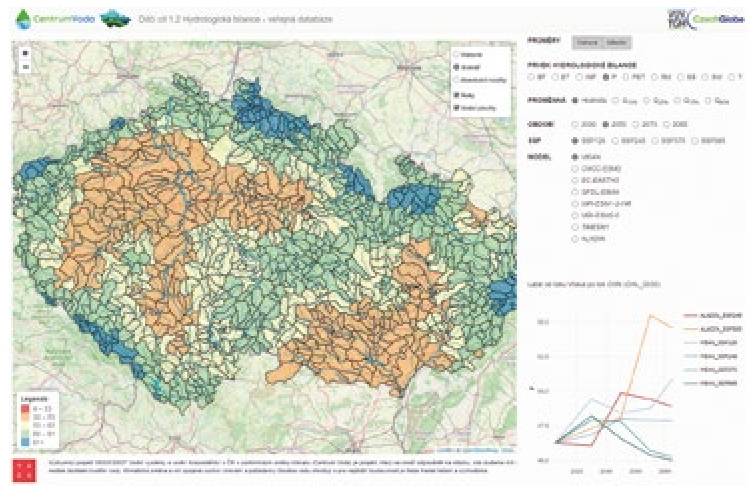

Fig. 4. Precipitation total for scenarios: outlook to 2050, SSP126, and MEAN (arithmetic mean of all simulations)

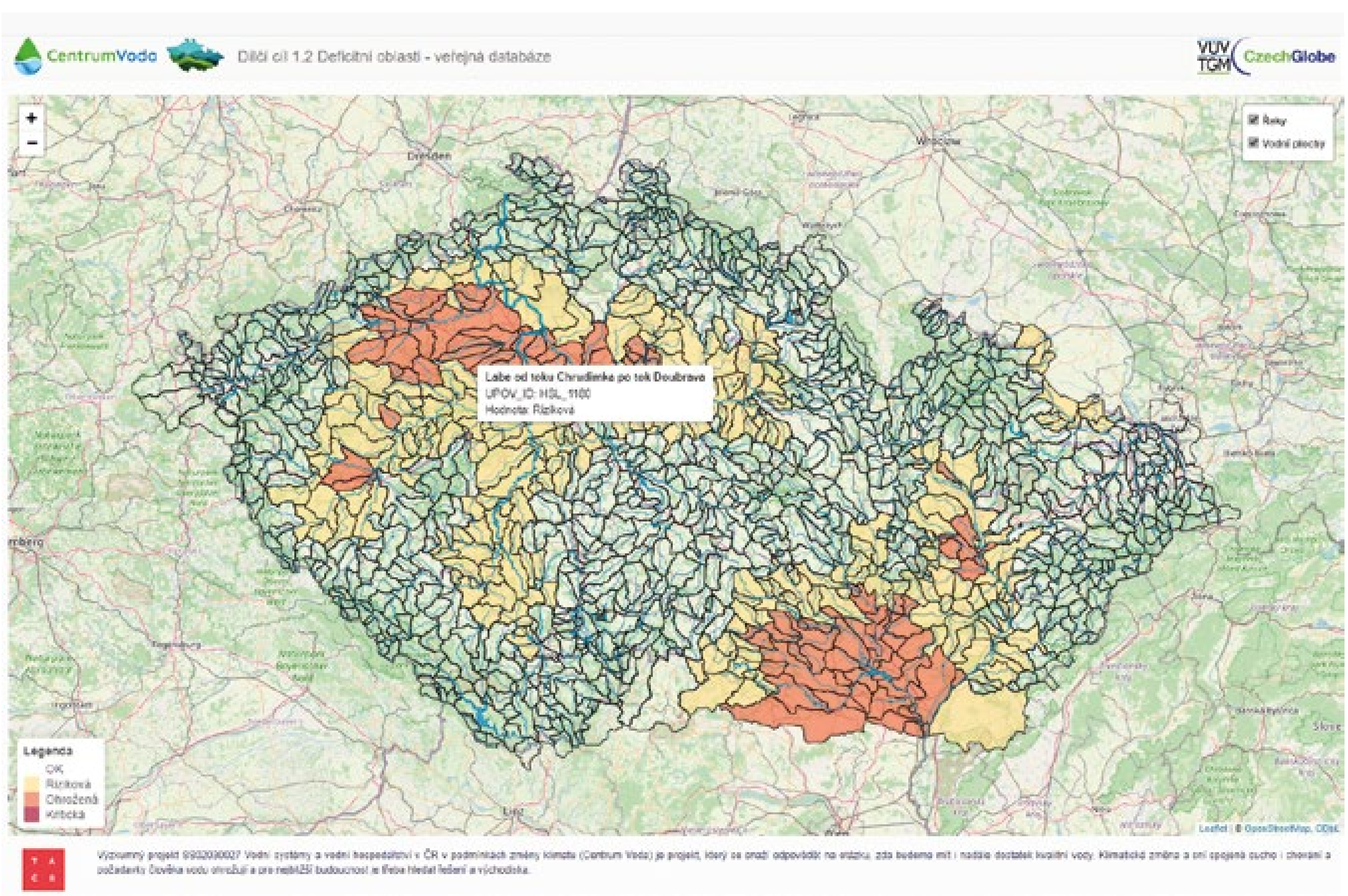

Fig. 5. Evaluated deficit areas

Deficit areas

At the beginning of the *"Water Centre"* project (2020), so-called deficit areas of the Czech Republic were defined, which were determined by expert assessment based on previous studies dealing with the impact of climate change on water regime and the definition of problematic hydrogeological regions. As part of the *"Water Centre"* project, these areas were specified based on the use of hydrological balance modelling in the distinction of water bodies and the updating of outputs from climate models. Adaptation measures should be proposed for deficit areas and their impact on the water regime of the given location should be evaluated.

Based on the aforementioned methodology for calculating deficit areas, the "Deficit areas" component shows a map of the Czech Republic (*Fig. 5*) with the delineation of updated areas. In the course of the project (by the end of 2024), the map should be supplemented with a layer that will also provide information on deficit areas from a water management point of view. To finalize the map, the materials showing the individual future simulations were also used.

Fig. 6 shows mean absolute changes in precipitation totals for the summary of simulations according to SSP scenarios and for partial time steps. Absolute mean changes in runoff heights are shown analogously in *Fig. 7*. An increase in precipitation totals can be observed in most simulations which, however, often cannot compensate for the increase in evapotranspiration primarily caused by increased air temperature. This has an impact on runoff levels.

Fig. 8 shows the deficit areas. The grey polygons delineate deficit areas established at the beginning of the "*Water Centre*" project implementation. A large dispersion is evident here, especially for more distant time horizons. For this reason, simulations for 2050 (also set as the reference year of the project) were considered for updating the areas.

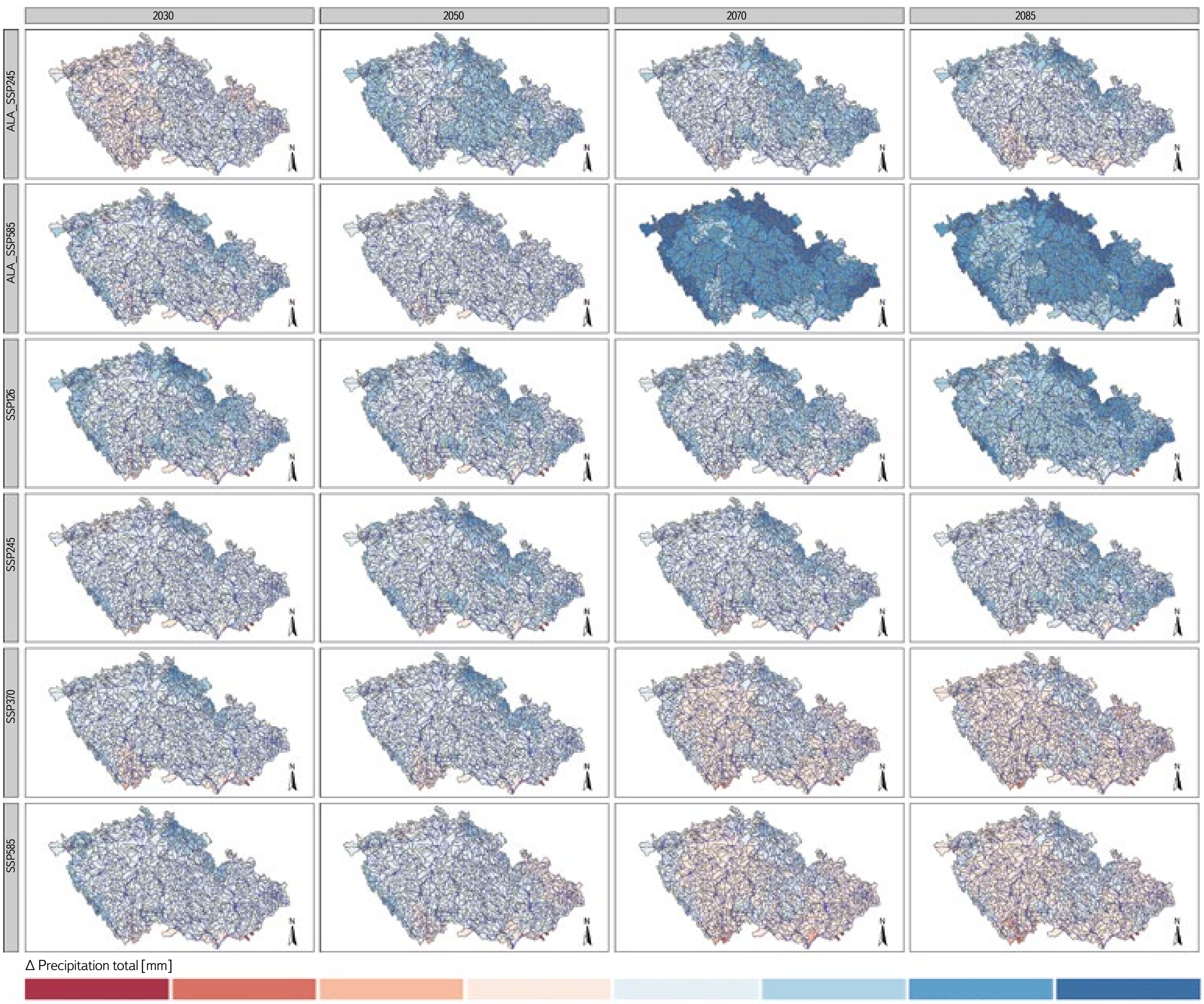

Fig. 6. Absolute changes in precipitation based on individual climate model simulations

CONCLUSION AND DISCUSSION

The goal of the project described above was to provide up-to-date information on the possible impacts of climate change on hydrological balance characteristics (runoff, base runoff, partial water reserves, evapotranspiration, etc.). The article itself does not describe in detail the individual methodological steps of the evaluation procedure, but rather the final synthesis of the data outputs of the given issue.

The HYMOD-KZ website at https://shiny.vuv.cz/HYMOD-KZ/ provides detailed results of hydrological modelling and analysis of the catchment area hydrological balance. This tool can be crucial for water management professionals as it provides data on different scenarios of climate change impact on water quantity. These data can be used for further follow-up studies, not only of a research nature. However, a significant variability of changes can be observed within the outputs, which are mainly determined by the input climate data (especially individual forecasts of precipitation totals and their temporal distribution during the year) and uncertainties in the simulations of the hydrological model, which is calibrated on the basis of available input data. A lot of studies and research deals with the calibration strategies themselves. Future research could be enriched by the use of different hydrological models and the development of ensemble solutions based on hydrological simulations with the same data inputs.

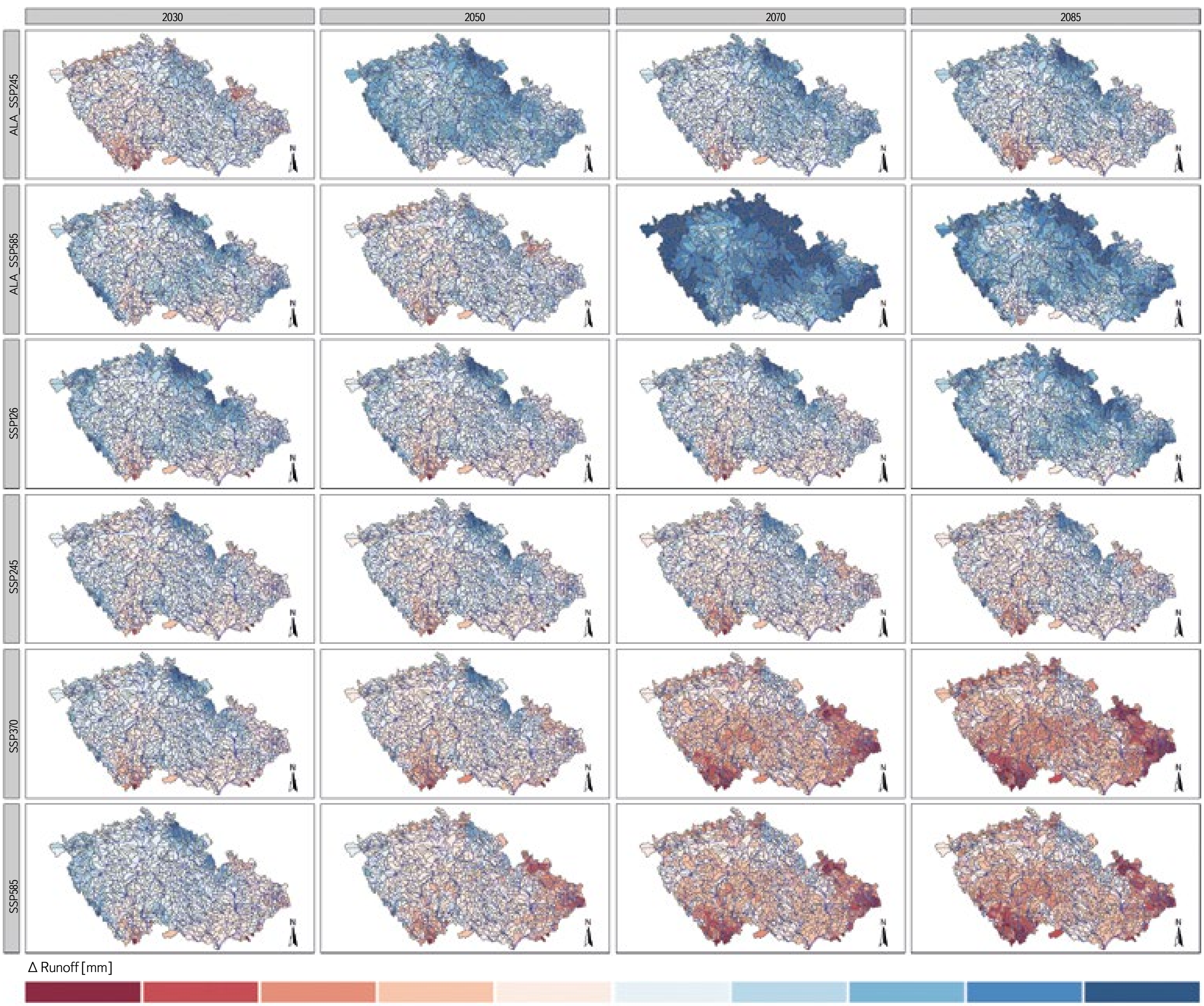

Fig. 7. Absolute changes in runoff based on individual climate model simulations

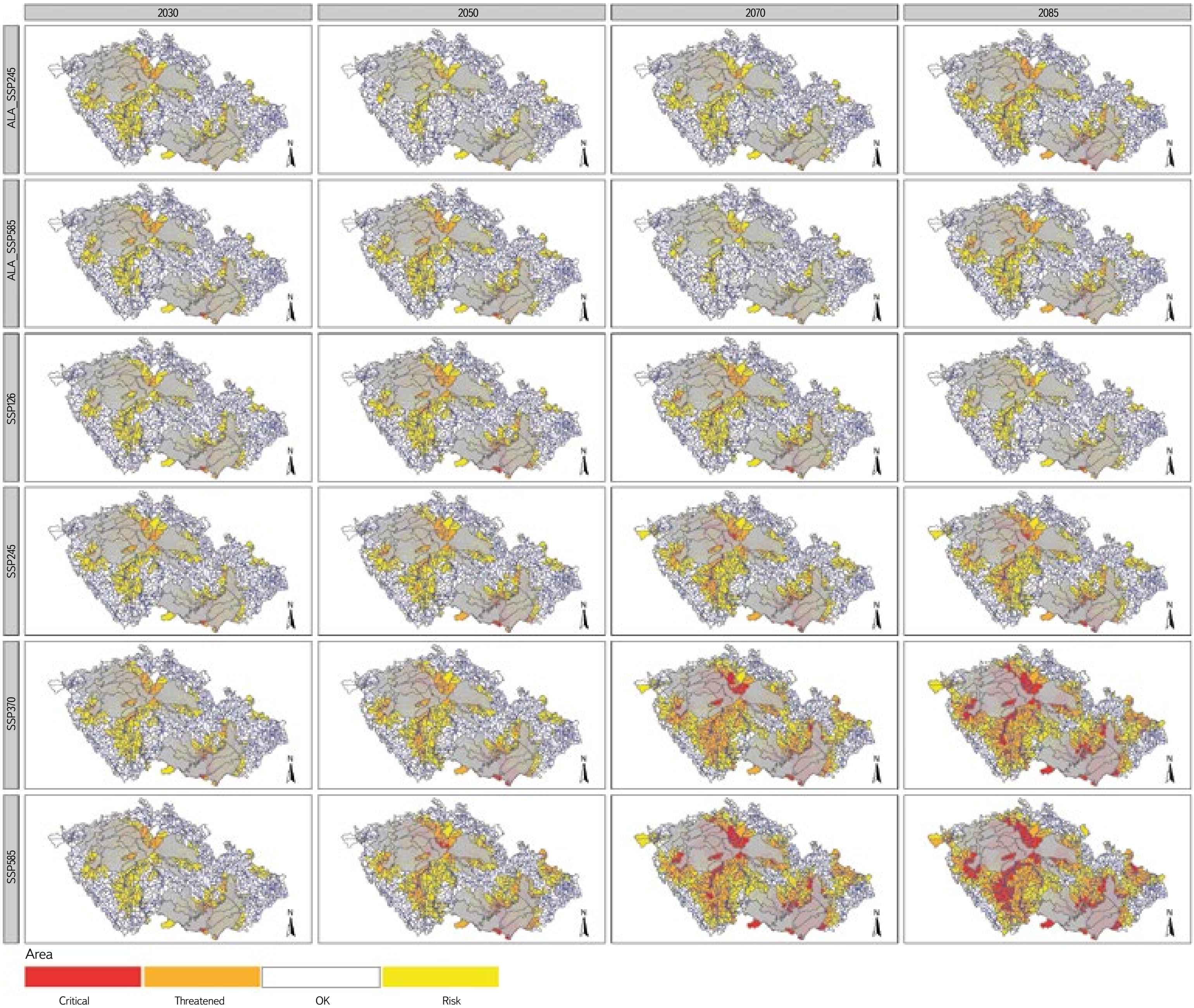

Fig. 8. Evaluation of deficit areas based on individual climate model simulations (grey polygons indicate the non-updated layer of deficit areas)

Acknowledgements

This article was created on the basis of research carried out as part of research project No. SS02030027 "Water systems and water management in the Czech Republic under conditions of climate change" ("Water Centre"), work package 1 and sub-goal 1.2. Data from the project No. SS02030040 "Prediction, assessment and research on the sensitivity of selected systems, the influence of drought and climate change in the Czech Republic" (PERUN) were also used for the modelling itself.

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The Czech version of this article was peer-reviewed, the English version was translated from the Czech original by Environmental Translation Ltd.

DOI: 10.46555/VTEI.2024.09.003

ISSN 0322-8916 (print), ISSN 1805-6555 (on-line).

The issue of antimicrobial resistance in the aquatic environment of the Czech Republic

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Keywords: antimicrobial resistance — surface and wastewater — disk diffusion method — multiresistance — antibiotics — ESBL

ABSTRACT

Antimicrobial resistance (AMR) has emerged as a high priority global problem in recent decades. Its severity lies in the critically increasing number of pathogenic bacteria that carry resistance genes to previously common antibiotics (ATB), making them a health threat. The emergence of resistance is a consequence of the long-term misuse of ATB in human medicine and veterinary practice (with the most significant contribution from developing countries). In 2017, the UN warned that the issue is not limited to these areas and that the environment can also be a significant reservoir and vector for the spread of AMR. The issue has been included in the "One Health" initiative, which is based on a collaborative approach to combat AMR across the health, agriculture, and environment sectors. AMR enters the aquatic environment in the form of resistant bacterial strains (ARB) or resistance genes (ARG) shed by patients through municipal wastewater treatment plants (WWTPs), runoff, or agricultural waste.

In our study, screening was performed for the occurrence of ATB resistance to selected ATBs (cefuroxime, cefotaxime, cefepime, gentamicin, sulfamethoxazole/trimethoprim, fosfomycin, nitrofurantoin and meropenem) in indicator bacteria *Escherichia coli* (*E. coli*) isolated from surface water and wastewater in influent and effluent of a wastewater treatment plant. A culture disk diffusion method was used to detect resistance. *E. coli* with proven resistance was detected in almost 100 % of the samples tested, with the exception of resistance to nitrofurantoin and meropenem in samples of the category above the WWTP effluent. The highest proportions of resistant *E. coli* were found for gentamicin in all categories. Multi-resistant strains and strains producing extended-spectrum beta-lactamases (ESBLs) were also observed.

The detection of high numbers of resistant or multi-resistant *E. coli* strains in and downstream of treated effluents indicates the importance of the aquatic environment in the spread of AMR, which may be a consequence of the suggested transfer of resistance between bacterial strains in WWTP. The screening findings point to the need for detailed study of AMR in the environment, which is essential for success in efforts to reduce the current health threats posed by ATB resistance in the Czech Republic and worldwide.

INTRODUCTION

Antimicrobial resistance (AMR) is the ability of bacteria to resist the effect of antibiotics (ATBs), i.e. substances that can kill them or stop their growth. The natural property of every organism, including bacteria, is to survive and reproduce. If contact with ATB prevents them from doing so, they will try to find a way to avoid their negative effect. This is how mutations and genetic transfers occur, which cause the initially sensitive bacteria to become partially or completely resistant to the action of ATB. The main cause is excessive contact of bacteria with ATB caused by their incorrect or inappropriate use and the occurrence of ATB in the environment. The consequence is the fact that there are dangerous resistant bacteria in the world today, for which neither standard nor reserve ATBs work. Currently, we can only defend against them with higher doses or other types of ATB which, however, are in limited quantities; this can mean a greater burden on the body and more side effects for patients. At the same time, there is a possibility that the bacterium will find a way to defeat ATB; over 35,000 people are reported to die in the EU each year related to AMR [1, 2].

Contributing to the spread of AMR is the excretion of ATB into wastewater (up to 80 %) and the overuse of ATB in the agricultural sector, where, until 2006, preventive administration of ATB to farm animals to promote growth was practiced (and in some non-EU countries it is still being practiced). The emergence of resistant bacteria in the ATB-contaminated environment is a source of AMR that has not yet been fully explored. In the clinical sector, the use of broad-spectrum ATBs that act against a wide spectrum of bacteria, underdosing of recommended therapeutic doses that cause bacteria to adapt to low ATB levels, and inconsistent diagnosis of the causative agent (e.g. viral infections treated by ATB) contribute to AMR.

ATB effect of is also complicated by the ability of some bacteria, including *E. coli*, to produce extended spectrum beta-lactamases (ESBL), which hydrolyse frequently used ATB (including penicillins and cephalosporins).

Clinical and veterinary medicine at the European and global level has been studying AMR and the effects of its spread intensively. In 2019, the WHO ranked AMR among the ten most significant health threats; in 2022, the European Commission, together with EU member states, designated AMR as one of the three priority health threats [3]. Adopted in June 2023, the European Council's recommendation on strengthening EU measures to combat antimicrobial resistance within the framework of the "One Health" approach [4] now contains specific goals that each member state should achieve by 2030. For the Czech Republic, the goals are listed in the *Strategy of the National Antibiotic Programme of the Czech Republic for 2024–2030*:

A. reducing total ATB consumption by 9 % (compared to 2019), whereby at least 65 % of ATB used in all EU states should be basic, narrow-spectrum ATB;

B. reducing the overall incidence of bloodstream infections caused by ATB-resistant bacteria; for methicillin-resistant *Staphylococcus aureus*, the incidence should decrease by 6 %, for third-generation cephalosporin-resistant *E. coli* by 5 %, and for carbapenem-resistant *Klebsiella pneumoniae* by 2 %.

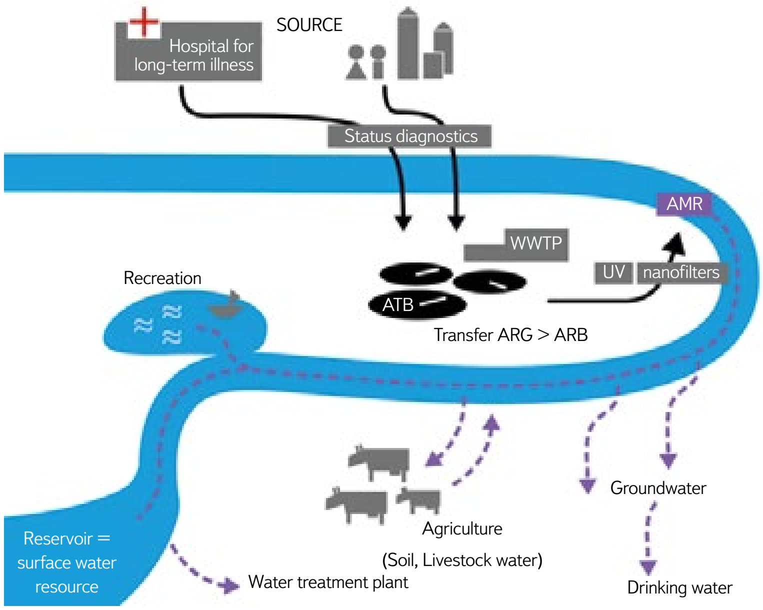

Fig. 1. Mechanisms of potential spread of AMR in the water environment

AMR in the environment was not a priority concern until recently. Findings demonstrating its importance were accepted in 2017 in the UN *Frontiers 2017* study [5–7]. Professor W. Gaze pointed out that ATB release is an overlooked problem, but one that could be key to the development of resistant strains, and sparked a commitment to tackle AMR across sectors, resulting in the "One Health" initiative. The risk lies in the fact that the majority of ATB in non-metabolized form together with resistant bacteria (ARB) gets into water and soil, where it meets environmental bacteria and creates conditions for the mutual exchange of genetic information. Environmental conditions and other contaminants (heavy metals, disinfectants, etc.) also contribute to the transmission, which can increase selection pressure and thus the potential for the emergence of a large number of new resistances. Pathogenic bacteria with clinically relevant genes originating from the environment have been found [7]. So far, both resistant and multi-resistant bacteria (i.e. those that carry resistance to more than three ATB groups) have been found in all types of water, including groundwater. Contamination with resistant bacteria or resistance genes is risky for sources of drinking water and surface water used for bathing, where it can be transmitted to the human body via the faecal-oral route. Food chain AMR contamination can occur with irrigation water, aquaculture, and the application of sewage sludge and farmyard manure to agricultural land [8]. The mechanisms of possible aquatic environment contamination by AMR are shown in *Fig. 1*.

The aquatic environment is contaminated with resistant bacteria primarily through wastewater treatment plants (WWTPs), which are considered hot spots for the spread of AMR in the aquatic environment. Together with ATB, ARBs enter WWTP from human digestive and excretory systems and are present here in varying degrees of metabolism, depending on their stability in the aquatic environment. Despite the high efficiency of existing treatment technologies, which reach values of around 99 % when removing microbial pollution, a large amount of ARB and ARG is released into the recipient. A large amount of ATB which cannot be broken down by current technologies is also present in treated municipal wastewater and wastewater from the production of pharmaceuticals discharged into rivers, together with little-known products of their decomposition. To supplement information on the AMR occurrence in the population connected to individual WWTPs [4], data is also used which is obtained during monitoring of raw wastewater based on WES principle (Wastewater and Environmental Surveillance).

Knowledge of the current state of AMR occurrence in the Czech Republic is at a very low level; following the activities of other EU countries, it is necessary to contribute to its expansion in order to obtain data for effective protection of human health and the environment.

In the Czech Republic, there is currently no systematic monitoring of watercourses with regard to AMR. Information on the status can only be derived from the research activities of several scientific teams that deal with this issue from different perspectives (e.g. University of Chemistry and Technology, Prague; Pardubice University; Veterinary University, Brno; National Institute of Public Health, Prague). Interest in the AMR issue is supported by the revised Urban Wastewater Treatment Directive 271/91/EEC, which will enter into force at the end of 2024. Within this Directive, a number of changes are expected to help improve the quality of surface water and reduce the health risks associated with its use. The monitoring of substances that can affect human health should be gradually introduced, including, in addition to AMR, the direct monitoring of viruses, PFAS (perfluorinated and polyfluorinated alkyl substances) and microplastics. In the future, the issue should also be included in the *Water Framework Directive 2000/60/EC*.

Our goal was to obtain initial information about AMR occurrence in surface and wastewater in the Czech Republic. The screening was aimed at detecting the occurrence of antibiotic resistance to selected ATBs in the indicator bacterium *E. coli*, isolated from surface and wastewater at WWTP influent and effluent using the disk diffusion method.

METHODS

Sampling

To compare the WWTP influence, the locations of surface water from main watercourses above and below the effluent of municipal wastewater from large urban areas with uniform sewage, and surface water samples from smaller watercourses flowing into the Vltava were selected. At the same time, wastewater samples were analysed at the influent and effluent of these WWTPs. The samples were taken continuously in 2022–2024 and were classified into the categories ABOVE (13 samples from watercourses above large municipal WWTPs), BELOW (53 samples from watercourses below the effluent of treated wastewater from large municipal WWTPs at a distance of 500 m to 10 km), INFLUENT (19 samples from influents to the WWTP after rough mechanical pretreatment), EFFLUENT (26 samples of treated wastewater on effluent from WWTPs with different treatment technologies), and STREAM (20 samples from the Vltava tributaries of different water bearing, into which smaller WWTPs and other effluents are discharged). A total of 131 samples were included in the study. Samples were taken in the standard sampling method for microbiological analysis.

Procedure for *E. coli* isolation and determination of sensitivity to antibiotics by disk diffusion method

In the samples, *E. coli* bacteria were determined by cultivation on mFC agar [9]. From each sample, in the optimal case, four different *E. coli* strains were selected and isolated, for which AMR was determined by the disk diffusion method. A pure bacterial culture grown overnight on a solid non-selective

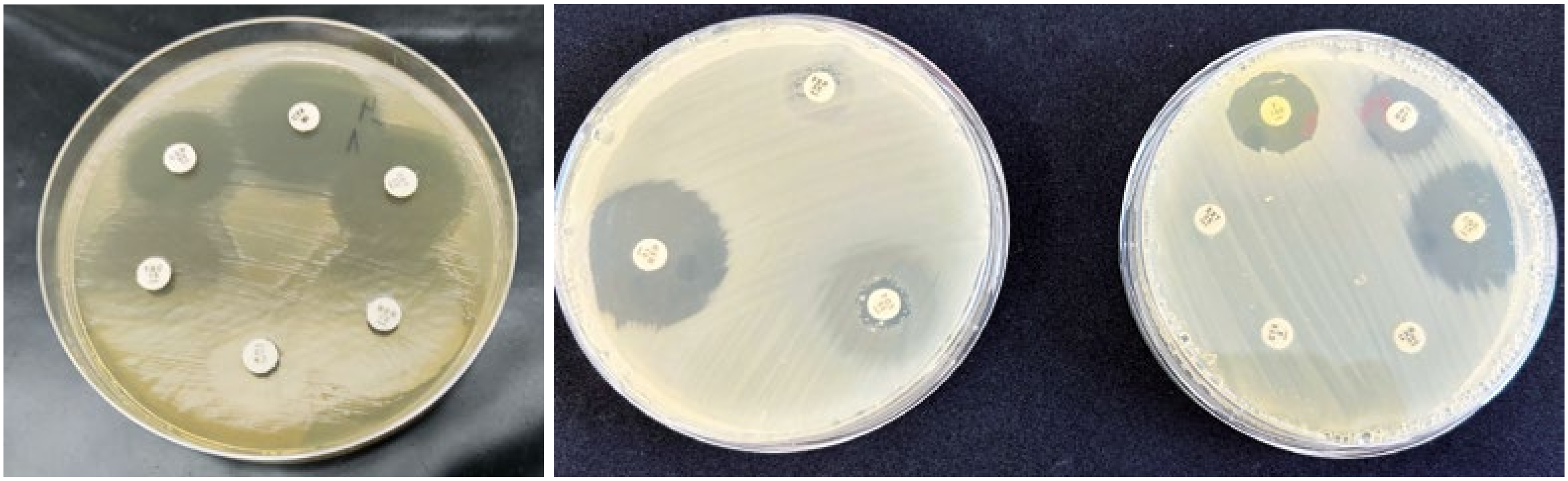

Fig. 2. Inhibition zones of the tested *E. coli* strain, example of a sensitive (obvious inhibition zone around the antibiotics disc) and resistant strain (small or no inhibition zone around the antibiotics disc); the size of inhibition zones is given in EUCAST

medium (Trypton Yeast Extract Agar) was suspended in physiological solution to a turbidity level of 0.5 ± 0.1 according to the McFarland turbidity scale, i.e. 1–2 × 108 cells/ml. The suspension was spread evenly on plates with Mueller-Hinton agar, on which disks containing ATB of different concentrations were subsequently placed using an applicator (*Tab. 1*). After 18 ± 2 hours of incubation at 36 ± 2 °C, the inhibition zones of individual ATBs were read (breakpoint means of inhibition zones were adopted from the EUCAST tables [10]), see *Fig. 2*. ATBs and their concentrations were selected based on information on the occurrence of resistance in clinical areas, the use of ATB in the Czech Republic, and the properties of ATB in the aquatic environment so as to cover as many ATB groups as possible (source: NRL for ATB SZÚ, EUCAST [10]).

Tab. 1. List of antibiotics used and their concentration in the discs

Antibiotics	Abbreviation	Antibiotic concentration in disc [µg]	Group
Cefuroxime	CXM	30	2nd generation cephalosporins
Cefotaxime	CTX	5	3rd generation cephalosporins
Cefepime	FEP	30	4th generation cephalosporins
Gentamicin	CN	10	aminoglycosides
Sulfamethoxazole/Trimethoprim	SXT	25	sulfonamides
Fosfomycin	FOS	50	broad spectrum ATB
Nitrofurantoin	F	100	nitrofurans
Meropenem	MEM	10	carbapenems

E. coli determination with production of extended-spectrum beta-lactamases

The determination of *E. coli* resistance to selected ATBs was complemented by the detection of the production of extended-spectrum beta-lactamases (ESBL).

A selected sample volume (usually 1–100 ml) was filtered through a sterile nitrocellulose membrane filter with a porosity of 0.45 µm, which was then placed on a TBX agar (Tryptone Bile × Glucuronide agar) plate supplemented with cefotaxime (4 µg/ml). TBX agar without ATB was used to determine the total number of *E. coli* in the water sample. Cultivation took place in an incubator at a temperature of 36 ± 1 °C for 21 ± 3 hours. From each sample, four presumptive colonies of ESBL-positive *E. coli* strains were subjected to two tests – CDT (Combination Disk Diffusion Test) and DDST (Double Disk Synergy Test) according to the procedure for performing and interpreting the results [11], see *Fig. 3*. ESBL detection uses inhibition of ATB hydrolysis by clavulanic acid.

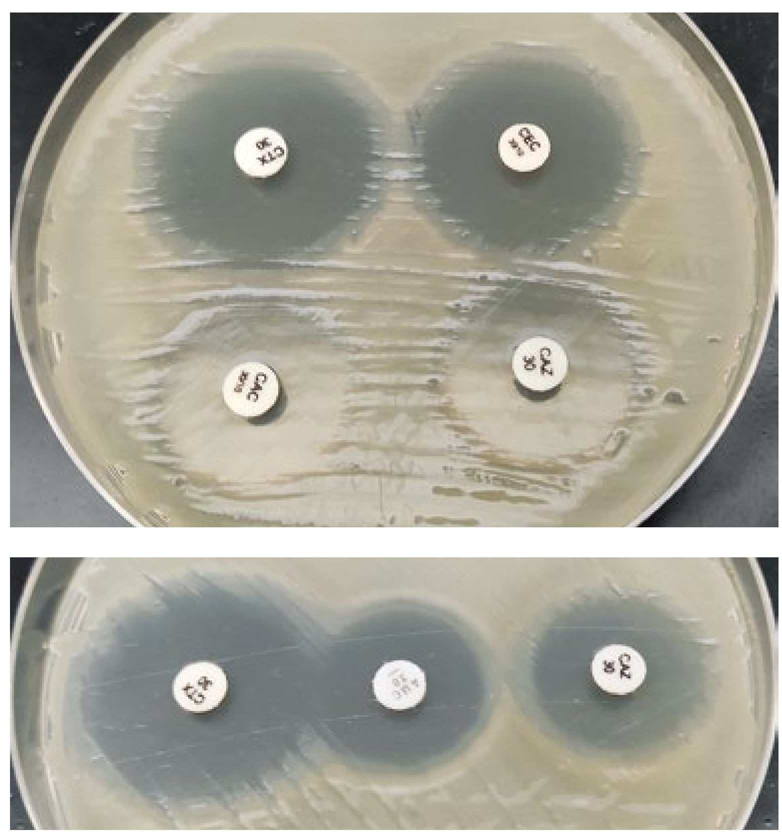

Fig. 3. Confirmation of ESBL on the *E. coli* isolates by CDT and DDST tests (above: CDT test, below: DDST test)

Tab. 2. Relative proportion of E. coli strains with proven AMR in each category

Sample category	Number of samples	Total amount of *E. coli*	Number of *E. coli* strains tested	Proportion of *E. coli* strains tested	Cefuroxime	Cefotaxime	Cefepime	Gentamicin	Sulfamethoxazole/ Trimethoprim	Fosfomycin	Nitrofurantoin	Meropenem
		[KTJ/100 ml]	[KTJ/100 ml]	[%]	[%] of strains with proven AMR							
ABOVE	13	26,075	50	0.19	10	12	6	46	14	10	0	0
BELOW	53	404,043	201	0.05	20	15	10	55	11	22	2	1
INFLUENT	19	199,300,000	77	0.00004	12	9	3	55	9	17	1	1
EFFLUENT	26	1,005,929	102	0.01	26	23	16	50	19	24	8	8
BROOK	20	1,094,560	80	0.01	9	6	5	50	8	18	6	3

For CDT, cephalosporin disks containing cefotaxime and ceftazidime and combined cefotaxime/clavulanic acid and ceftazidime/clavulanic acid disks are used. Four disks (two cephalosporins and two combination disks) are used per isolate. The interpretation of the CDT test results (*Fig. 3*) is based on the reading of the size of the inhibition zones of each cephalosporin separately compared to the combination of the cephalosporin and clavulanic acid. For DDST, cephalosporin disks and a clavulanic disk are used. The principle is to use cephalosporin disks next to a clavulanic disk with a distance of 20 mm from the centre. After incubation, the interaction between individual cephalosporins and clavulanic acid is monitored (*Fig. 3*).

Evaluation of results

The samples were divided into five categories to evaluate the indicative occurrence of AMR in surface and wastewater. Samples taken at influents (INFLUENT) and effluents (EFFLUENT) from large WWTPs, in watercourses above (ABOVE) and below (BELOW) the effluent of treated wastewater from WWTPs and in smaller watercourses (STREAM) where smaller WWTPs are located were compared. The obtained results were evaluated within individual categories and processed into a graph. The assessment was made for the "relative percentage of strains with proven resistance" to individual ATBs. This was obtained by adding the actually tested proportion of strains to the total number of *E. coli* in the sample.

The accuracy of the results is affected by the relatively low proportion of tested strains (0.00004–0.19 %) due to high microbial load of surface and wastewater samples. The proportion of ESBL-positive and multi-resistant strains was evaluated separately (i.e. strains with simultaneous resistance to at least three groups of ATBs, with 3rd and 4th generation cephalosporins considered as one group).

RESULTS

During 2022–2024, 131 water samples from five categories were tested. The numbers of samples in individual categories are shown in *Tabs. 2* and *3*. *Tab. 2* also shows the relative percentage shares of *E. coli* strains with proven antibiotic resistance to the tested ATB in individual categories; *Tab. 3* shows the number of samples with proven antibiotic resistance to the tested ATB in individual categories. The results are shown in *Fig. 4*.

Most samples were tested from the BELOW category, which included wastewater recipients at different distances (500 m to 10 km) from their effluents. In this category, 201 *E. coli* strains were tested out of a total of more than 400,000 detected. Resistance to all tested ATBs was found; compared to the other categories, there was a high proportion of fosfomycin-resistant strains (22 %), in a similar proportion to the INFLUENT and EFFLUENT category (17–24 %). The most common was resistance to gentamicin (55 %), the least common, as in the other categories, was resistance to meropenem (1 %).

Lower proportions of antibiotic-resistant strains were found in the ABOVE category, where the profiles of larger watercourses above the WWTP effluent were included. This category served as a control comparison of the status above versus the status below the effluent of large WWTPs, which are considered significant AMR sources. However, even in this "control" category, *E. coli* with resistance to six of the eight tested ATBs were found. However, no sample showed resistance to nitrofurantoin and meropenem.

Other significant categories for comparison were INFUNENT and EFFLUENT from the WWTP. Despite a significant reduction in the number of *E. coli* in the effluents due to good treatment efficiency, resistance to all tested ATBs was found in both categories. The share of both resistant strains and positive samples was unexpectedly higher in the EFFLUENT category. The exception was resistance to gentamicin, which was similarly high in both categories (50–55 %). The most significant increase in the proportion of ARBs occurred with cefepime, nitrofurantoin, and meropenem.

In the STREAM category, where samples of different Vltava tributaries were included, into which smaller WWTPs are discharged, resistance to all tested ATBs was also demonstrated. The proportions of resistant *E. coli* and samples were lower, similarly to the ABOVE category.

The largest proportion of resistant *E. coli* and samples was clearly identified for gentamicin (46–55 % of strains), while the least represented was resistance to meropenem and nitrofurantoin (0–8 % of strains). Resistance to second generation cephalosporins was detected in 9–26 % of *E. coli* strains; it was also significant in third and fourth generation cephalosporins (3–23 % of strains), see *Fig. 5*.

Many *E. coli* strains showed multiple resistance (*Fig. 6*). The occurrence of resistance to three to five ATB groups was most common in the BELOW and EFFLUENT category. In the EFFLUENT category, resistance to six and seven ATB groups was also detected.

In part of the samples processed for the international action within the framework of EIONET WG on AMR in surface waters, *E. coli* isolates were tentatively tested for the production of extended-spectrum beta-lactamases. Five samples (25 isolates) in the BELOW category and eight samples (33 isolates) in the EFFLUENT category were processed in this way. The proportion of ESBL strains was higher in samples from WWTP effluents (0.2–3.6 %); the occurrence of ESBL-positive *E. coli* was also demonstrated in the recipients (BELOW category): see *Tab. 4*.

Tab. 3. Numbers of samples in each category with demonstrated AMR in E. coli

Sample category	Number of samples	Cefuroxime	Cefotaxime	Cefepime	Gentamicin	Sulfamethoxazole/ Trimethoprim	Fosfomycin	Nitrofurantoin	Meropenem
		Relative percentage of strains with proven resistance							
ABOVE	13	23	23	15	77	38	31	0	0
BELOW	53	38	30	17	81	23	55	38	6
INFLUENT	19	32	26	11	84	32	42	37	5
EFFLUENT	26	54	42	35	81	38	50	42	15
BROOK	20	25	15	10	85	20	50	45	10

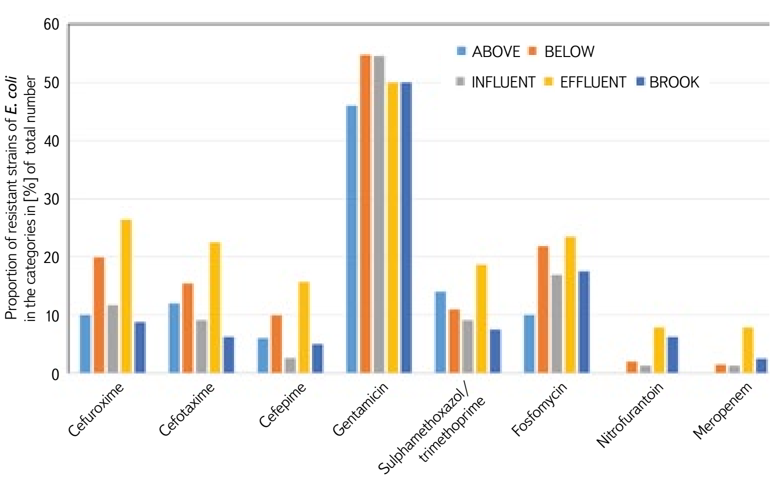

Fig. 4. Relative proportion of *E. coli* strains with proven AMR in each category

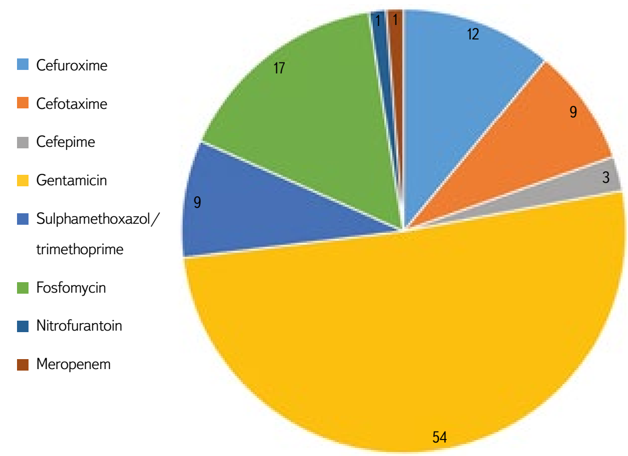

Fig. 5. Relative proportion of occurred resistance to individual antibiotics (incl. Multiple resistance; in %)

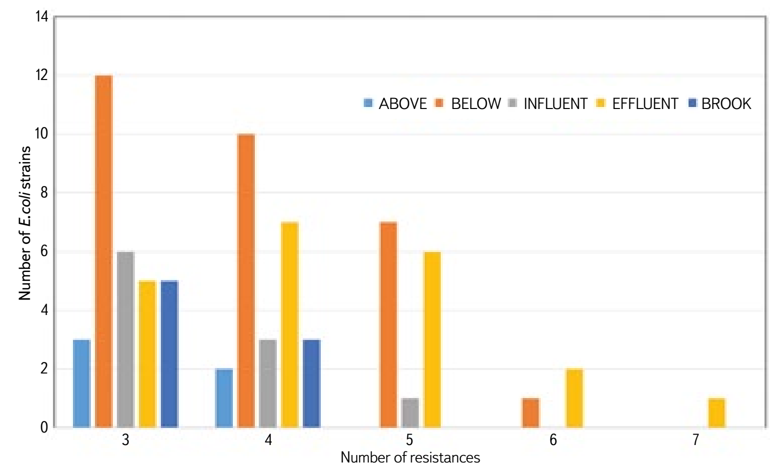

Fig. 6. Number of *E. coli* strains with proven resistance to 3–7 groups of antibiotics

Tab. 4. Ratio of samples with proven ESBL in E. coli

Sample category	Number of samples	Number of strains tested	Number of positive strains	Proportion of ESBL from all *E. coli* strains in the sample [%]
BELOW	5	25	13	0–2.4
EFFLUENT	8	33	23	0.2–3.6

DISCUSSION

The role of the environment in the AMR development and spread is receiving increasing attention. Based on current knowledge, it is not possible to predict the intensity of AMR occurrence from any other data (e.g. ATB residues, nutrients); therefore, it is necessary to monitor AMR directly, i.e. with ARB or ARG. Among ARBs, AMR is most often observed in *E. coli* isolates [12, 13]. In our study, *E. coli* isolates from surface and wastewater were tested for the presence of AMR. ATBs to which significant resistance is currently documented in clinical sphere and which cause difficulties in the treatment of serious infections were mainly chosen for testing.

Our results confirm that the AMR occurrence in the aquatic environment is not unique; on the contrary, in the vast majority of analysed samples (95 %), *E. coli* isolates were found to be resistant to at least one ATB. The most common was resistance to gentamicin, fosfomycin, and beta-lactam ATB. Gentamicin is an ATB used against serious infections. It is often administered in combination with other beta-lactam ATBs and is mainly used in surgery [14]. It is known for the frequent occurrence of resistance to it [15]. Fosfomycin is an ATB used to treat uncomplicated urinary tract infections. It is also used against already resistant strains of bacteria [16]. The least frequent was the occurrence of resistance to meropenem (a carbapenem). These ATBs are among the less commonly used, for the treatment of serious infections caused by multi-resistant strains of enterobacteria and non-fermenting gram-negative rods. Resistance to carbapenems is therefore a very serious issue from a clinical and epidemiological point of view [17]. The results of this study are consistent with our earlier data [18]. Various studies document that the proportion of resistant enterobacteria from wastewater, including *E. coli*, can range from less than 1 % to more than 20 %, especially for penicillins, cephalosporins, quinolones, and tetracyclines [12, 13, 19]. A research team from the USA addressed a similar topic [20]. The authors describe the AMR occurrence in Salmonella, *E. coli*, and enterococci in surface and wastewater. Their results showed the AMR occurrence in 9.6 % of *Salmonella* isolates, 6.5 % of *E. coli* isolates, and 6.8 % of enterococci isolates. AMR for tetracycline and ampicillin was most often detected in *E. coli* isolates. Similar results were observed in other works, such as [21, 22]. In our study, 8 % (for meropenem) to 55 % (for gentamicin) of strains with proven resistance were detected. Overall, 60 % of all strains showed resistance to at least one ATB. Samples from WWTP effluents contained a significantly higher proportion of resistant strains, especially to cefepime, nitrofurantoin, and meropenem, which may be a dangerous consequence of suitable conditions for resistance transfer in WWTP technologies. Multi-resistant strains can be found in the aquatic environment as well. These were isolated mainly from surface water below the sewage effluent and in the effluents from the WWTP. The assumption that WWTPs act as hot spots for AMR spread of is thus confirmed.

ESBL was detected in the majority of *E. coli* isolates, with a share of up to 3.6 % of all *E. coli* strains in the sample. These findings are not an exception; they were confirmed, for example, by the above-mentioned authors [20]. Resistance to beta-lactam ATBs, particularly through extended-spectrum beta-lactamases and carbapanemases, is increasing and is a significant worldwide problem.

Current wastewater treatment technologies are not able to remove AMR sufficiently. The solution could be wastewater treatment directly at the source (hospitals, nursing homes, homes for the elderly, abattoirs, etc.), i.e. before the pollution reaches a WWTP (https://www.niva.no/en/projects/hotmats). Attention is often focused on testing advanced procedures (e.g. ozonation, use of UV), nano and ultrafiltration, but also nature based solutions (e.g. root cleaning plants) [23–25].

Importation of resistant bacteria from third world countries also appears to be a significant problem, undesirably widening the spectrum of resistances with which human medicine can no longer work. In recent years, AMR determination in the aquatic environment has been directed towards the use of molecular-biological methods based on PCR. There are many studies that deal with ARG determination [26–28]. Attention is paid to ARGs with common occurrence in the aquatic environment, but also to those that are clinically significant, such as genes encoding extended-spectrum beta-lactamases and carbapanemases [26, 28]. Both mentioned approaches have their advantages and disadvantages, but in order to obtain the most comprehensive information, it is most appropriate to combine them [19].

The issue of AMR in the aquatic environment has been receiving a lot of attention abroad for a long time, an example being France with the AMR-Env network (https://amr-promise.fr/amr-env/). In the Czech Republic, until recently, activities in the field of AMR have been directed mainly at clinical and veterinary medicine, with the environment being largely neglected. The issue of AMR in the aquatic environment has been addressed by several research teams, for example a team from the University of Chemistry and Technology, Prague [29], the Faculty of Chemical Technology at the University of Pardubice [30], the team of doc. Dolejská at Brno University of Veterinary Sciences [31], and the National Institute of Public Health (EU-WISH project). Our team at TGM WRI deals with the study of AMR in the aquatic environment, especially within the framework of projects No. SS02030008 *"Centre for Environmental Research: Waste and Circular Management and Environmental Safety"* and No. SS02030027 *"Water systems and water management in the Czech Republic under conditions of climate change".* It is also involved in several initiatives such as EIONET WG on AMR in surface waters, AMR One Health Network, CZEPAR, Central Coordination Group of the National Antibiotic Programme.

CONCLUSION

The aim of our study was to examine AMR occurrence in different types of aquatic environments with regard to its possible sources, which could be municipal WWTPs. Resistance was determined using the disk diffusion method on *E. coli* isolates, detected by default as an indicator of faecal water pollution. The relative proportion of *E. coli* strains with proven resistance to some of the eight ATBs, classified into seven groups, was determined in the samples. Samples taken between 2022 and 2024 were evaluated within five categories of differently polluted surface water and wastewater.

E. coli with proven resistance was determined in almost 100 % of the tested samples, with the exception of resistance to nitrofurantoin and meropenem in samples of the ABOVE category. The highest proportions of resistant *E. coli* were found for gentamicin in all categories.

The most AMR positive strains and samples were detected in WWTP effluents, simultaneously with a significant increase in numbers when compared to raw wastewater samples in WWTP influents. The cause may be the dangerous transfer of resistance between bacterial strains in WWTP conditions. Positive AMR results were also found in samples from large watercourses above the WWTP effluent, while below the WWTP effluent there was a relatively significant increase in the occurrence of resistant *E. coli*, which confirms the assumption that treated wastewater from the WWTP is the source of AMR in watercourses. The category of samples from smaller tributaries of the Vltava, on which WWTPs are located, was at the medium level of AMR load, which shows that even these smaller streams need to be monitored. The proven occurrence of multi-resistant strains in effluents from WWTPs and below their effluent into recipients, together with the occurrence of *E. coli* producing extended-spectrum beta-lactamases, is alarming.

Our study showed that the problem of AMR in the environment needs to be given increased attention; so far, it has been neglected, not only in the Czech Republic. In key categories of water samples in the Czech Republic, the presented study showed an almost 100 % occurrence of *E. coli* bacteria resistant to at least one of the tested ATBs, including resistance to fourth generation cephalosporins. Detection of high numbers of resistant or multi-resistant *E. coli* strains in treated wastewater and below their effluents shows the importance of the aquatic environment in AMR spread and the necessity of its detailed study in efforts to reduce the current health threats posed by antibiotic resistance in the Czech Republic and around the world.

Acknowledgements

The article was created with the support of institutional resources of the MoE and projects No. SS02030008 "Centre for Environmental Research: Waste and Circular Management and Environmental Safety" and No. SS02030027 "Water systems and water management in the Czech Republic under conditions of climate change" of the Technology Agency of the Czech Republic. The authors thank the WWTP operators for their helpful cooperation in providing wastewater samples.

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The Czech version of this article was peer-reviewed, the English version was translated from the Czech original by Environmental Translation Ltd.

DOI: 10.46555/VTEI.2024.09.004

ISSN 0322-8916 (print), ISSN 1805-6555 (on-line).

Tools for risk assessment of catchment areas for abstraction points of water intended for human consumption

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Keywords: categories of abstraction — catchment areas — raw water — risk analysis — water supply and protection — water quality

ABSTRACT

In December 2020, the new EU Directive 2020/2184 on the quality of water intended for human consumption was published. This Directive places a strong emphasis on comprehensive protection of water resources and introduces an obligation to carry out risk assessment and risk management of the catchment areas for abstraction points of water intended for human consumption, compared to the previous Directive from 1998. The risk analysis of the catchment areas must be carried out for all water abstractions for drinking purposes that abstract more than 10 m^3 raw water per day. In the Czech Republic, this concerns approximately 3,650 abstractions (of which about 3,500 are groundwater abstractions and about 150 surface water abstractions). On a nationwide scale, it is therefore a considerable amount of risk analyses of parts of the catchment areas, which, according to the Directive, must be performed by 2027. The main aim of the project "*Tools for risk assessment of catchment areas for abstraction points of water intended for human consumption*" (supported by the Technology Agency of the Czech Republic) is to develop a methodology for the preparation of this risk analysis of the catchment areas. In order to ensure that the risk analyses of the catchment areas to be prepared by different entities have a uniform form and structure, a form (mock-up) of what the risk analyses of the catchment areas should look like and what they should contain has been developed within the framework of the methodology. As this is a very complex issue, only the main skeleton of the methodology will be presented in this article, focusing on the basic characteristics of the abstraction and the definition of the area (the catchment areas) in which the risk activities for the quality of the abstracted raw water are determined.

INTRODUCTION

Protecting water resources is key to achieving good water quality and, at the same time, ensuring a sufficient amount of high-quality drinking water for human consumption. The European Union is also aware of this fact; in 2020, it issued the new European Directive EU 2020/2184 on the quality of water intended for human consumption [1]. One of the significant changes compared to the original directive from 1998 [2] is Article 8, which deals with the risk assessment and risk management of the catchment areas for abstraction points of water intended for human consumption. This risk analysis should then be followed by risk analyses of the water supply system processed according to Article 9 of EU Directive 2020/2184 [1].

The EU Drinking Water Directive [1] describes only the basic points and objectives of the risk analysis of the catchment areas. By 2023, each member state had an obligation to transpose the Directive requirements into its legislation based on the conditions of each country. In the Czech Republic, the ministries have agreed that these risk analyses will be part of the basin sub-plans, and therefore the Basin State Enterprises will have the obligation to develop them according to Annex No. 3 to Decree No. 50/2023 Coll. [3]. In Slovakia, all risk analyses will be developed by the Slovak Water Research Institute [4].

The main purpose of developing risk analyses of the catchment areas is the comprehensive protection of water resources in the natural environment, i.e. before the water is abstracted. It is important to identify potential risks in the catchment areas associated with water abstraction points intended for human consumption. Thanks to this identification, targeted measures can subsequently be proposed to mitigate these risks. Other objectives are to ensure proper monitoring of relevant parameters in raw water and to assess the need to establish new or adapt existing protection zones of valuable water resources.

The aim of the project TA CR No. SS05010210 "*Tools for risk assessment of catchment areas for abstraction points of water intended for human consumption*" is the creation of a methodological procedure for the development of risk analysis of the catchment areas.

METHODS

Risk analyses of the catchment areas will be developed for all abstractions in the *Surová voda* (*Raw Water*) database [5], for which at least one monitoring of parameters in raw water was reported in 2019–2023. The *Surová voda* database [5] is used for uploading and managing raw water quality data in the scope of complete and abbreviated analyses in accordance with the requirements of Decree No. 428/2001 Coll. [6], as amended. Access to the system (https://surovavoda.chmi.cz) is given to state administration bodies, sanitary stations, basin managers, water infrastructure operators, and laboratories authorized by these operators to upload the results of laboratory analyses into this system.

This time range was chosen because data in the *Surová voda* database [5] older than 2019 show a higher error rate. The final year will then be 2023, as more recent data will probably not be available during the processing of the first risk analyses of the catchment areas. According to EU Directive 2020/2184 [1], risk analyses of the catchment areas must be prepared no later than 12th July 2027, but given that according to Decree No. 50/2023 Coll. [3] the risk analyses will be part of the basin sub-plans, it is necessary to process them between 2025 and 2026.

According to EU Directive 2020/2184 [1], risk analyses of the catchment areas are to be regularly reviewed at least once every six years and subsequently updated if necessary. The next review will therefore be in 2032 at the latest.

A form (mock-up) was created for the uniform development of risk analyses of the catchment areas, describing both their form and content. Two types of forms were created, one for groundwater abstraction and one for surface water abstraction. These forms will be binding for the development of risk analyses of the catchment areas and are divided into five chapters:

1. Basic abstraction characteristics
2. Characterization of the catchment area related to the abstraction point
3. Identification of potential risks in the catchment area related to abstraction points of water intended for human consumption
4. Assessment of appropriate monitoring of relevant parameters in raw water and verification of potential risks
5. Conclusion

In the following text, the basic characteristics of abstraction and definition of the area (catchment area) in which risk activities for the quality of sampled raw water are evaluated will be discussed in more detail.

Basic abstraction characteristics

The Basic abstraction characteristics chapter contains the most important data on the abstraction. The basic abstraction identifier is the abstraction identification number from the *Surová voda* database [5]. It is a unique eight-digit number. The basic data also include the name of the abstraction, number of structures analysed, whether it is a mixture from several raw water sources, type of abstraction, number and types of structures abstracted, category of the treatment plant, information on the basin manager and abstraction operator, abstraction size, and abstraction size category.

One of the most important basic data is the abstraction location; it is given in S-JTSK coordinates. It should be based both on the coordinates listed in the *Surová voda* database [5], as well as on the coordinates from the *Evidence uživatelů vody* database (*Water User Records*, EvUživ) [7] and on the coordinates of the first degree of protection zone for vulnerable water resources (OPVZ) [8]. If the location differs significantly according to the mentioned sources, the location according to the *Surová voda* database [5] and according to the EvUživ register [7] should always be indicated, but the information about the location in the relevant OPVZ [8] should primarily apply. At the same time, any discrepancy should be commented on. If it is not possible to find OPVZ [8] for an abstraction point for which the location in the *Surová voda* database [5] is significantly different from the location in EvUživ [7], the actual location cannot be identified without information from the water supplier.

Characterization of the catchment area related to the abstraction point

The second chapter in the form for processing the risk analysis of the catchment areas is characterization of the catchment areas related to the abstraction point. The basic characteristics for surface water abstraction include data on fourth order hydrological basin, surface water body, name of the watercourse, river kilometre and, for groundwater abstractions, data on the fourth order hydrological basin, groundwater body, and hydrogeological district.

Other important characteristics of the catchment areas include information on the protection zone for vulnerable water resources (OPVZ) for the given abstraction. OPVZ are updated annually in the OPVZ register, where documents establishing the OPVZ (decisions/measures of a general nature) are attached. Attribute information is attached to each OPVZ (date of definition, office, procedure number, municipality, region, source type, and others) [8]. This database, managed by the Ministry of the Environment and updated by TGM WRI, contains all OPVZ for which documents on their definition were found and which are registered in the *Centrální registr vodoprávní evidence* (*Central Register of Water Rights Records*, CRVE) [9]. If there is no document establishing OPVZ for a given abstraction, it is considered non-existent. However, it is necessary to verify this information with the local water authority (VPÚ). It may happen that the VPÚ or the water resource user did not submit the document to the OPVZ records.

Furthermore, for each abstraction, its inclusion in the relevant abstraction category must be carried out. Abstractions are first divided into groundwater and surface water abstraction. The risk analysis forms of the catchment areas differ for these two types of abstraction; also, some attributes are specific and set only for a certain type of abstraction. Surface water abstractions are then further divided into abstractions from reservoirs, abstractions from watercourses, and others (e.g. abstractions from a flooded gravel sandpit). The categorization of groundwater abstractions is more complex and is based on the division of groundwater abstractions into groups according to the natural characteristics of the abstracted water, focused on hydrogeological structures that are specific in terms of their

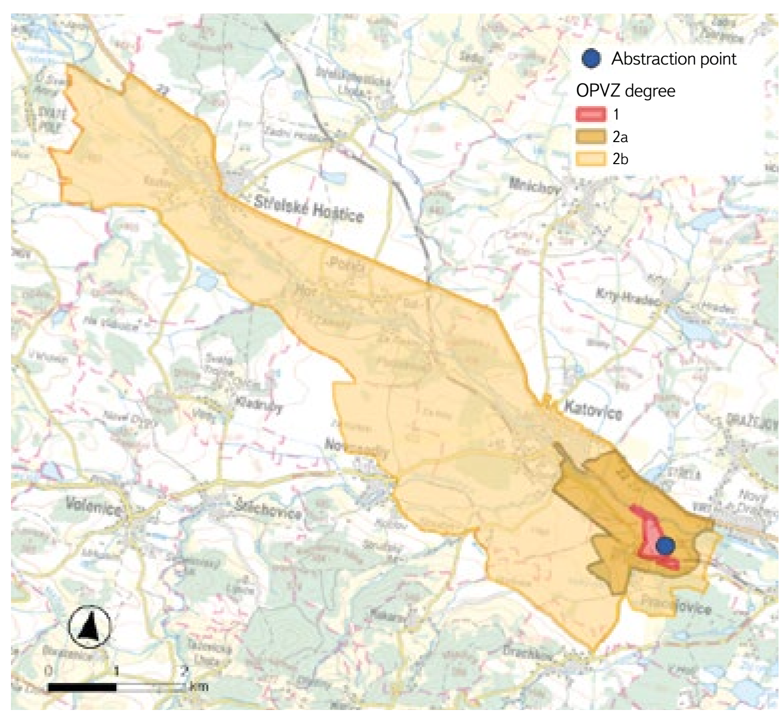

Fig. 1. TS STRAKONICE Pracejovice protection zones for vulnerable water resources (ID *Surová voda*: 11701200)

time-space water flow regime. Based on this criterion, groundwater abstraction is divided into three basic groups: abstraction from deep structures, abstraction from fluvial Quaternary, and abstraction from the subsurface zone. Samples from deep structures include groundwater samples from Cretaceous and Tertiary basins, samples from karst and samples from glacial Quaternaries. Abstractions from the fluvial Quaternary include groundwater abstractions from Quaternary groundwater formations and also abstractions from floodplains. The last group is abstraction from the subsurface zone, including other abstractions. These are mainly abstractions from Crystalline and similar geological formations.

Another important step in the risk analysis of the catchment areas is the definition of the catchment area. Defining the catchment area is generally one of the key steps in risk analysis. This is because it is an area in which risk activities can potentially or actually affect the quality of the abstracted water. In other words, it defines a part of the territory on which the risk analysis of the catchment area will take place. Even though those preparing risk analyses of the catchment area should primarily be based on the OPVZ definition, they must first determine whether the OPVZ corresponds at least approximately to the catchment area. The catchment area should be specifically defined according to the category of abstraction.

RESULTS AND DISCUSSION

Using specific examples of abstractions, we will present how the definition of the catchment areas should be carried out for different categories of abstraction.

The catchment area for surface water abstraction is given by all fourth order hydrological basins located above the abstraction point. However, it is always important to consider the specifics of the given abstraction and, based on expert assessment, it is possible to reduce this area in the case of a very large catchment area (for example, on the basis of information on the use of the area, potential sources of pollution, and the distance from the abstraction). We regard groundwater abstractions from fluvial Quarternary in a similar way to abstractions from surface water; this is because, in addition to the inflowing groundwater, they also receive a greater or lesser amount of surface water from the watercourse. The share of surface water abstracted will vary based on the hydrological situation (at higher levels of surface water, groundwater may be recharged by water from the watercourse) and according to the amount of water abstracted (if more water is abstracted than groundwater inflow, surface water infiltration occurs). Since it is not easy to define for individual abstractions which part of the water abstracted is from groundwater and which from surface water, it is better to treat all of them as if they were surface water abstractions; this is because surface water is usually

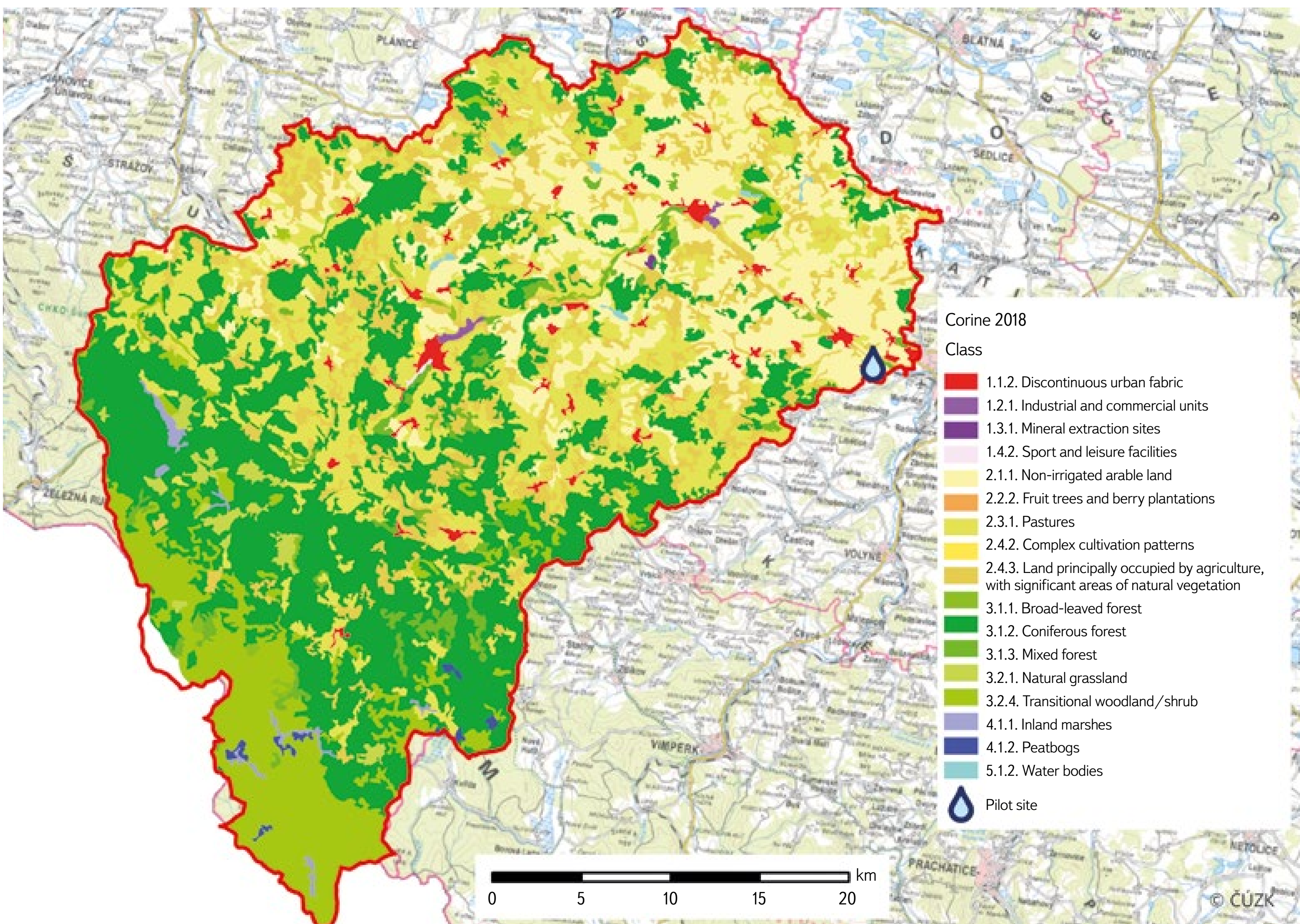

Fig. 2. Land use based on CORINE Land Cover 2018 data in the catchment area of groundwater abstraction TS STRAKONICE Pracejovice (ID *Surová voda*: 11701200)

more vulnerable to anthropogenic pollution. The catchment area for groundwater abstractions from the fluvial Quaternary is therefore, similarly to surface water abstractions, defined by all fourth order hydrological basins above the abstraction point. Even in this case, it is possible to reduce a very large area based on the specifics of the given abstraction and expert assessment, similar to the case of surface water abstractions. An example is the abstraction of groundwater TS STRAKONICE Pracejovice (ID *Surová voda*: 11701200). It is an abstraction in the hydrogeological district of the Otava and Blanice Quarternary near the Otava river. The abstraction is defined by OPVZ of the first and second degree (*Fig. 1*).

In the case of defining the catchment area for this abstraction, all fourth order hydrological basins of the Otava river above the abstraction point should be considered. This is a very large area; however, with the use of additional information (e.g. from CORINE Land Cover 2018 data) it is possible to reduce this area, as the Šumava PLA and the Šumava National Park are located in the southwest of the catchment area, where there are no major potential risks, such as arable land and larger settlements (*Fig. 2*).

Definition of the catchment area in the shallow near-surface Crystalline zone, which makes up about three-quarters of the Czech Republic, is relatively simple. As a first approximation, it is possible to use the fourth order basin in which the abstraction is located. However, the catchment area often does not include the entire basin – it is usually significantly smaller. On the one hand, the abstraction is rarely located near the fourth order basin closing profile, but on the other, it does not occur in the river floodplain, as in that case it would belong to the fluvial Quarternary. The catchment area can be estimated according to the contours of the terrain – the catchment area starts below the abstraction (this is because during the abstraction, a cone of depression of the groundwater level is formed and the groundwater is also pumped below the abstraction); the catchment area is further defined by perpendiculars to the contours up to the highest point. Such a definition of the catchment area can be seen in the example of the Dolní Niva abstraction (ID *Surová voda*: 32207000), where only the first degree of OPVZ is defined. The catchment area begins about 100 m below the abstraction point (which is probably much more than the distance of the actual cone of depression) and is defined from above by the Vysoká jedle summit (735.4 m a.s.l.) and elevation point 207 (726.9 m a.s.l.) (*Fig. 3*).

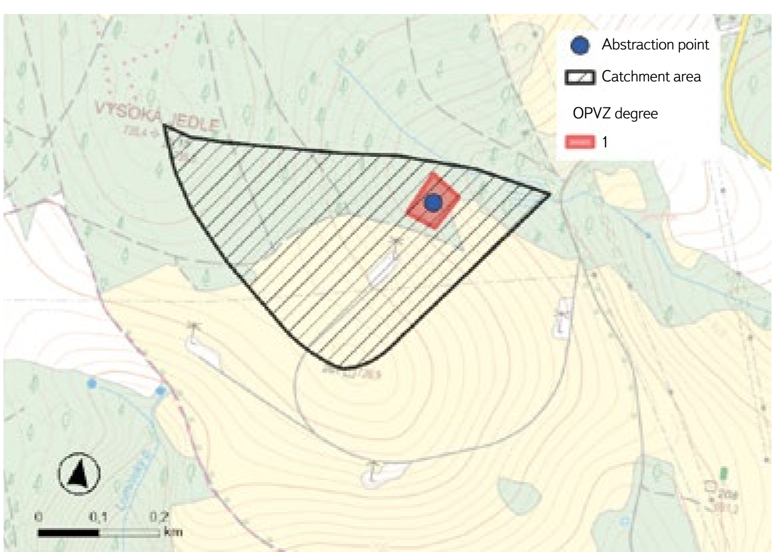

Fig. 3. Catchment area of groundwater abstraction Dolní Nivy (ID *Surová voda*: 32207000)

The most complicated catchment area definition is for abstractions of groundwater from deep structures. In the Czech Republic, this concerns the area of the Permocarbon basins, the Czech Cretaceous basin and both South Bohemian basins, the areas of Tertiary, flysch and Kulm in Moravia, and the Moravian Karst. However, the mere geographical situation of collection structure in the space where the deep structure occurs does not necessarily mean that the deep structure is actually used. Depending on the depth of the abstraction object, the case can occur where a shallow collection structure uses only the subsurface zone. The issue of defining the catchment area is the most difficult in structural basins, where in the extreme variant the abstracted groundwater can come from several aquifers of mutually different, often large areas. In addition, these aquifers are covered on some areas or separated from each other by an impermeable insulating layer, which protects the respective aquifers from contamination from the surface. The automatic application of the fourth-order hydrological basin for the definition of the catchment area in the subsurface zone environment would therefore in most cases give a distorted picture.

According to the degree of exploration of the given hydrogeological district, we can divide the methodological procedures for defining the catchment area for abstraction from deep structures into four variants. Here are examples of defining the catchment area according to these methodological procedures.

1) Defining the catchment area by a hydrogeologist on the basis of a hydraulic model

The absolutely ideal and most accurate solution is to consult a hydrogeologist who works in the given district and knows the infiltration areas of the respective aquifer. If a hydraulic model of groundwater flow is available in a given district, then it is possible to define the infiltration space for individual aquifers using GIS tools, used in the construction of the model geometry and its calibration. These data quite precisely define the environment on which the risk analysis should focus.

This case was tested at the abstraction of ČEVAK Suchdol n/Lužnicí (ID *Surová voda*: 11300600). It is a complicated case of the Cretaceous Klikov formation abstraction in the Třeboň basin. The collection structure connects several dozen sandy aquifers, which are separated from each other by clay insulators or sandy-clay semi-insulators. The catchment area was defined on the basis of the infiltration area used in the 3D hydraulic model of the company Progeo, s. r. o., which considered the direction of groundwater flow in the basin system to the abstraction point in the final form; see *Fig. 4*.

Fig. 4. Catchment area (purple marked area) of groundwater abstraction ČEVAK Suchdol n/Lužnicí (ID *Surová voda*: 11300600) on the basis of the Progeo, s. r. o., hydraulic model and its inclusion in the broader context of the relevant hydrogeological district

Třeboňská pánev – jižní část (blue highlighted area)

2) Defining the catchment area based on documents from the "*Rebalancing of groundwater supplies*" project

Consultation with a hydrogeologist may not always be possible for various reasons. Therefore, two alternative variants are offered, which bring with them the risk of simplification, and therefore also the possibility of introducing inaccuracies. The first option, which still provides a relatively high degree of credibility, is the use of information from the "*Rebalancing of groundwater supplies*" project [10], implemented by the Czech Geological Survey. It covers most of the major structural basins.

An example of an abstraction where it is possible to use information from the "*Rebalancing of groundwater supplies*" project is the abstraction of SčVK Dubnice pod Ralskem (ID *Surová voda*: 33045800), which is located in hydrogeological district 4640 – Cretaceous upper Ploučnice. According to the decision of the Česká Lípa District Office, the environment department from 1997, this abstraction is limited only to the first degree of OPVZ with dimensions of 20 × 20 metres. The database of geologically documented structures, which can be accessed using the *Vrtná prozkoumanost (Drill Exploration)* map application [11] and which is maintained and managed by the Czech Geological Survey, shows that the abstraction of SčVK Dubnice pod Ralskem (ID *Surová voda*: 33045800) is 400 metres deep and abstracts the Coniacian aquifer. It is therefore evident that it is a collection structure of deep circulation, without the influence of the near-surface zone. Such a deep hydrogeological well always has a technically sealed upper zone. It is therefore possible to use the information from the Final Report of the "*Rebalancing of groundwater supplies*" project for hydrogeological district 4640 – Cretaceous upper Ploučnice [12] when defining the catchment area. This report shows that there are three significant hydrogeological aquifers in the district at different depth levels: aquifer A (Peruc–Korycany formations of Cenomanian age); above it, aquifer BC (Bílá Hora and Jizera formations of lower to upper Turonian age); and in part of the district, aquifers D (Teplice and Březno formations of Upper Turonian to Coniacian age). The abstraction of SčVK Dubnice pod Ralskem (ID *Surová voda*: 33045800) abstracts the uppermost aquifer D, which is developed in the northwestern part of the district in the form of several more or less independent bodies. The base of aquifer D generally dips from north to south and is often interrupted by vertical tectonic displacements. The chapter on the definition of infiltration areas shows that the occurrences of aquifer D are divided by erosional valleys into several balance-independent water subsystems with infiltration in the areas of their occurrences and with drainage of groundwater into the surrounding watercourses – especially into Ploučnice with its tributaries. The water level is mostly open. Aquifer D is fed by precipitation infiltration throughout the area of occurrence, except for areas covered by loess, where infiltration is considerably limited. Based on the above findings, it can be stated that the catchment area for the abstraction of SčVK Dubnice pod Ralskem (ID *Surová voda*: 33045800) will be defined by the basins of the Dubnický and Ještědský streams. It is obvious that the quality of the abstracted water will not be actually affected by the entire defined area. A limiting role will be played by insulating surfaces formed by loess, as well as by tectonics extending in the direction of drainage. However, the inclusion of the entire Dubnický and Ještědský stream basins is an optimal compromise on the side of precautionary risk.

3) Defining the catchment area in an environment that is not covered by the "*Rebalancing of groundwater supplies*" project, but has a defined credible second-degree protection zone for vulnerable water resources

This method of defining the catchment area is burdened with a greater degree of uncertainty and is also more time-consuming. An example is the definition of the catchment area for abstraction of SčVK Holedeč vrty

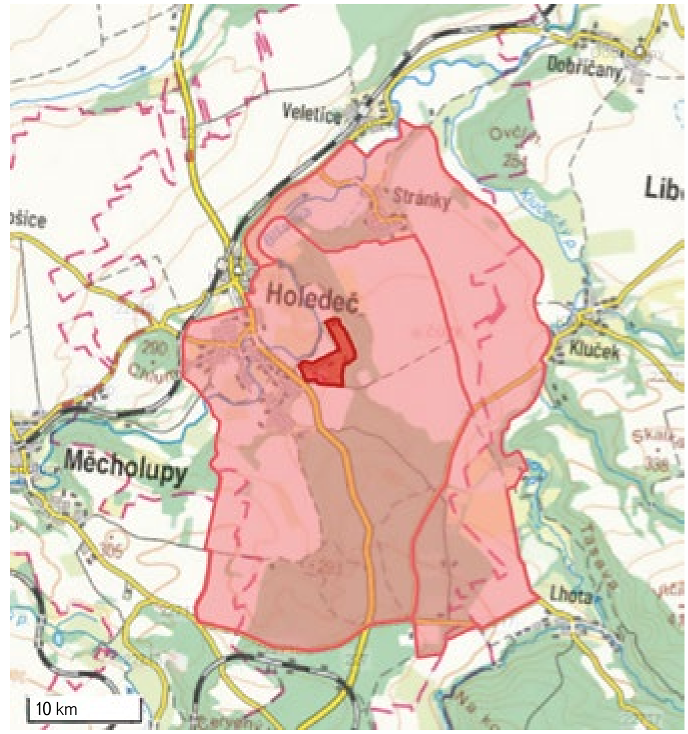

Fig. 5. Catchment area of groundwater abstraction SčVK Holedeč vrty (ID *Surová voda*: 33070200) based on the protection zone for vulnerable water resources

(ID *Surová voda*: 33070200). There is no information about this resource regarding its technical parameters. The only data that can help is the decision of the environment department of the District Office in Louny from 1991, which establishes the first and second degree of OPVZ. This decision talks about eleven collection structures, but without mentioning their names according to which they could be identified, or compared to the wells in the *Vrtná prozkoumanost* map application [11]. Therefore, it was necessary to turn to a different procedure. It can be assumed that the first degree of the OPVZ is in the immediate vicinity of the collection structures, and thus an appropriate selection can be made using the *Vrtná prozkoumanost* map application [11]. The wells located inside the first degree of the OPVZ have a depth of 100 metres and abstract a Neogene aquifer. Since no further information is available for the given site, with some uncertainty, it is possible to consider the extent of the second degree of the OPVZ defined in the aforementioned decision as the catchment area (*Fig. 5*). In this case, this consideration can be based on the legitimate assumption that this zone was created on the basis of a previous detailed hydrogeological assessment, which considered the directions of groundwater flow from the infiltration area towards the abstraction point.

4) Defining the catchment area in an environment that is not covered by the "*Rebalancing of groundwater supplies*" project and does not have a defined second-degree protection zone for vulnerable water resources

The most difficult variant, burdened with the greatest uncertainty and, in the extreme variant, even without the possibility of defining the catchment area, is the case where the abstraction object:

- lies in a structure that falls into the deep structure category,
- this area is not covered by the "*Rebalancing of groundwater supplies*" project [10],
- does not have a defined second degree OPVZ,

— there are no technical parameters on the method of abstraction. The depth of the boreholes/wells, their number or their designation, i.e. the parameters that would enable the structure identification in the *Vrtná prozkoumanost* map application [11], are not known.

The only and most time-consuming procedure is to try to find at least part of the missing data and proceed to define the catchment area in the same way as a hydrogeologist processes a second degree OPVZ proposal. It should be emphasized that, based on our experience, this case is rather exceptional; however, we must mention it for the purpose of objectivity.

CONCLUSION

The main purpose of developing a risk analysis of the catchment areas is the comprehensive protection of water resources. It is important to identify potential risks in the catchment areas associated with water abstraction points intended for human consumption. However, for this, it is necessary to know the extent of the catchment area, which does not always correspond to the OPVZ. Thanks to the identification of potential risks and verification based on monitoring, targeted measures to mitigate potential risks should be proposed. Therefore, proper monitoring of relevant parameters in raw water and assessment of the need to establish new or adapt existing OPVZ must be ensured. For uniform processing of risk analyses of the catchment areas, a form was created with a precise structure, which should be followed by the processors of risk analyses of the catchment areas. The form has five basic chapters and clearly summarizes what should be part of the risk analysis of the catchment areas. This article is focused on the basic characteristics of the abstraction and the catchment area, which are one of the most important steps in the risk analysis processing. A high-quality risk analysis of the catchment areas cannot be developed without the correct definition of the catchment area.

Acknowledgements

The article was created within the framework of the Technological Agency of the Czech Republic project No. SS05010210 "Tools for risk assessment of catchment areas for abstraction points of water intended for human consumption".

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The Czech version of this article was peer-reviewed, the English version was translated from the Czech original by Environmental Translation Ltd.

DOI: 10.46555/VTEI.2024.09.002

ISSN 0322-8916 (print), ISSN 1805-6555 (on-line).

Future water demand scenarios to 2050: sectoral analyses and forecasts

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Keywords: scenarios — future water demand — 2050 — agriculture — irrigation — livestock — industry — power engineering — water for human use — climate change

ABSTRACT

This article presents the results of the sub-objective "*Scenarios of future water demands for different climate scenarios and individual sectors of water use*" (DC 1.1). Which is part of TA CR project No. SS02030027 "*Water systems and water management in the Czech Republic and climate change conditions (Water Centre)*" and is a sub-part of the WP 1 "*Prediction of the development of water resources security in the Czech Republic until 2050 in regions depending on climate change*". The project was implemented between 2020 and 2024 and involved the following organisations: TGM Water Research Institute (TGM WRI); University of Chemistry and Technology in Prague (UCT); Czech Technical University in Prague (CTU), Faculty of Civil Engineering; CzechGlobe – Global Change Research Institute of the Czech Academy of Sciences (CAS); Czech University of Life Sciences in Prague (CZU); and Charles University in Prague, Faculty of Science – as a subcontractor. This article deals with the projection of future water demand up to 2050 through sectoral analyses and forecasts. The solution uses different scenarios that consider factors such as population growth, economic development, climate change, technological advances and policy decisions, and focuses on water demand for the following sectors: agriculture, industry, energy industry, and households. It also assesses the potential impacts of different scenarios on the availability of water resources. The results show that in some regions, depending on the scenario considered, there may be a significant increase in water demand, which could lead to water scarcity and therefore require the implementation of new strategies for efficient water management. Conversely, in some regions, a decline in economic activity and population migration may lead to a reduction in water demand. The paper further describes the potential uncertainties and variables affecting the prediction of future water demand, while highlighting the importance of sectoral analysis for understanding future trends in water management.

INTRODUCTION

Water is an essential resource for life on Earth and at the same time plays a key role in all areas of human activity, from agriculture to industry, electricity and heat production to household operations. With climate change and changing water demands from different sectors, the issue of future water demand is becoming increasingly urgent. The issue of the future availability of water resources is a complex topic that includes a number of key aspects, such as changes in the distribution of precipitation in time and space (some areas may experience periods of drought, others periods of torrential rain), increase in temperature, increase in water evaporation from vegetation and water bodies, economic development and industrialization requiring more water for industry and energy industry, increasing population living standards and the associated higher water consumption in households, and the growing demand for water in agriculture to ensure food security. The basic prerequisite for solving the aforementioned issue is to obtain information about the future demand for water in various sectors and its distribution across the Czech Republic, with a subsequent comparison with future available sources. The result should then be a more efficient use of water in agriculture, industry, energy industry and households, associated with the development of technologies for water treatment and recycling, building water infrastructure for water retention and transport, and also with the improvement of forecasting systems for water management. It is a key integrated approach that considers all the aspects mentioned above and seeks levelled off solutions to ensure sustainable management of water resources in the future. As this is a relatively extensive issue, it was dealt with by a wider team of experts of various specializations divided into several teams focused on a certain area of water demand estimation. Based on available data and forecasts, the development of water demand in the coming decades will be predicted. Based on these findings, the follow-up activities of other work packages within the "*Water Centre*" will determine what strategies can be implemented to ensure sustainable and equal distribution of this valuable resource.

Water demand analysis for industry

METHODOLOGY AND SOURCES USED

The goal of the researchers from UCT was to analyse the current demand for water in industry in the Czech Republic and to obtain data for the quantification of future demand. The input was data on registered surface and groundwater abstractions and wastewater discharges for 2009–2019, based on Decree no. 431/2001 Coll., managed by the State River Basin Authorities. These are data on direct abstractions and discharges reported by individual entities; therefore, they do not include information on the use of water from public water supply systems and the discharge of water into public sewers.

The data was divided into three groups:

1. Aggregated data on annual discharge/abstraction volumes for individual sectors for 2009–2019 related to regions and districts that became the basis for monitoring development and trends.
2. Detailed data on the most important entities in water management in individual sectors. The so-called TOP 7 – detailed data for entities reporting the largest volumes of water abstracted and/or discharged in the given sector. Each of the selected parameters (surface water abstraction, groundwater abstraction, wastewater discharge) was evaluated separately, with 2019 being the most important year.
3. Complete unclassified data on abstraction and discharge (i.e. for all sectors, not only industry) for 2009–2019, used primarily in the checking for and tracing of possible discrepancies.

The aggregated data was processed in both tabular and graphical form, so that it was possible to determine the most important sectors for individual territorial units and to monitor possible trends in the demand and consumption of water. The initial analysis was carried out at the level of the Czech Republic and its regions, then it was extended to districts. In addition to annual abstraction (or discharge), data on seasonal fluctuations were also processed, i.e. abstractions in individual months.

SUMMARY OF RESULTS

It was found that in the case of surface water, the chemical industry is the largest user in the Czech Republic, followed by paper production, metal processing, and mining. Groundwater abstraction is generally associated primarily with mining and food industry; other sectors show significantly lower values. There are also big between regions; at the regional level, the largest industrial surface water abstraction was recorded in the Ústí Region, mostly involving chemical and paper industries. Regarding groundwater, the Moravian-Silesian and Central Bohemian Regions show the highest values, with the majority in the Moravian-Silesian Region associated with mining.

Although it is a generally accepted fact that industrial demand for water in the Czech Republic has been decreasing for a long time, this rule cannot be applied as universally valid under all conditions. Data analysis shows that there are differences both between industries as a whole and between individual regions. However, despite these differences, it can be stated that the prevailing trend toward the end of the analysed period 2009-2019 was balancing the volumes of water abstracted, without extreme fluctuations.

At the district level, the resulting progress of abstraction and discharges is in many cases much more fluctuating, often without clear trends. This is partly due to the fact that the sources of discrepancies found in regional analysis are more pronounced in smaller territorial units, and partly due to the fact that at the district level the number of entities of one industry is limited. Sometimes an industry is represented by a single enterprise whose operation defines the entire progress of time. It is in such cases (i.e., there is only one important water management entity in an area) that it is possible to observe the convergence of trends at the regional and district level. A typical example is the Ústí Region and the Litoměřice District, where the values of abstraction and discharge of paper industry are basically determined by a single company, Mondi Štětí, a. s.

As part of the research, the seasonality of abstraction was also determined. The analysis confirmed that there are differences not only between sectors, but also within individual sectors. Some sectors show more or less levelled off consumption throughout the year; for others a decrease in the summer is characteristic, indicating regular summer shutdowns, or other reasons for the abstraction regime reducing abstractions in the summer period. In contrast, there are companies showing abstraction peaks in July and August. An important finding is the fact that recorded monthly deviations can vary significantly from year to year for a given entity.

CONCLUSIONS AND THEIR UNCERTAINTIES

Industry in the Czech Republic is still diverse, export-oriented, and not subject to central planning. It is therefore influenced by a number of factors (economic, social, political; not only at the local but also international level), which are difficult or even impossible to predict with sufficient accuracy. More detailed outlooks for individual sectors as a whole are not available, and obtaining information about specific entities is complicated.

With regard to the above-mentioned facts, a simplified approach was chosen based on a combination of monitoring current trends in water abstraction and discharge, with an effort to obtain at least a general idea of the development of individual industries until 2050.

The results of data analyses can be summarized in a relatively simple statement: as the size of the analysed territorial units decreased, the volatility of the data series increased and clear long-term trends disappeared. In contrast, possible seasonal fluctuations became more apparent.

Based on the results achieved, it was decided that the issue of future water demand in industry will not be dealt with by predicting changes over time, but by setting three fixed levels which will enable the comparison of realistically available water resources at a given time. The starting point for their determination was the abstraction analysis at the regional level. This approach can be used not only for annual, but also for monthly values, to capture fluctuations in abstraction during the year.

Baseline value

Baseline values are based on the assumption that industrial demand for water in the future will be similar to the present, or by the end of the evaluated period 2009–2019. The value for each sector will be calculated as an average of four years, which were selected based on data evaluation at the regional level. In most cases, it concerns years 2016–2019, when Czech industry was in good shape and the most common trend in water abstraction was a more or less steady state. For industries or regions where there were significant fluctuations in these years, development of water demand was analysed in more detail and other years were selected for calculation (*Fig. 1*).

Maximum value

The largest volume of abstracted water recorded in 2009–2019 will be used as the maximum value of future abstractions. This provides a realistic estimate of possible positive deviations from the baseline (*Fig. 1*).

Critical value (must not be exceeded)

The data contains information not only on abstraction and discharge, but also on maximum permitted volumes. In the analysed period 2009–2019, the limits for groundwater and surface water abstractions were not fully used, and therefore provide a reserve that is at least theoretically available to the relevant businesses. It is a realistic assumption that the limits for specific entities will not be increased in the future, and thus determine a critical limit for the use of water resources, which can be compared with the expected future demand (*Fig. 1*).

The above-mentioned approach naturally brings with it certain risks and uncertainties:

1. Insufficiently clear or misleading trends
Total demand for water in industry in the Czech Republic has been decreasing for a long time; however, simply projecting this fact into the future could lead to completely wrong conclusions (theoretically to almost zero water demand). Conversely, any growth observed in a certain industry and region cannot simply be extrapolated into the future based on a mathematical calculation. Even the steady state observed in a number of industries in recent years does not mean that there will be no fundamental changes in the future.

2. The issue of transferring trends and forecasts to a lower level of territorial units or individual entities
Trends valid at the national or regional level may not be valid for a smaller area. The project envisages modelling water management balance at the level of small units – hydrogeological districts and water bodies, where it can be expected that the situation will also be assessed at individual abstraction points, i.e. individual entities. In such a case, it will largely depend on local conditions.

3. Creation or disappearance of entities
A prediction based on the analysis of historical data cannot, in principle, work with the possible demise of the business (in the sense of ending production) and especially with the construction of a new one (primarily on so-called green field).

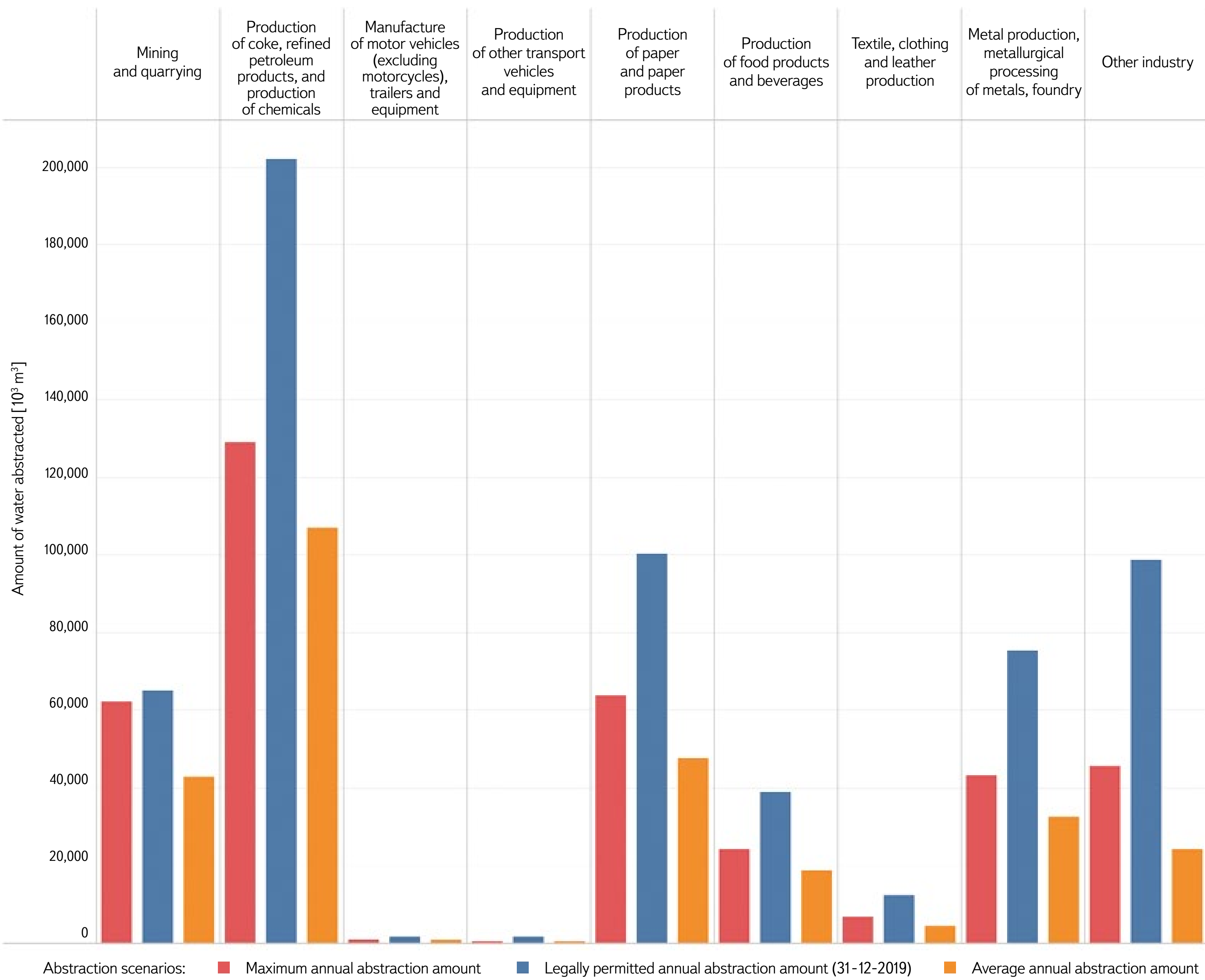

Fig. 1. Surface and groundwater abstraction scenarios for industry up to 2050 based on data from 2009–2019 in sub-sectors

4. Suitability of authorized abstraction
   As mentioned earlier, permitted abstraction of surface and groundwater will serve in the prediction of water demand as a limit that future development must not exceed. Given that in some cases the permitted values are significantly higher than the real state, it is not guaranteed that the current yield of the relevant water resources allows them to be achieved.

Water demand for agriculture: Irrigation water demand – from the point of view of irrigation technology

METHODOLOGY

The aim of the CTU working group was to try to outline the development of irrigation in the Czech Republic by 2050 and to hypothesize what technology will be used and whether the irrigable area will increase or decrease; subsequently, in cooperation with project partners, determine how many water resources for irrigation and other sectors of human activity would need to be secured in this time horizon in individual regions.

An analysis of the available documents describing the current state was used [1–4]. It mainly concerned information on the structure of crop production and on the technical parameters of irrigation – i.e. where it is technically possible to irrigate crops with regard to the availability of resources and infrastructure (irrigable areas). The irrigation detail enabling efficient irrigation was also dealt with (minimization of water loss and accurate dosing of irrigation water). For its current use for crop irrigation, the values of the loss coefficients K_1 and K_2 were specified; see *Tab. 2* (CzechGlobe). For the prediction of water requirements, the long-term trend of the development of climatic parameters determining the demand for additional irrigation for individual crops in the event of changes in agroclimatic areas is also considered (Czech Statistical Office – CZSO and the Crop Research Institute – CRI).

Current data on irrigation (irrigated areas) was taken from the ISMS database (SOWAC-GIS geoportal map project). Data from the *Land Parcel Identification System* (LPIS) were used for crop occurrence [5, 6].

An analysis of the irrigation abstraction database (TGM WRI) was carried out for individual catchments, and the ambiguities found were discussed with representatives of the State River Basin Authorities [7]. The database provided the amount of surface and groundwater currently abstracted for irrigation for 2014–2021; the data was subsequently processed for individual sub-basins and surface water bodies [8].

By determining the demand for water for individual crops (data from CZU) [9], an estimate was subsequently created of total demand for irrigation water for individual surface water bodies and quantification of the necessary water sources for irrigation. When predicting future water abstraction for irrigation, updated water losses forced by irrigation technology are already considered [10], and all calculations and estimates were made for predicted climatic conditions.

RESULTS

For selected relevant data from the TGM WRI database, the annual volume of water abstracted for irrigation in 2014–2021 was in the range of 18–31 million m^3, which accounted for roughly 1.4 % of total annual water consumption in the Czech Republic. The biggest amount of irrigation water was abstracted in 2018; the amount has been gradually decreasing since. Water was abstracted mainly from surface water, with less than 10 % reported from groundwater. The largest amount of irrigation water for the analysed period (45 % of the total average amount) was abstracted in the Dyje catchment. The rate of use of the monthly amount of water legally abstracted (in the months of the general growing season) was recorded partly inaccurately; for example, collectively for the growing season, by wrong reading of the water meter, or ambiguously in the case of groundwater abstraction. In some cases, the permitted values were exceeded (around 30 %).

The provided soil water balances of individual crops (CZU) were evaluated; consequently, the water demand for individual surface water bodies was recalculated for the selected crops and the considered periods.

As part of determining scenarios for irrigation water abstraction, combinations of irrigation water demand for "hop fields", "vineyards", "orchards", "arable land", and "permanent grassland" were created for each surface water body for irrigated and non-irrigated areas in the "average growing season GS", in "Dry season – sensitive growing season SGS" and as "horizon 2050 prediction for growing season GS" [11–15]. All results are part of the overall CTU report in tabular digital form and an example of the graphical display of irrigation water demand for individual surface water bodies in the "forecast GS" variant; see *Fig. 1*.

- "Average 12 years GS" variant describes the current state calculated from real measured values 2010–2021; it can be considered as the lowest demand of water for irrigation.
- "Dry SGS" variant was calculated for sensitive growing seasons as the average of the two extreme years 2015 and 2018, representing the potentially highest irrigation water demand in a sensitive growing season.
- "Forecast GS" variant estimates future demand for irrigation water for the vegetation period of the given crop (GS) from the simulated values of soil water balances 2022–2050.

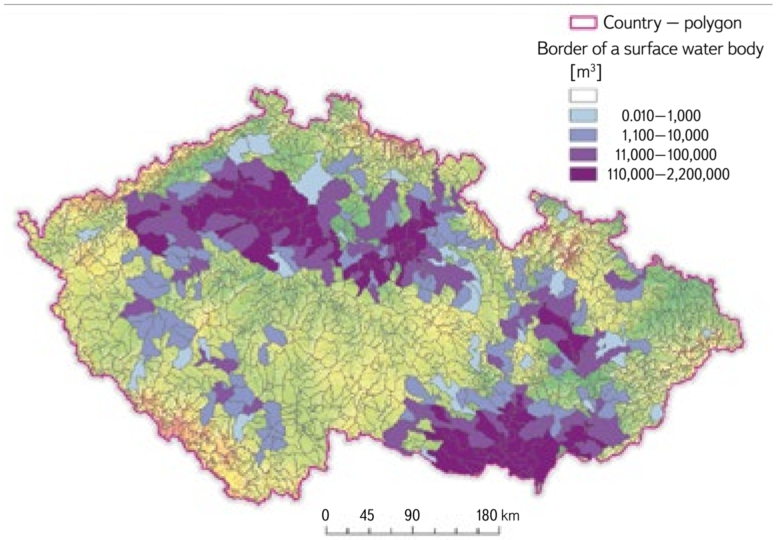

Fig. 2. Illustration of irrigation water requirements per growing season in m^3 in individual UDPs, variant „forecast GS" (Source: CTU)

UNCERTAINTIES

Considering the ambiguities of the recorded values of irrigation abstraction, the rates of use of the monthly amount of water legally abstracted were discussed with the employees of the State River Basin Authorities. Calculations of irrigation water demand are made on the basis of current knowledge and currently available data. Clearly, even these results are burdened with uncertainties; for example, there is a lack of updating of the database of actually irrigated areas and their connection to abstraction points. When calculating the amount of water for irrigation, uncertainties arose due to the inconsistency of the defined LPIS categories ("hop fields", "vineyards", "orchards", "arable land", and "permanent grassland") with the provided soil water balances of individual specific agricultural crops (see CzechGlobe). Uncertainties also exist in the socio-economic area because the structure of crops, as well as the decisions of economic entities to support the construction and subsequent use of irrigation, are significantly influenced by the economy, subsidy titles, and the common European market. In comparison to the previous ones, the uncertainties in the area of regional climatic development are also lower (although not negligible).

CONCLUSIONS AND RECOMMENDATIONS

The analysis of the irrigation abstraction database determined the used amounts of water in individual river basins, searched for and named ambiguities in the entries of values.

Analysis of irrigation technologies in the Czech Republic and estimation of their irrigation water losses enabled calculation of the approximate maximum amount of water needed for the irrigation of typical cultures "vineyard", "hop fields" and "orchards", including a possible extrapolation to the scenario of covering the entire area of these cultures with irrigation. The indicative amount of water needed to irrigate "arable land" and "permanent grassland" was calculated; it is clear that irrigation on arable land will be decisively concentrated on vegetables and early potatoes, and on permanent grassland on meadows for the production of fodder for dairy cattle. Development towards full irrigation is not realistic here – it was only applied where irrigation is already in place (which was considered an indicator of the fact that irrigated crops are grown there). This fact was verified according to CZSO data – which, however, are only available at the district level until 2014.

Without being able to make a realistic balance of the availability of water resources for individual irrigated areas, it is quite obvious that groundwater should not be massively used for irrigation in critical areas, as it is valuable water that should be reserved for drinking purposes. In addition, there will obviously be simultaneous occurrences of the demand for irrigation (longer periods of heat and drought) and, simultaneously, low flows in watercourses (longer periods of drought and heat). Water demand will thus be covered only by the construction of additional reservoirs, or by modifying the handling regulations of existing reservoirs (if they have free capacity).

Implementation of irrigation mathematical models can help (e.g. the AQUA CROP model, registered by FAO). These methods will rather help to optimize the size and timing of irrigation doses; however, they do not influence the overall water balance.

We can see that the state records a large amount of data and information, but often without a concept, in different places and without mutual continuity. Therefore, it is recommended to:

- link the information from the Ministries for the purpose of efficient management of water and other resources.
- carry out a detailed inventory of land in the "irrigated" and "irrigable" category and introduce these as parameters into the LPIS database.
- separate the category "water for irrigation" in the records of water abstraction and assign irrigated land to individual sources – this can also be done in the LPIS or in the ISMS databases.

Water demand for irrigation from the point of view of plant demand modelling: preparation of scenarios for the development of climate parameters – selection of models

Based on analysis within the excellent research projects of the Operational Programme Research, Development and Education – Sustainability of Ecosystem Services (OPVVV SustES) and the Operational Programme Jan Amos Komenský – Advanced Methods of Emission Reduction and Sequestration of Greenhouse Gases in Agricultural and Forest Landscapes (OP JAK AdAgriF), the CzechGlobe team systematically tested the suitability of methods for the preparation of usable and robust data for estimating future climate developments. The team considered the fact that the latest set of intercomparison projects of the Coupled Model Phase 6 – Global Circulation Model (CMIP6 GCM) includes models with different degrees of spatial detail. Most simulations of climate development in the 21st century have a horizontal spatial resolution of around 100 or 250 km. There is also a small subset of Global Circulation Models (GCMs) with a resolution of around 50 km, but their simulations end in the mid-21st century. Individual GCMs also differ in the complexity of the descriptions of events in the climate system, the methods of parametrization of smaller-scale phenomena, as well as the formulation and numerical solution of basic physical equations. It is natural that the simulated climate diverges to a certain extent from reality and this difference changes in space, time, or across physical quantities. After five years' research, GCMs that best affect the climate of Central Europe were preferred for simulations of the future Central European climate. Simultaneously, it is necessary to ensure that the preferred GCMs (which are only a subset of all available GCMs) affect the future climate development in the same way, with the same degree of uncertainty, as the full set of all available GCMs. That is, for the selected subset of GCMs not to represent models that, under the same conditions, expect e.g. higher increase in temperature (or changes in precipitation, wind, sunshine, etc.) than models that are outside the selection. The narrowing of the set of climate models was carried out by the procedure proposed by Meitner [16].

In accordance with the methodology, from the set of around twenty CMIP6 GCMs (which had all the necessary elements and emission scenarios available), those models that were not able to reliably simulate the Central European climate of the recent past were excluded based on validation. From the other models, six GCMs with a resolution of 100 km and representing all four emission scenarios were selected so that this narrower selection represented the entire original set of models with its statistical properties, but enabled working with a smaller number of simulations. GCM selection was done with regard to all basic meteorological elements, which are further analysed, or used for the calculation of reference evapotranspiration and soil moisture by the SoilClim model. The model selection, together with the available climate change scenarios, is shown in *Tab. 1* below. GCMs with finer spatial resolution (100 km versus 250 km) were preferred.

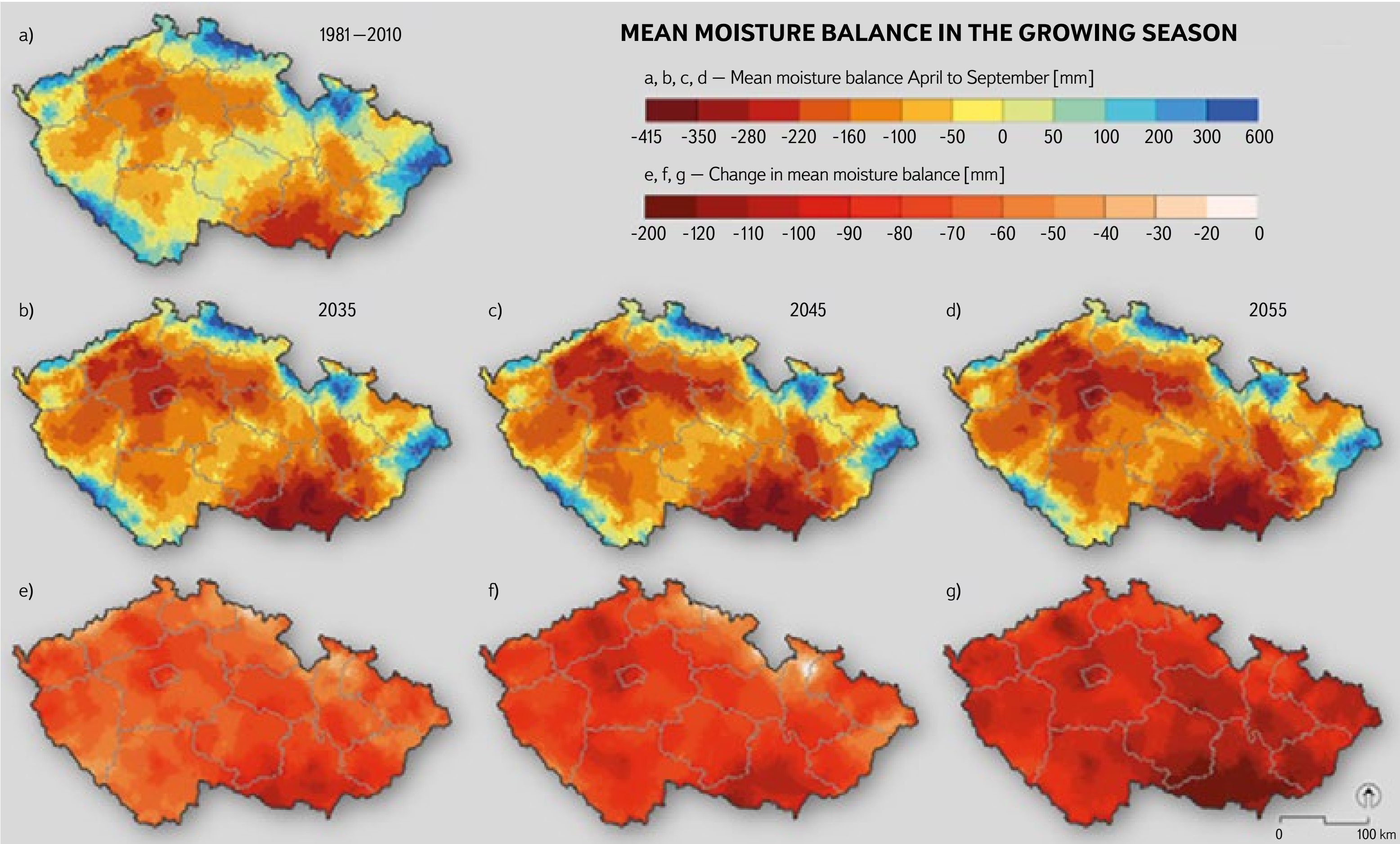

Fig. 3. Illustration of the difference between the sum of precipitation and reference evapotranspiration in the so-called warm half-year (April–September) for the reference period (a) 1981–2010 and the periods, (b, e) 2020–2050, i.e. 2035, (c, f) 2030–2060, i.e. 2045, and (d, g) 2040–2070, i.e. 2055, for basin level IV. Maps b–d show the change in absolute value, maps e–g show the nature of the climate signal, i.e. the relative change

Tab. 1. Overview of models and country of origin; the nominal grid size in the equatorial region was approximately 100 × 100 km, and simulations of all models were available for all socioeconomic scenarios (SSP – see below)

Model	Author's workplace
CMCC-ESM2	*CMCC Centro Euro-Mediterraneo sui Cambiamenti Climatici,* Italy
EC-EARTH3	*EC-Earth Consortium Europe,* EU
GFDL-ESM4	*NOAA-GFDL National Oceanic and Atmospheric Administration, Geophysical Fluid Dynamics Laboratory,* USA
MPI-ESM1–2-HR	*MPI-M Max Planck Institute for Meteorology,* Germany
MRI-ESM2–0	*MRI Meteorological Research Institute,* Japan
TAIESM1	*AS-RCEC Research Center for Environmental Changes, Academia Sinica,* Taiwan

Climate change scenarios serve as a source of so-called boundary conditions for GCMs and reflect various possible future trajectories of global development not only from the point of view of emissions or resulting concentrations of greenhouse gases in the atmosphere, but also in terms of various economic and social developments on the planet. The latest sixth assessment report of the IPCC (AR6) (available at: https://www.mzp.cz/cz/souhrnna_zprava_ipcc) works with scenarios of socioeconomic development, known as Shared Socioeconomics Pathways (SSP). In current nomenclature, the SSP code includes both the path of socio-economic development (first number) and the predicted impact of anthropogenic emissions on the greenhouse effect enhancement in tenths of W. m^{-2} (watts per square metre – energy flow density).

In simple terms, the individual climate change scenarios used for input into GCM simulations can be interpreted as follows:

- SSP1–2.6: sustainability; a path of development with the greenhouse effect enhancement by up to 2.6 W. m^{-2} compared to the pre-industrial period,
- SSP2–4.5: middle of the road; degradation of environmental systems, but some improvements regarding resource and energy use leading to the greenhouse effect enhancement by up to 4.5 W. m^{-2},
- SSP3–7.0: regional rivalry; conflicts allowing little economic development and the greenhouse effect enhancement by 7.0 W. m^{-2},
- SSP5–8.5: fossil-fuelled development; potential to enhance the greenhouse effect by up to 8.5 W. m^{-2}.

Preparation of climate scenarios

Unless we are concerned only with the relative change of meteorological elements, GCM outputs cannot be used directly. They are burdened with systematic error (e.g., in Central Europe – an underestimation of temperature by 1 °C, or overestimation of precipitation by 25 %, etc.), which must first be removed by so-called bias correction. Alternatively, it is possible to work with climate change resulting from climate model simulations, which is linked directly to observed data. The second approach is referred to as the "incremental method" or "direct modification" and is commonly used in the Czech Republic for modelling the climate change impacts (e.g. on hydrological balance) as there is greater robustness using this method than when using climate model simulations with systematic error correction (so-called bias correction). To use the "incremental method" in the daily step, it is advisable to apply transformations that consider not only changes in averages, but also variability. This is made possible, for example, by the Advanced Delta Change (ADC) method. Thanks to the ADC method, the change in variability can also be included in the transformation. This simply means that the extremes can vary differently than the average, which correctly reflects our experience in the real world. When deriving precipitation changes from the climate model, the ADC method also considers systematic simulation errors, which may not be linear. Further details can be found in van Pelt et al. [17]. The development of the basic set of scenarios using the ADC method, as well as the selection and analysis for the purposes of this project, were carried out iteratively and in close cooperation between the CzechGlobe, CZU, and TGM WRI teams.

These scenarios obtained as part of the OPVVV SustES and OP JAK AdAgriF projects were adapted for the teams at the "*Water Centre*" into a form suitable for the model tools used here and tested in detail. Although the actual preparation of scenarios and data analysis was not directly part of the contract for "*Water Centre*", it is necessary to mention the basic description of the methods. At the same time, the individual simulation runs within the cascade of irrigation and hydrological models are unique and used only within the "*Water Centre*".

With regard to the interpretation of results, in addition to the reference period 1981–2010, we are working with 30-year time windows for the future climate: 2020–2050 (referred to as "2035"), 2030–2060 ("2045"), and 2040–2070 ("2055"). The periods overlap each other. Within these time windows, statistical characteristics (including extremes) for the given period can be evaluated. Similar to climate model simulations, it does not make sense to analyse and present individual days or years, but only statistics for the entire period. Long-term trends can then be evaluated by connecting individual (sliding) periods in future climate. An example of the output for the water balance (i.e. difference between ETref and precipitation) in growing season is shown in *Fig. 3*.

Analysis of water demand for crop production

As part of the project, the SoilClim model was used, among other things, for drought monitoring and forecasting in the www.intersucho.cz system, which is based on the recommended methodology of FAO [18] and ASCE [19]. The SoilClim model outputs for the climatological water balance were compared in the past for greater robustness with the model of the Czech Hydrometeorological Institute AVISO with goodness of fit (e.g. Štěpánek et al. [20]). Model estimates of water demand in the SoilClim model were made for each grid with a resolution of 500 × 500 m across the entire Czech Republic based on daily meteorological data, data on inclination and exposure of the land (for considering the radiation and energy balance), data on the retention capacity and soil depth, and the possible influence of groundwater. In individual cases, the calculation was limited only to grids with agricultural land, or to irrigable grids. The dynamics of vegetation growth in the SoilClim model took into account the connection of plant development (but also the date of sowing/planting/sensitive periods/harvest) to weather. Key factors influencing water demand (e.g. variable leaf area or rooting depth) are considered and change dynamically during the season. For the cases of calculating water demand in the expected climate, the CO_2 effect on the water regime of plants is also included. On the basis of previous studies dealing with irrigation in our country and a search of world specialist literature, the key parameters of vegetation cover were determined, which represented a total of 20 crops/cultures, some of which were assessed in different regimes (e.g. orchards with bare soil or active growth in intermediate rows). It was thus possible to determine the relative water demand of individual cultures. The methodology includes a change in the onset of phenological works, changes in sowing and harvesting dates, and thus also reflects a change in the seasonality of the need for irrigation.

When determining the demand for soil water, all calculations were performed at the level of individual grids in a daily step, and the irrigation dose was applied whenever soil water content of a root zone fell below 30 % of retention capacity, i.e. the limit was reached when water is relatively difficult for plants to access and their growth is subsequently significantly limited by lack of soil water. With this "maintenance" irrigation, the survival of the culture is guaranteed. A special regime was used for weeks when the value of the irrigation efficiency factor taken from ČSN 75 0434 for the given week and the given crop indicated an efficiency factor higher than 40 (which means a significant influence of irrigation on economic yield). In these cases, soil water content of the root zone was maintained at values of at least 50 %. Such type of irrigation would be relatively very effective.

Final iteration of determining irrigation sources and demands

Currently, the final determination of soil moisture demand is underway by the cascade of SoilClim and BILAN models, using the knowledge obtained in cooperation with WP1 partners. Currently, calculations of the possible irrigable area for the following selected commodities were performed for each surface water body: spring barley, winter wheat, maize, winter rapeseed, early potatoes, apples – bare surface, apples – active surface, cherries – bare surface, cherries – active surface, apricots – bare surface, apricots – active surface, peaches – bare surface, peaches – active surface, vineyards, hop fields, strawberries, garlic, onions, carrots, peppers, cucumbers, cauliflower, cabbage.

After all the calculations were done, this soil moisture demand was determined, and in the next step, the TGM WRI team worked with the data not only for the current climate, but for the most current climate change scenarios based on the CMIP6 model suite. Based on the provided climate data and soil moisture from the SoilClim model, TGM WRI determined the available water resources for each surface water body for current and future climate. TGM WRI, in agreement with CzechGlobe, carries out calculations in variants, namely in the variant that takes into account the fact that water is managed in the entire system (that is, we have water available from reservoirs and from the catchment further downstream), but also in the variant where water management is limited to the given surface water body. From this available amount, for example, resources can be deducted to cover losses during the transport of water to irrigated land based on the methodology of the CTU team. Through a gradual iterative calculation, the available water in each surface water body can be divided for individual grids so that the water was first distributed to irrigable grids, according to the soil quality. If the water in the given surface water body was sufficient to cover the requirements of all irrigable grids, the irrigation water was subsequently distributed to other grids (again, according to soil quality). The result of the calculation is the potentially irrigable area, both in a normal year and in the case of a five- and ten-year drought. The calculation of irrigation demand for individual commodities is dynamic and is based on an analysis of the moisture demand of the given commodity in the root zone. Irrigation is indicated if soil moisture in the root zone drops below 0.3. The irrigable area was then determined in cooperation between CTU, TGM WRI and CzechGlobe,

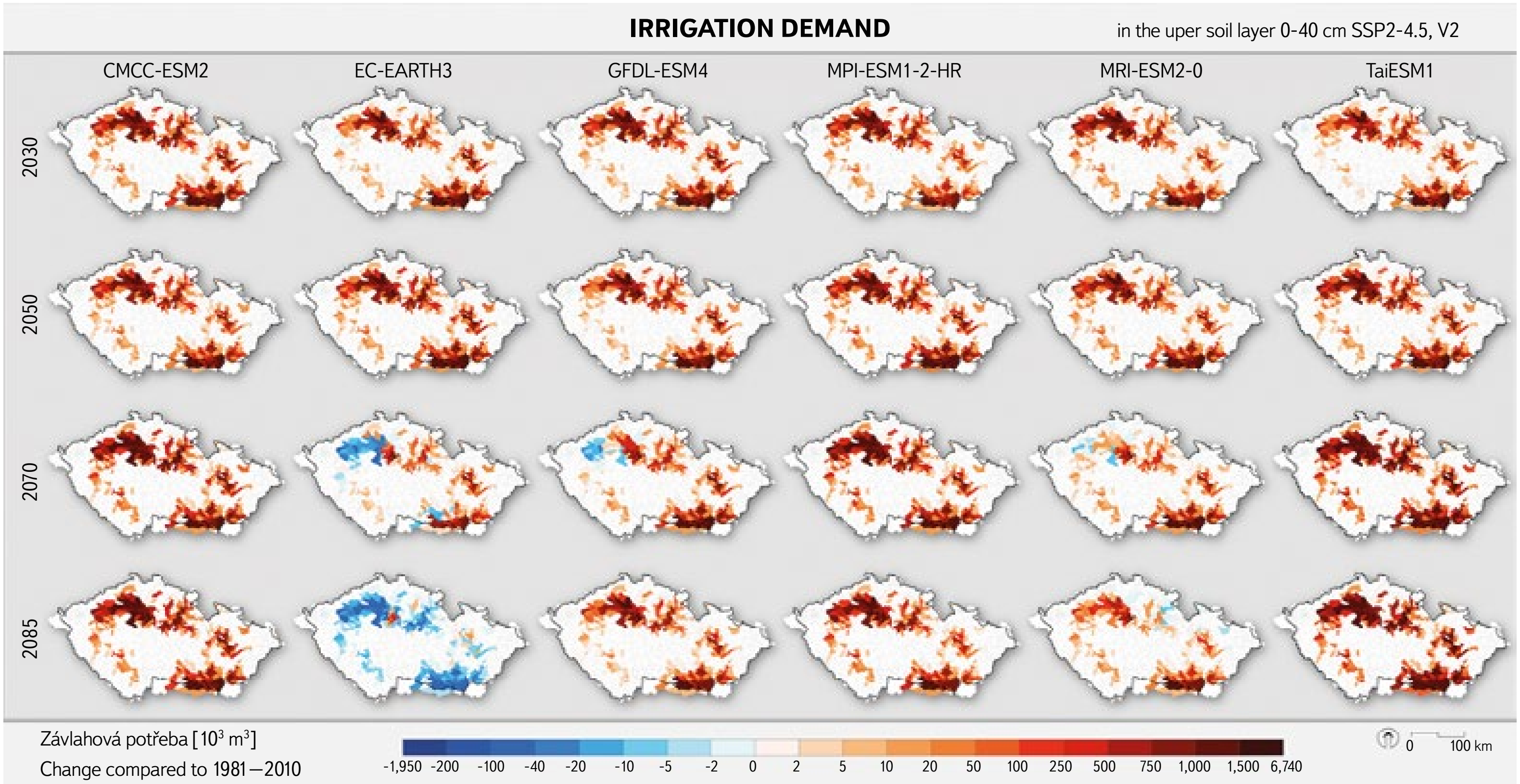

Fig. 4. Change in average annual irrigation demand for surface water bodies between the reference period (a) 1981–2010 and the periods 2030 (2015–2045); 2050 (2035–2065); 2070 (2055–2085) and 2085 (2070–2099), for the six Global Circulation Models from the CMIP6 model suite for the SSP 2-4.5 emission scenario. The set of maps shows the shift in moisture demand under production optimization efforts

and simultaneously, based on CTU's analysis, the parameters for calculating irrigation water losses were changed as the sum of losses on the line and irrigation detail.

$$KZ = K_1 + K_2$$

The value of K_1 was defined as 0.12 (i.e. 12 %) and the value of K_2 was determined according to *Tab. 2*. Depending on the crop, it is thus newly calculated with a loss of 17–37 %.

Tab. 2. Value of parameter K_2

K_2	**Irrigation detail contemporary**
1.05	Orchards (peach, apple, apricot, cherry), vineyards, strawberries, cucumbers, peppers, tomatoes.
1.15	Hop plants, onions, carrots, early potatoes (drip irrigation).
1.25	Early potatoes (spray), alfalfa, maize, cabbage, cauliflower.

These changes represent a relatively significant change in the entire methodological procedure. In the final calculation, sowing procedures were applied to potentially irrigated areas according to data from LPIS based on real data from 2015–2023, processed by CzechGlobe. This made it possible to determine the "real" demand for water within the irrigation systems and subsequently to standardize the calculations for the future climate. The outputs of the joint work are being prepared for publication in an impact journal (*Agricultural Water Management*).

The final calculation of moisture demand thus combines innovative procedures based on the valid ČSN 75 0434, practical experience from irrigation practice and also the real composition of crops in surface water bodies with irrigation, because the specific use of irrigation so far cannot be determined otherwise. Two scenarios were created to determine irrigation needs.

The first was based on the goal of maximizing production and not allowing soil water content to drop below the point of reduced moisture availability, to which plants respond by reducing production (in simple terms). The second was aimed at not allowing soil water content to fall below values of intense water stress, i.e. a situation where crop production is significantly reduced due to a lack of water. While the first procedure aims to maximize production in conditions of limited water resources, the second procedure serves primarily to maintain the basal level of production and conserve water resources to the maximum extent possible. From the point of view of profitability, the first of the chosen procedures is suitable in situations where water resources in the catchment are sufficient, the second can be seen as an emergency scenario, as it does not guarantee producers an adequate yield; however, in a number of seasons, especially during shorter episodes of drought, it can fundamentally contribute to reducing damage with relatively less water consumption.

Simultaneously, the calculations dealt with ensuring moisture demand for the upper 40 cm variant or the profile up to a depth of 100 cm. In *Fig. 4*, both variants are presented for ensuring soil moisture in the corresponding

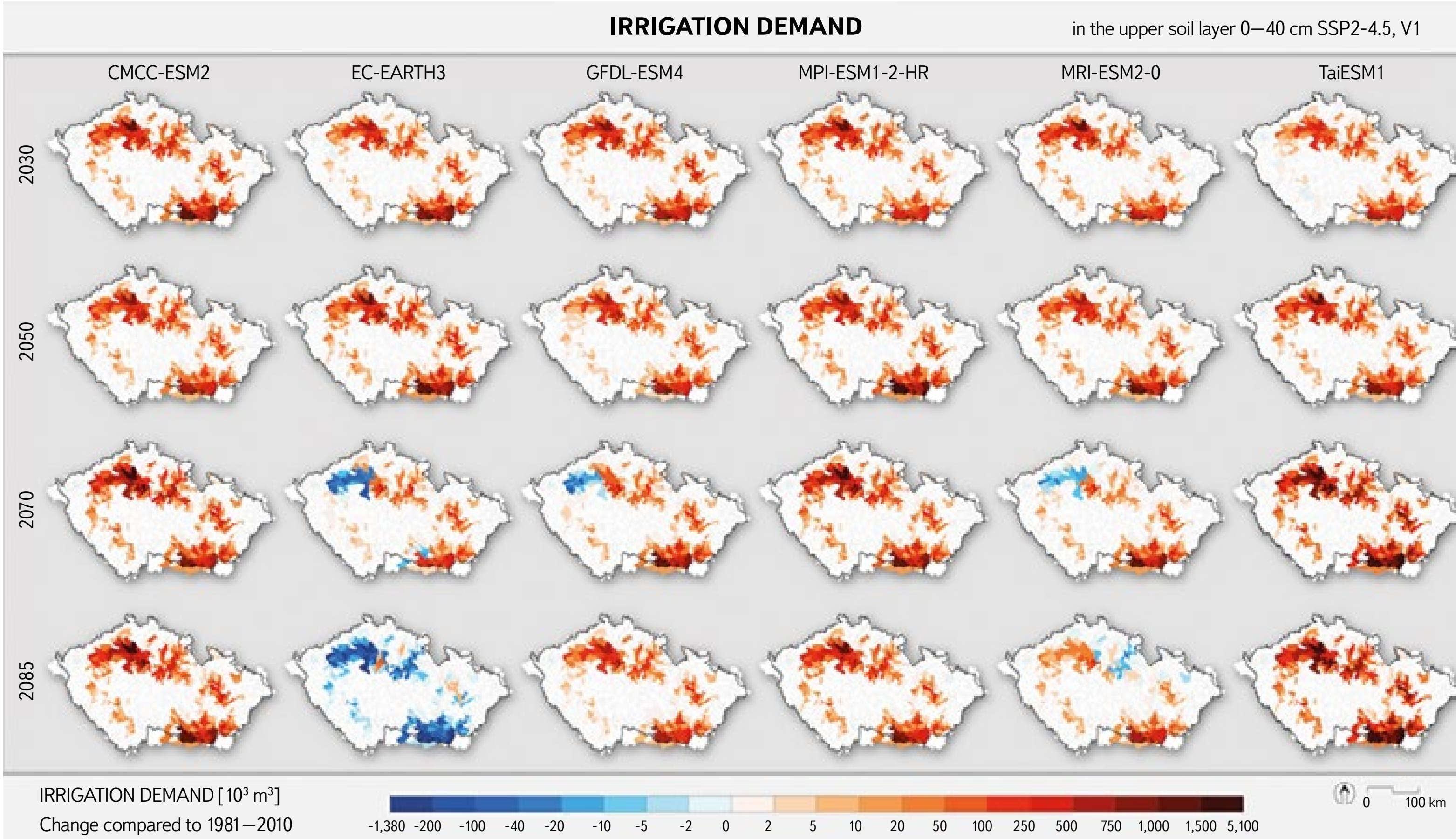

Fig. 5. Change in average annual irrigation demand for surface water bodies between the reference period (a) 1981–2010 and the periods 2030 (2015–2045); 2050 (2035–2065); 2070 (2055–2085) and 2085 (2070–2099) for the six Global Circulation Models from the CMIP6 model suite for the SSP 2-4.5 emission scenario. The set of maps shows the change in irrigation demand to avoid drought stress for crops

volume in the upper 40 cm of the profile as a change in demand compared to the period 1981–2010 for the realistic emission scenario SPSS 2-4.5. It is clear that the entire spectrum of expected changes cannot be covered on the basis of one GCM model, nor can it be done on the basis of using only one emission scenario.

The results clearly show significant variability in lines of the same GCM models for different emission scenarios, especially for the periods 2015–2045 (2030) and 2035–2065 (2050). Even in regions where, on average, there is a reduction in moisture demand, there is still a need to irrigate. However, what still remains an unanswered question is the impact of the not yet considered variant based on the estimate of the GLOBIOM-CZ agro-economic model. It shows the considerable comparative advantage of Czech agricultural production in the expected environmental conditions, and therefore the possibility to increase the profitability and market share of Czech agriculture despite climate change. That is, a situation where conditions on the world markets will be economically favourable to the expansion of domestic production, potentially even without state intervention. In such a situation, there could be pressure on using two harvests per year, which with a certain combination of crops grown today and/or a combination of suitable varieties will be possible in a few years/decades. However, the success of the second crop will be determined by the ability to harvest the first crop in time and, especially after sowing, to ensure good uptake of the second crop in the height of summer. Without additional irrigation, the latter will not be possible in most years in the warmest regions of Bohemia and Moravia.

Water demand for animal husbandry

The aim of the CZU research, which is the development of water consumption by livestock in the Czech Republic, is to compile scenarios of animal husbandry in individual regions of the Czech Republic. The result is finding out what kind of livestock have been bred in individual areas in the last 20 years and in the future, and what their water consumption will be, both throughout the year and in individual seasons. Livestock such as cows, pigs, sheep, goats, horses, and poultry are a significant source of commodities used by humans. In connection with climate change, adaptation measures for livestock will be addressed, mainly with regard to their loading caused by the increase in spring and summer temperatures. There is also the increasing number of consecutive tropical days; such conditions cause thermal stress in animals, which is manifested, for example, in cattle by lower milk yield and weight gain [21]. Stressful conditions will occur in both stables and pastures, and animal performance will probably decrease.

Livestock have a considerable consumption of water. In addition, growing human population and demand for animal products are expected to increase demand for water and changing precipitation patterns worldwide. Therefore, the question arises whether there will be enough available water in the future and what effect the (in)availability of water will have on the possibilities of breeding livestock [22].

METHODOLOGY

As part of the data analysis, data were first collected on the number of livestock in individual regions of the Czech Republic for the period 2002–2020. The obtained tables included data on the number of cattle, pigs, sheep, goats, horses, and poultry (*Tab. 3*). Due to the fact that the numbers of cows, sows, and hens were additionally listed in the tables, it was necessary to adjust the data. The numbers of cows, sows, and hens were subtracted from the total numbers of cattle, pigs, and poultry, so that the resulting values correspond to the number of cattle without cows, pigs without sows, and poultry without hens.

Tab. 3. List of breeding animals (according to CSU tables)

Name in the table	Definition
Cattle	Domestic animals of the domestic bull (*Bos taurus*) species (not incl. cows).
Cows	Female cattle that have already calved (including those that calved before the age of two years).
Pigs	Domestic animals of the domestic pig subspecies (*Sus scrofa domestica*) (not incl. sows).
Sows	Female pigs that have already farrowed. Does not include neuted sows.
Sheep	Domestic animals of the domestic sheep species (*Ovis aries*).
Goats	Domestic animals of the domestic goat subspecies (*Capra aegagrus hircus*).
Horses	Domestic animals of the domestic horse species (*Equus caballus*).
Poultry	Domestic birds of the domestic chicken species (*Gallus gallus*), the turkey genus (*Meleagris spp.*), the duck genus (*Anas spp.*), the Muskovy duck species (*Cairina moschata*), and the domestic goose subspecies (*Anser domesticus*).
Hens	Domestic female chickens of the laying and meat type that have reached egg-laying maturity.

Tab. 4. Water consumption by species (according to standards)

		Cattle	Cows	Pigs	Sows	Sheep + goats	Horses	Hens [thousands]	Broilers [thousands]	Ducks + geese [thousands]	Turkeys [thousands]
Average water consumption per animal [l/head/day]	**Spring**	49.00	126.25	4.75	14.67	3.00	38.75	230	110	500	550
	Summer	60.00	170.00	6.00	17.33	4.25	47.50	280	120	450	575
	Autumn	49.00	126.25	4.75	14.67	3.00	38.75	230	110	500	550
	Winter	38.00	82.50	3.50	12.00	1.75	30.00	180	100	550	600
Average water consumption per animal [l/head/day]	**Spring**	4,557	11,741	442	1,364	279	3,604	21,390	10,230	46,500	51,150
	Summer	5,580	15,810	558	1,612	395	4,418	26,040	11,160	41,850	53,475
	Autumn	4,410	11,363	428	1,320	270	3,488	20,700	9,900	45,000	49,500
	Winter	3,382	7,343	312	1,068	156	2,670	16,020	8,900	48,950	53,400
Average water consumption per animal [m³/head/year]		17.93	46.26	1.74	5.36	1.10	14.18	84.15	40.19	182.30	207.53
Maximum water consumption per animal [m³/head/year]		21.90	62.05	2.19	6.33	1.55	17.34	102.20	43.80	20.75	219.00

In the next step, it was necessary to determine water consumption for livestock [22]. In the overall table, water consumption is divided for young animals, for nursing/lactating females, and for fattened animals. Minimum and maximum water consumption in litres per piece per head are always indicated, as well as maximum consumption in cubic metres per head per year. The minimum water consumption per day applies to the winter, the maximum water consumption per day to the summer. The average of these minimum and maximum values was determined as water consumption per day in the spring and autumn (*Tab. 4*). The average water consumption per head during the seasons (in units of l/head/season), the average water consumption per head (in the units of l/head/year and m^3/head/year), as well as the maximum water consumption per head (in units m^3/head/year) (*Tab. 4*).

Since poultry includes not only chickens, but also ducks, turkeys and geese (which have different water consumption), it was necessary to determine the approximate percentage representation of individual animal species in the Czech Republic. For this, the *Situation and outlook report Poultry and eggs* was used (available at: https://mze.gov.cz/public/portal/mze/publikace/situacni-vyhledove-zpravy/zivocisne-komodity-hospodarska-zvirata/drubez-a-vejce); on its basis, the percentage representation of farmed poultry species between 2010 and 2018 was calculated. In the next step, by multiplying the number of individual species of livestock and the average (or maximum) water consumption per head of a single farm animal species, water consumption by individual farm animal species was determined; after adding up the data, the total water consumption by livestock per year was determined. This was calculated for each year between 2002 and 2018 and for each region separately. Estimates of the number of individual farm animal species and water consumption were made for 2025, 2030, 2035, 2040, 2045, and 2050 using the Forecast Sheet tool. The tool calculated the mean estimate and its lower and upper bounds. Estimates were again carried out separately for each region. In order to calculate water consumption by livestock during individual seasons, the average percentage of water consumption in these seasons compared to the whole year was first determined, which was 25.34 % for spring, 30.19 % for summer, 24.53 % for autumn, and 19.94 % for winter. Water consumption in individual seasons was then calculated based on the values found for the entire year, namely for 2005, 2010, 2015, 2020, 2025, 2030, 2035, 2040, 2045, and 2050.

RESULTS

Number of livestock and average water consumption per year for individual regions

The resulting values and conclusions always apply to the year 2050 compared to 2005.

Tab. 5. Number of animals and average water consumption (m^3/year) for each animal group

	Number					Average water consumption [m^3/year]				
	2005	2020	2035	2050	[%]	2005	2020	2035	2050	[%]
South Bohemian Region										
Cattle	211,413	219,914	221,264	222,448	+5.22 %	6,294,977	6,518,437	6,585,213	6,649,032	+2.00 %
Pigs	348,209	85,091	0	0	-100 %	709,413	172,383	0	0	-100 %
SHG	25,861	36,721	51,972	66,772	+158.19 %	66,349	105,865	148,887	189,112	+78.63 %
Poultry [thousands]	4,647	1,869	0	0	-100 %	243,936	99,817	0	0	-100 %
Total	-	-	-	-	-	7,314,677	6,896,502	6,734,100	6,838,144	-0.85 %
South Moravian Region										
Cattle	75,511	64,374	57,348	50,188	-33.53 %	2,195,581	1,900,160	1,909,400	1,912,454	-12.89 %
Pigs	433,761	126,594	0	0	-100 %	888,974	241,950	0	0	-100 %
SHG	5,842	12,845	19,731	26,788	+358.54 %	24,109	36,625	46,747	58,072	+140.88 %
Poultry [thousands]	4,303	4,037	2,251	1,189	-72.37 %	220,335	214,769	131,944	86,009	-60.96 %
Total	-	-	-	-	-	3,328,999	2,393,504	2,088,091	2,056,536	-38.22 %
Karlovy Vary Region										
Cattle	34,689	43,021	56,242	69,167	+99.39 %	1,054,921	1,343,166	1,790,120	2,199,331	+108.48 %
Pigs	42,349	16,435	0	0	-100 %	85,902	28,725	0	0	-100 %
SHG	15,987	15,373	18,671	21,704	+35.76 %	32,535	34,384	42,298	48,239	+48.27 %
Poultry [thousands]	249	249	179	202	-18.87 %	16,123	18,439	15,096	17,027	+5.61 %
Total	-	-	-	-	-	1,189,481	1,424,713	1,847,514	2,264,597	+90.39 %

	Number					Average water consumption [m³/year]				
	2005	2020	2035	2050	[%]	2005	2020	2035	2050	[%]
Vysočina Region										
Cattle	218,625	218,641	217,181	216,175	-1.12 %	6,366,182	6,402,983	6,421,984	6,461,977	+1.50 %
Pigs	391,482	319,055	158,107	63,395	-83.81 %	790,335	620,526	274,909	110,227	-86.05 %
SHG	9,344	18,312	33,209	44,828	+379.75 %	19,656	44,862	77,835	107,202	+445.40 %
Poultry [thousands]	1,231	391	0	0	-100 %	61,866	20,309	0	0	-100 %
Total	-	-	-	-	-	7,238,039	7,088,680	6,774,728	6,679,407	-7.72 %
Hradec Králové Region										
Cattle	109,527	101,233	90,676	80,119	-26.85 %	3,236,934	2,990,927	2,690,593	2,390,258	-26.16 %
Pigs	209,737	56,489	0	0	-100 %	424,888	110,020	0	0	-100 %
SHG	11,380	20,991	31,570	42,137	+270.27 %	31,953	60,665	87,347	113,942	+256.59 %
Poultry [thousands]	1,520	2,749	3,554	4,572	+200.80 %	95,048	185,492	269,748	362,159	+281.03 %
Total	-	-	-	-	-	3,788,824	3,347,105	3,047,688	2,866,359	-24.35 %
Liberec Region										
Cattle	38,051	48,729	55,134	61,289	+61.07 %	1,187,320	1,456,722	1,567,575	1,669,691	+40.63 %
Pigs	43,166	19,005	426	0	-100 %	86,050	37,885	2,283	0	-100 %
SHG	10,117	19,637	34,390	49,144	+385.76 %	29,426	55,422	96,778	138,138	+369.44 %
Poultry [thousands]	112	75	49	25	-77.39 %	6,272	3,589	2,230	1,164	-81.43 %
Total	-	-	-	-	-	1,309,067	1,553,618	1,668,866	1,808,994	+38.19 %
Moravian-Silesian Region										
Cattle	80,661	86,747	107,606	127,994	+58.68 %	2,464,819	2,664,950	3,093,312	3,511,096	+42.45 %
Pigs	149,142	37,905	0	0	-100 %	303,019	73,919	0	0	-100 %
SHG	14,233	21,126	30,089	38,949	+173.65 %	39,983	59,454	82,495	104,580	+161.56 %
Poultry [thousands]	1,645	945	159	0	-100 %	96,384	60,672	13,382	0	-100 %
Total	-	-	-	-	-	2,904,205	2,858,995	3,189,189	3,615,676	+24.50 %
Olomouc Region										
Cattle	96,851	93,149	85,032	77,477	-20.00 %	2,860,439	2,786,049	2,585,676	2,411,287	-15.70 %
Pigs	215,185	68,370	0	0	-100 %	435,891	134,489	0	0	-100 %
SHG	7,243	12,169	18,228	24,232	+234.56 %	22,838	37,647	53,532	68,662	+200.65 %
Poultry [thousands]	613	425	176	56	-90.89 %	36,317	24,412	8,106	2,567	-92.93 %
Total	-	-	-	-	-	3,355,484	2,982,596	2,647,313	2,482,516	-26.02 %

	Number					Average water consumption [m³/year]				
	2005	2020	2035	2050	[%]	2005	2020	2035	2050	[%]
Pardubice Region										
Cattle	121,379	113,308	105,299	97,289	-19.85 %	3,574,579	3,310,899	3,044,693	2,778,487	-22.27 %
Pigs	193,783	163,130	145,235	130,498	-32.66 %	391,870	318,677	264,300	226,904	-42.10 %
SHG	10,741	15,417	22,192	29,029	+170.27 %	34,703	52,271	68,545	85,715	+147.00 %
Poultry [thousands]	1,560	4,240	6,233	8,018	+414.11 %	94,885	263,251	366,548	460,276	+385.09 %
Total	-	-	-	-	-	4,096,037	3,945,098	3,744,086	3,551,382	-13.30 %
Pilsen Region										
Cattle	155,285	161,706	164,925	168,042	+8.22 %	4,566,030	4,856,781	5,077,715	5,296,814	+16.00 %
Pigs	212,974	112,189	3,200	0	-100 %	433,511	218,694	17,165	0	-100 %
SHG	16,985	20,335	14,389	7,585	-55.34 %	36,811	55,536	63,445	69,851	+89.76 %
Poultry [thousands]	1,869	2,837	2,989	3,374	+80.50 %	96,683	177,010	192,358	228,571	+136.41 %
Total	-	-	-	-	-	5,133,035	5,308,022	5,350,683	5,595,237	+9.00 %
Prague + Central Bohemian Region										
Cattle	154,934	148,749	133,779	117,284	-24.30 %	4,479,486	4,364,063	3,978,862	3,523,076	-21.35 %
Pigs	415,646	315,113	155,118	13,142	-96.84 %	843,429	613,222	269,712	22,850	-97.29 %
SHG	15,780	36,062	60,524	85,069	+439.09 %	54,096	153,035	245,156	338,955	+526.58 %
Poultry [thousands]	4,907	5,264	5,359	5,475	+11.57 %	269,672	313,540	339,718	366,047	+35.74 %
Total	-	-	-	-	-	5,646,683	5,443,860	4,833,447	4,250,928	-24.72 %
Ústí Region										
Cattle	39,652	41,484	40,006	38,340	-3.31 %	1,176,507	1,241,420	1,227,577	1,210,375	+2.88 %
Pigs	116,604	108,400	145,812	182,292	+56.33 %	236,946	212,951	260,230	316,960	+33.77 %
SHG	13,033	17,347	28,850	37,470	+187.50 %	27,467	49,961	83,890	111,244	+305.01 %
Poultry [thousands]	1,531	489	0	0	-100 %	94,653	22,931	0	0	-100 %
Total	-	-	-	-	-	1,535,574	1,527,263	1,571,697	1,638,580	+6.71 %
Zlín Region										
Cattle	60,730	63,062	64,215	65,434	+7.74 %	1,846,582	1,934,708	1,956,930	2,003,772	+8.51 %
Pigs	104,796	71,531	28,053	0	-100 %	214,733	141,449	48,777	0	-100 %
SHG	16,835	24,283	35,963	47,728	+183.51 %	39,706	50,083	66,534	83,078	+109.23 %
Poultry [thousands]	1,184	677	0	0	-100 %	61,036	35,055	0	0	-100 %
Total	-	-	-	-	-	2,162,057	2,161,295	2,072,241	2,086,850	-3.48 %

Note: SHG stands for sheep, horse and goat. The percentages (%) are calculated as the increase/decrease in the number of head or average water consumption from 2005 to 2050. E.g. a value of + 5.22 % means that in 2050 the number of animals is expected to increase by 5.22 % compared to 2005.

The development of water consumption by livestock was predicted for each region separately, with trends varying across individual regions. A steady state of water consumption by livestock is expected for the South Moravian, Ústí, Zlín, and Vysočina regions; a slight increase is expected in the South Bohemian and Pilsen regions; a significant increase in water consumption is predicted for the Karlovy Vary, Liberec, and Moravian-Silesian regions; a future decrease in water consumption by livestock is expected in the Hradec Králové, Olomouc, and Pardubice regions, as well as in Prague and the Central Bohemian region. Water consumption trends in individual regions are the same for both average and maximum water consumption by livestock (*Fig. 6*).

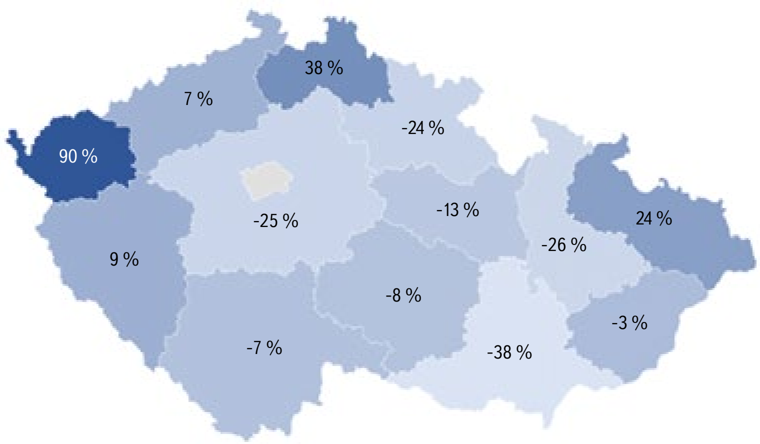

Fig. 6. Percentage change in average water consumption in individual regions of the Czech Republic in 2050 compared to 2005

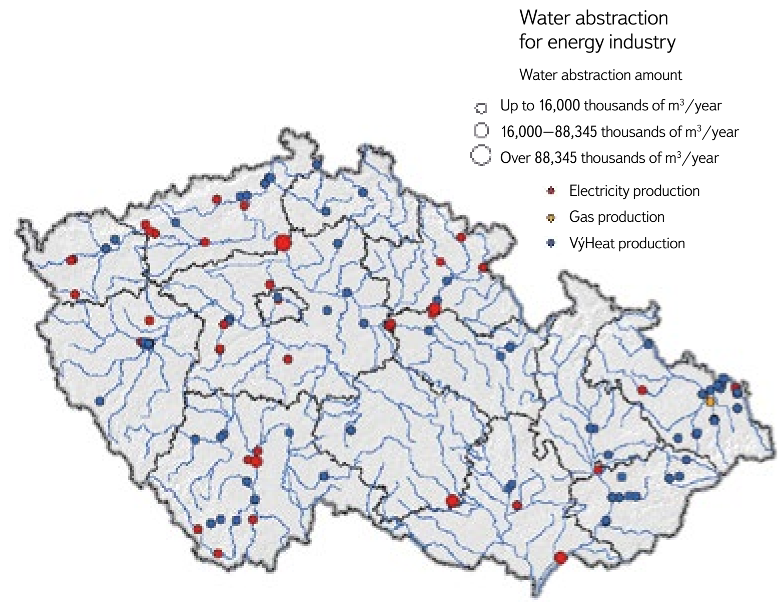

Fig. 8. Surface and groundwater abstraction locations for energy in 2013–2022: differentiation by quantity and type of production

The results point to significant differences in water consumption between regions, which is influenced both by the specific conditions in each region and by the type and number of livestock (*Fig. 6*). Forecasts for 2025–2050 point to possible changes in agricultural practices that will have an impact on future water demand. A detailed description of the results was published in the methodology [22] entitled *Metodika hodnocení spotřeby vody hospodářskými zvířaty v letech 2002–2020 a predikce vývoje spotřeby vody hospodářskými zvířaty v letech 2030, 2035, 2040, 2045 a 2050 v jednotlivých krajích ČR* (Methodology for evaluating water consumption by livestock in the years 2002–2020 and prediction of the development of water consumption by livestock in 2030, 2035, 2040, 2045 and 2050 in individual regions of the Czech Republic), published by CZU [22]. This publication provides a detailed overview of the methodology and forecasts that were used in this study and are key for the further development and planning of water management in the Czech Republic.

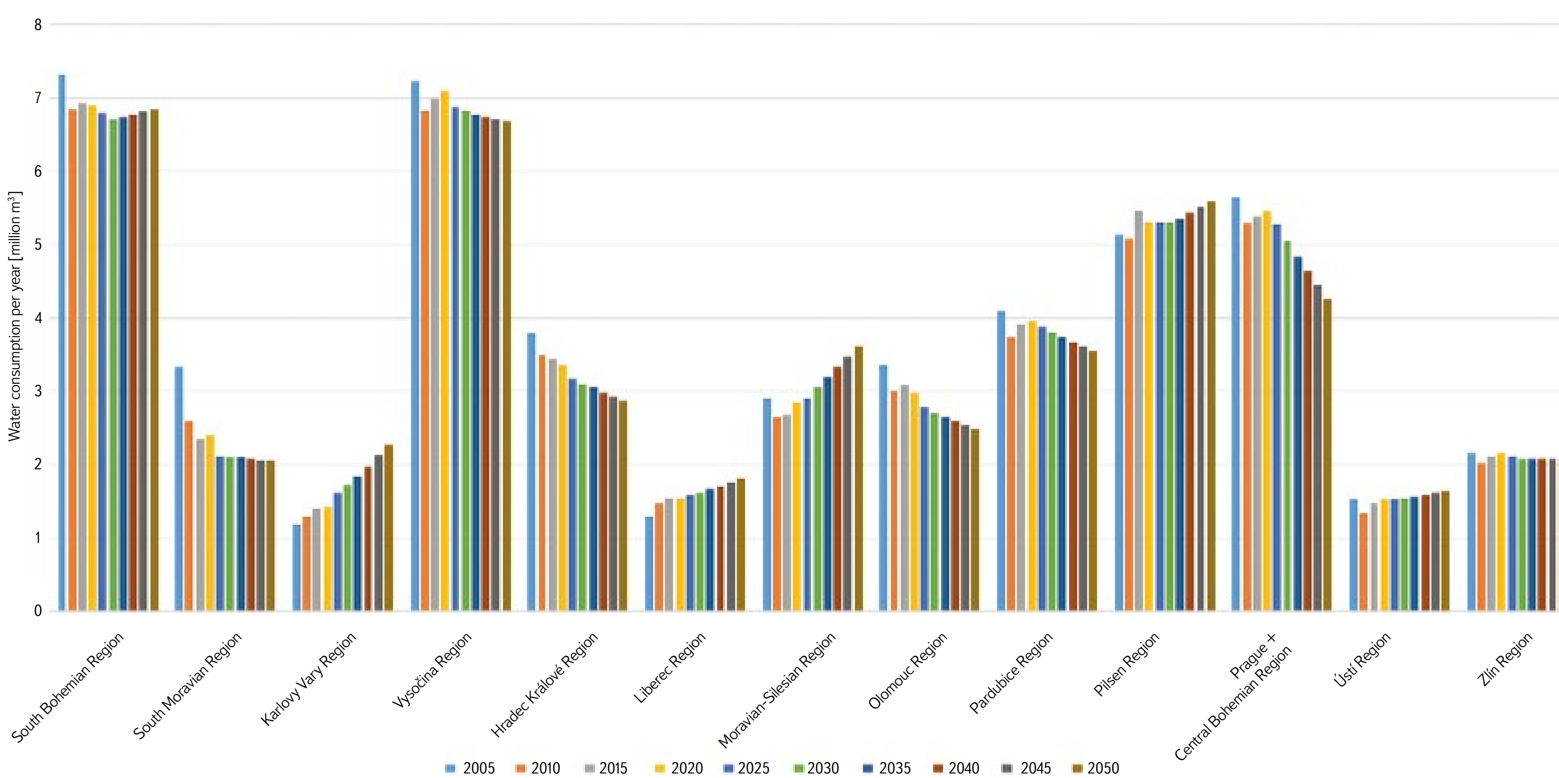

Fig. 7. Average water consumption by region 2005–2050

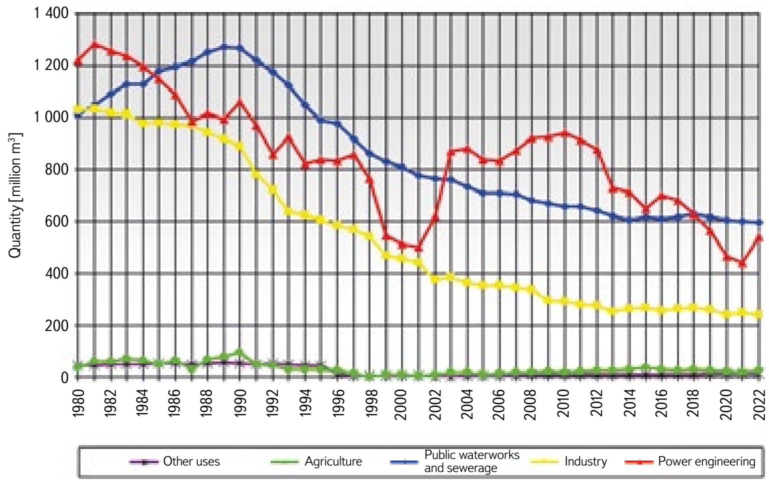

Fig. 9. Groundwater and surface water abstraction in the Czech Republic 1980–2022

CONCLUSION

As part of this analysis, the numbers of cattle, pigs, sheep, horses, goats, and poultry (hens, ducks, turkeys, geese) bred in 2002–2020 were evaluated, and their number in the following years until 2050 was also predicted (*Fig. 7*). Based on the livestock numbers, their water consumption was determined. By 2050, a significant reduction in the breeding of pigs and poultry is expected in most regions of the Czech Republic and, in contrast, a significant increase in the number of sheep, horses, and goats. This is probably related to the subsidies for the breeding of these animals. Livestock numbers will increase in some regions and decrease in others. Significantly higher water consumption by livestock is expected in the Karlovy Vary, Liberec, and Moravian-Silesian regions, while consumption in the other regions will probably be similar or lower. In very vulnerable areas from the point of view of water shortage, such as South Moravia and the Central Bohemian region, a significant decrease in the amount of water consumed by livestock is probable.

Analysis of water demand for energy industry

METHODOLOGY

To estimate the water demand for energy industry sector in the Czech Republic, researchers from TGM WRI used a systematic approach that includes data collection, analysis of current conditions, and prediction of future demand.

1. Data collection: This included the collection of data on water consumption in various branches of energy industry and the identification of key consumption locations.

2. Analysis of data on current water use in energy industry: This phase focused on the evaluation of historical data and the current state of water use in energy industry.

3. Prediction of future demand: This included the prediction of future water consumption with respect to planned changes in the power generation mix, including the transition to renewable sources and technology modernization.

SUMMARY OF RESULTS

1. Data collection: Data on surface and groundwater abstraction for energy industry by type of production (electricity production, heat production, gas production) for 2013–2022, recorded on the basis of Decree no. 431/2001 Coll., by State River Basin Authorities. A total of 124 locations meeting the above-mentioned conditions and also meeting the limit of abstracted water above 6,000 m^3/year or 500 m^3/month were selected. The abstraction points are shown in *Fig. 8*.

2. Analysis of data on the current use of water in energy industry: The data show, among other things, that mainly surface water is abstracted for energy industry. Furthermore, it is possible to observe the downward trend in water consumption for energy industry since 2016; for example, in 2020 there was a decrease in water consumption due to the transition to circulation cooling at Mělník and Opatovice power stations. In contrast, in 2022 there was a significant increase in water consumption for once-through cooling at Mělník and Opatovice power stations when, due to the energy crisis on the European market caused by the war in Ukraine and the subsequent lack of natural gas, the condensation production of electricity obtained from coal increased significantly. These examples show that sudden and unforeseen events can have a significant impact on water consumption for energy industry. *Fig. 9* shows an overview of the current use of water in energy industry for 1980–2022 in comparison with other sectors.

3. Prediction of future demand: The basic scenario that sets long-term goals and direction in the field of energy industry at the country level is the *State Energy Concept* (SEC). It is a key strategic document whose main purpose is to ensure the stability, security, and sustainability of the energy industry sector in the long term, which has a major impact on the economy, the environment, and social aspects. SEC formulates priorities in the area of energy production and consumption and sets the development in the area of energy sources; on the basis of stricter environmental regulations, preferred or, conversely, non-preferred energy sources will be determined. By the editorial deadline of this article, the new SEC had not yet been approved (its approval was postponed by the government on 17th July 2024). The authors of this article therefore base their predictions on the published MPO document "*Aktualizace Státní energetické koncepce*" (Update of the State Energy Concept) dated 8th February 2024 [23]. According to this document, the not-yet-approved SEC envisages a reduction in the use of coal – especially in connection with the production of electricity and heat – with the fact that, after 2033, coal consumption will be limited to non-energy use only (see *Tabs. 6* and *7*). On the basis of this available information, the water demand was predicted according to future operated energy industry sources.

Tab. 6. Corridors for primary energy sources (relative to their total annual consumption)

Energy source	Minimum	Maximum
2050		
Coal and coal derivatives	3 %	4 %
Natural gas	7 %	7 %
Crude oil and crude oil products	12 %	13 %
Nuclear power	32 %	42 %
Renewable resources	36 %	44 %

Tab. 7. Corridors for gross electricity generation (relative to total annual generation)

Energy source	Minimum	Maximum
2050		
Coal and coal derivatives	0 %	0 %
Natural gas	0 %	0 %
Nuclear power	36 %	50 %
Renewable resources	43 %	56 %
Other	7 %	8 %

Overall, it can be assumed that more than a third of coal-fired power stations will be shut down, and those that remain will switch to burning biomass. There will also be an increase in water consumption for the Temelín and Dukovany nuclear power stations. In the case of most heating plants, it is expected that after the necessary modernization, they will remain in operation and burn biomass.

The prediction itself was determined by calculating the average maximum and minimum quantity abstracted in 2013–2022 for individual consumers. For each abstraction point, an index of future demand was determined, which was then used to calculate the average maximum and minimum amount per demand in 2050. For the maximum and minimum estimated demand, the drop in surface and groundwater abstraction amounts to about 18 %. *Fig. 10* shows a comparison between the maximum and minimum average energy consumption for 2013–2022 and the prediction for 2050. *Fig. 11* shows this comparison broken down by regions.

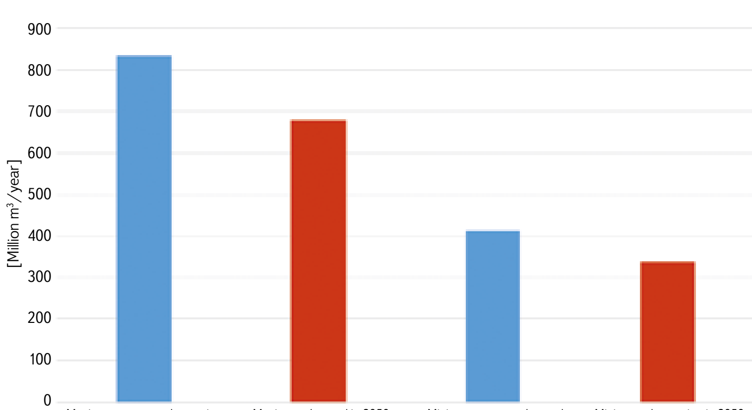

Fig. 10. Maximum and minimum average surface water and groundwater abstraction for energy for 2013–2022 vs. estimated minimum and maximum abstraction for energy in 2050

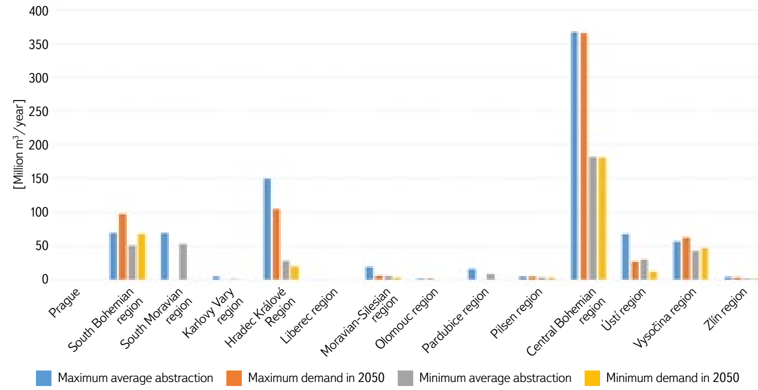

Fig. 11. Maximum and minimum average surface water and groundwater abstraction for the power sector for the years 2013–2022 vs. estimated minimum and maximum abstraction for the power sector in 2050 by region

CONCLUSIONS AND UNCERTAINTIES

The estimate of water consumption for the energy industry indicates a reduction in water demand for this sector compared to the current situation; the reduction in water demand by 2050 will be about 18 %. Despite the large degree of uncertainty, which is caused by the year of prediction, these values are actually realistic. It is also assumed that, due to the complexity of large constructions, there will be no significant transfer of energy production between regions. Similar to other sectors, in the case of predicting water demand for the energy industry, there are uncertainties, which are reflected in the factors affecting water demand now and in the future. With a view to 2050, an increase in the demand for electricity generation is expected, which will be a direct consequence of a higher use of electricity than now (electromobility, heat pumps, air conditioning, etc.). On the other hand, an increase in electricity production from renewable sources (solar power, wind power, etc.) is expected, which do not affect water demand. Among the general factors that influence the water demand are, in particular, the technology used, installed capacity of the power station or heating plant, efficiency of cooling, and use of recycling technologies. In terms of natural resources, these are primarily precipitation and air temperature; a decrease in precipitation and an increase in temperature can affect both the availability of water for cooling and the demands on the necessary amount of water abstracted. A longer period of drought could then result in lowering water resource levels and thus an increase in water temperature, which would again increase demand on water for cooling. In terms of legislation, these are laws and regulations related to water use that affect the operation of power engineering facilities, while environmental regulations may require more efficient use of water. From an economic point of view, these are also the price of water and the costs of its treatment that will influence decisions on the types of energy sources and technologies. In view of ongoing changes, it is important to continuously monitor the development of this issue and regularly update predictions.

Analysis of water demand for human consumption

TGM WRI researchers found that water abstraction for public water supply systems (based on data recorded for the need to prepare the water balance according to Decree 431/2021 Coll.) currently accounts for around 40 % of total water abstraction, with about 30 % of total surface water abstraction and about 80 % of total groundwater abstraction. In the case of surface water, approximately 90 % of the amount abstracted is provided by reservoirs. The difference between surface and groundwater abstraction is in the number of abstraction points (and related mean capacity): while surface water for public water supply systems is abstracted from around 140 abstraction points (of which approximately 50 are from reservoirs), groundwater is provided by from approximately 2,500 abstraction points. Analysis of future water demand for public water supply systems is therefore important for both surface and groundwater balance; however, it is absolutely crucial for groundwater. While individual abstraction points (especially abstractions from reservoirs) can be assessed individually, groundwater abstraction must be aggregated into larger units for balance purposes. The solution can be provided by "working units of groundwater bodies" used in the Czech Republic in planning according to the Water Framework Directive (full name: Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000, establishing a framework for Community action in the field of water policy). These are about 1,200 territorial units covering the entire area of the Czech Republic in three horizontal positions.

METHODOLOGY

The forecast for water demand for public water supply systems is based on demographic development forecast for 2050, which was provided by the Faculty of Science Charles at University in Prague as a subcontract for the project. The forecast contains data on the development of the number of inhabitants in municipalities with extended powers in three variants (high, low, medium) and in the division into urban and rural areas. The rural population, according to the Czech Statistical Office (CZSO) definition, includes residents of all municipalities with a size of up to 2,000 inhabitants and also municipalities with a size of up to 3,000 inhabitants which have a population density of less than 150 inhabitants/km^2. In the next steps, the way the forecasted changes in the number of inhabitants can be reflected in the requirements for water abstraction was evaluated. For this purpose, data of the *Majetková evidence vodovodů* (*Property records of water supply systems*) recorded in accordance with Decree 428/2001 Coll., and data on the actual amount of water abstraction recorded for the need to prepare the water balance according to Decree 431/2021 Coll. were used. The researchers first calculated the forecasted changes in the number of inhabitants by 2050 provided for individual municipalities with extended powers based on the current number of inhabitants per individual municipality (using CZSO data on the current number of inhabitants in municipalities). In the next step, they projected the forecast of changes in the number of inhabitants into changes in water demand. The procedure was as follows: surface and groundwater abstraction for public water supply systems were identified in the register of places and the actual amount of water abstracted for the need to prepare the water balance. With the help of data from the Property records of water supply systems, abstraction points were connected to the supplied municipalities (the property records of water treatment plants state the abstraction point identifier according to the records for the water balance as well as the list of supplied cadastral areas). According to the ratio of predicted changes in the number of inhabitants in the supplied municipalities (compared to the present), future demand for the amount of water abstracted at individual abstraction points was also suitably adjusted (at the same ratio) compared to current demand. The average amount abstracted between 2016 and 2021 was considered as current demand. In the case of groundwater, abstraction data and their predicted changes by 2050 (for the purposes of the balance assessment of resources and demand) were further aggregated to the level of the so-called working units of groundwater bodies used (also as balance units) for planning purposes. This procedure was partially (to a lesser extent also details and on older data of the Record for the water balance and the Property records of water supply systems and sewerage) applied and verified in project No. VI20192022159 "*Vodohospodářské a vodárenské soustavy a preventivní opatření ke snížení rizik při zásobování pitnou vodou*" (*Water management and water supply systems and preventive measures to reduce risks in drinking water supply*).

RESULTS

Changes in the number of inhabitants in the supplied municipalities in the reference year 2050 compared to the present for current surface water abstraction points are shown in *Fig. 12*, and for the working units of groundwater bodies in *Fig. 13*. For significant (over 500,000 m^3. year^{-1}) current surface water abstraction for public water supply systems, an increased number of connected inhabitants by more than 10 % was predicted for the following water reservoirs: Švihov (by 23 % for the high variant, by 14 % for the medium variant), Klíčava (by 18 % for the high variant, by 11 % for the medium variant), Josefův Důl (by 114 % for the high variant) and Vrchlice (by 112 % for the high variant). In the case of groundwater abstraction, an increase in the number of connected inhabitants was predicted in particular in (parts of) hydrogeological districts 6250 Proterozoic and Palaeozoic in the Vltava tributary basin, 6320 Crystalline in the Middle Vltava basin, 6230 Crystalline, Proterozoic and Palaeozoic in the Berounka basin, 6240 Upper Silurian and Devonian Barrandien, and 4510 Cretaceous north of Prague.

UNCERTAINTIES

The work was based on data available nationwide, i.e. only on the forecast of the number of residents, and therefore did not take into account, for example, abstraction from public water supplies for services or industrial enterprises. The uncertainty in the prediction of the number of supplied residents was reflected by considering high, medium, and low variants of the demographic forecast. Some simplification was also achieved by considering the number of supplied residents on a municipal scale (the actual connection to a certain water abstraction may only concern parts of municipalities).

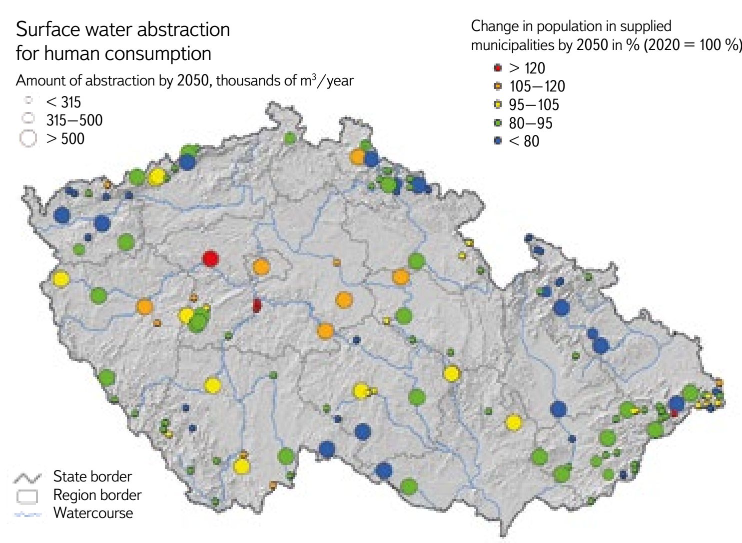

Fig. 12. Surface water abstraction for public water supply and change in the number of inhabitants supplied by 2050 – medium variant

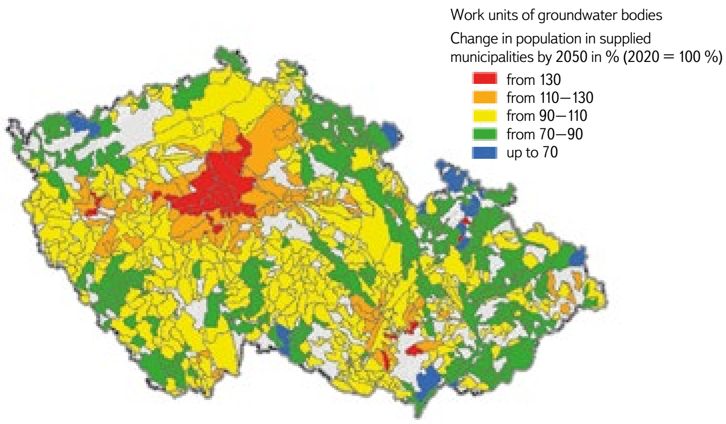

Fig. 13. Groundwater body work units and population change in municipalities supplied by public water supply by 2050 – medium variant

CONCLUSION

Ensuring sustainable management of water resources will be a key challenge in the coming decades, especially as climate change and other factors may significantly affect water availability and demand. It is therefore important to determine the future demand for water in important economy sectors.

Industry: The future water demand in industry was not addressed by predicting future developments, but by setting three fixed levels against which it will be possible to compare the actually available water resources at a given time. The starting point for their determination was an analysis of abstractions at the regional level. The baseline assumes that industrial water demand in the future will be similar to the current one, or at the end of the assessment period 2009–2019. *Maximum value of future abstractions:* the largest volume of water abstracted recorded in 2009–2019 is used; it provides a realistic estimate of possible positive deviations from the baseline. *Critical value (must not be exceeded):* in the analysed period 2009–2019, the limits (maximum permitted quantities) for groundwater and surface water abstractions were not fully utilized, thus providing a reserve that is at least theoretically available to the relevant businesses. We can assume that the limits for specific entities will not be increased in the future, thus determining a critical limit for the use of water resources.

Agriculture: Analysis of irrigation technology in the Czech Republic and estimation of irrigation water losses enabled calculation of the approximate maximum amount of water needed for irrigation of typical crops such as "vineyards", "hop fields", and "orchards". Calculation of the indicative amount of water needed for irrigation of crops such as "arable land" and "permanent grassland" was carried out, while it is clear that irrigation on arable land is concentrated to a decisive extent on vegetables and early potatoes, and on permanent grassland on meadows for the production of fodder for dairy cattle. Development towards full irrigation is not realistic – the assumption of using irrigation was applied only where irrigation is already established. It is quite clear that groundwater should not be used massively for irrigation in critical areas, as it is valuable water that should be reserved for drinking purposes. Moreover, there will obviously be a combination of the demand for irrigation and low flow rates in watercourses (longer periods of drought and heat). Water demand will therefore only be met by the construction of additional reservoirs, or by adjusting the handling schedules of existing reservoirs, if they have free capacity. The results of Global Circulation Models (GCM) for various emission scenarios, especially for the periods 2015–2045 (2030) and 2035–2065 (2050), show that irrigation is needed even in regions where the average water demand is decreasing. However, what remains an unanswered question is the impact of the yet unconsidered variant based on the estimate of the GLOBIOM-CZ agro-economic model. It indicates a significant comparative advantage of Czech agricultural production in the expected environmental conditions, and therefore the possibility – despite climate change – of increasing the profitability and market share of Czech agriculture on the market. The development of water consumption by livestock has been predicted for each region separately; trends across the regions vary. A steady state of water consumption by livestock is predicted for the South Moravian, Ústí nad Labem, Zlín, and Vysočina regions; a slight increase is expected in the South Bohemian and Pilsen regions; a significant increase in water consumption is predicted for the Karlovy Vary, Liberec, and Moravian-Silesian regions; a future decrease in water consumption by livestock is expected in the Hradec Králové, Olomouc, and Pardubice regions as well as in Prague and the Central Bohemian region. Trends in water consumption in individual regions are identical for both mean and maximum water consumption by livestock.

Energy industry: The water consumption estimate for energy industry indicates a reduction in water demand for this sector compared to the current situation. It is also assumed that, due to the complexity of large-scale construction, there will be no significant change in energy production between regions. One of the main factors influencing water demand for energy industry will be environmental regulations. From an economic perspective, this may also be the price of water and the costs of its treatment, which may influence decisions on the types of energy sources and technologies.

Public water supply: For significant (over 500 thousand m^3. $year^{-1}$) current surface water abstraction for public water supply systems, an increased number of connected residents by more than 10 % was predicted for the following reservoirs: Švihov (by 23 % for the high variant, by 14 % for the medium variant), Klíčava (by 18 % for the high variant, by 11 % for the medium variant), Josefův Důl (by 114 % for the high variant), and Vrchlice (by 112 % for the high variant). In the case of groundwater abstraction, an increased number of connected residents was predicted especially in (part of) the hydrogeological districts Proterozoic and Palaeozoic in the Vltava tributary basin, Crystalline in the Middle Vltava basin, Crystalline, Proterozoic and Palaeozoic in the Berounka basin, Upper Silurian and Devonian Barrandien, and Cretaceous north of Prague.

Estimates of water demand for various sectors of the economy are burdened by many uncertainties and variable factors. The main areas of uncertainty and variables that can affect the estimate of water demand include technological progress (innovation and new technologies), climatic factors, economic factors, demographics, and legislative measures. For more accurate estimates, it is therefore necessary to constantly update data and models based on new trends and technologies. Regular monitoring and adaptive management of water resources are key to efficient and sustainable water use.

This article briefly presents the results of the sub-objective "*Scenarios of future water demands for various climate scenarios and individual sectors of water use*" which is part of TA CR project No. SS02030027 "*Water systems and water management in the Czech Republic and climate change conditions (Water Centre)*". More detailed information can be found on the "*Water Centre*" website (https://www.centrum-voda.cz), including visualization of database data in the Tableau environment.

Acknowledgements

The article was prepared as part of project No. SS02030027 "Water systems and water management in the Czech Republic and climate change conditions" implemented with financial support from the Technology Agency of the Czech Republic within subprogramme 3 – Long-term environmental and climate perspectives of the SS programme – Programme of applied research, experimental development and innovation in the field environment – Environment for life. The authors would also like to thank Ing. Miroslav Bauer from CTU for preparing Fig. 2.

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The Czech version of this article was peer-reviewed, the English version was translated from the Czech original by Environmental Translation Ltd.

DOI: 10.46555/VTEI.2024.09.001

ISSN 0322-8916 (print), ISSN 1805-6555 (on-line).


Photo: J. Unucka

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Interview with Ing. Vladimír Novák, Director General of the Directorate of Water Policy of the Ministry of Environment of the Slovak Republic

This year, the Slovak Republic is chairing the largest commission focused on the protection of watercourses, the International Commission for the Protection of the Danube River (ICPDR). Therefore, we interviewed its president for the Year 2024, Ing. Vladimír Novák, who is also the General Director of the Directorate of Water Policy at the Slovak Ministry of Environment.

Mr. Novák, you studied hydraulic engineering at the Faculty of Civil Engineering of the Slovak Technical University in Bratislava. What drew you to the field of water management?

In simple terms, a family tradition. After graduation, my father joined the then Slovak Water Management State Enterprise; it was at the time of the devastating flood on the Danube in 1965 (June 12th 1965), when the Danube dam in Patince broke on 15th June, the dam between Čičov and Kľúčovec on 17th June, and near Kollárov on 25th June. During the flood, 60,000 inhabitants and 100,000 cattle were evacuated, 3,910 houses were destroyed, another 6,180 houses were damaged, and all water resources on Žitný ostrov were contaminated.

This event boosted the society awareness of the necessary comprehensive management of the area along the Danube, not only from the flood protection point of view, but also ensuring the required parameters of the Danube waterway as an inland waterway of international importance on one of its most critical sections, Rajka–Gönyű, and ensuring the use of the Danube's hydropower potential; and all this with regard to the protection of water resources and ecosystems of the Danube delta.

My father gradually worked his way into positions from which he determined the manner and style in which the laying out of the waterway, including the supply and outlet canal, was carried out for many years, as well as the lock chambers of the Gabčíkovo stage of the Gabčíkovo-Nagymaros waterworks; and, at the end of his working career, he put his experience to good use as head of the Department of Waterways and Navigation Safety at the State Navigation Administration (today's Transport Authority).

Basically, during my entire childhood, as well as a university student, I had the opportunity to sail with my father on the Čajka and Gabčíkovo stake vessels as well as on the Tekov and Hont push boats, and also participate in activities related to the creation of maps for staking the shipping channel, cooperation in the creation of studies of the Vážská waterway and, last but not least, in passporting and processing navigation studies of the Zemplín waterway. By that time, I had already studied at the Faculty of Civil Engineering of the Slovak Technical University in Bratislava.

Moreover, my grandfather spent most of his working life on the Danube as a technician on various vessels, especially the group of ships consisting of excavator Kriváň and elevator Radhošť. An interesting fact: during an air raid by the American Air Force, when 158 B-24 Liberator bombers of the 15th Air Force attacked the Apollo refinery in Bratislava on 16th June 1944, the Kriváň – Radhošť complex was damaged. After the repair, it continued to serve until the excavator Kriváň sank in the 1970s, while two members of the crew unfortunately did not manage to save themselves.

All the things I mentioned determined and established the direction of my studies to a large extent, but also shaped and laid the foundation of my professional focus.

Where did your path lead you after graduating from the Faculty of Civil Engineering?

After completing my studies in 1997, I continued as a doctoral student at the Department of Hydraulic Engineering of the Faculty of Civil Engineering of the Slovak Technical University in Bratislava until September 2000. Subsequently, I was employed by the Ministry of Agriculture and Rural Development of the Slovak Republic at the Water Section, Department of Watercourse Management. My job was mainly the agenda of bilateral cooperation on border waters with neighbouring states, the agenda connected with the character and course of the state border on border waters, as well as the agenda of the development of inland waterways and navigation. I gradually acquired experience related to the creation of strategic, planning and conceptual materials, as well as legislative proposals not only from the above-mentioned area of competence, but also from other areas, which included, for example, the development of public water supply systems and public sewers, the protection of valuable water resources and last but not least technical and safety supervision of water structures and flood protection.

With a break, you have worked in various managerial positions within the Ministry of Agriculture, or Ministry of Environment, for almost twenty years. What was the reason for leaving the positions in which you established yourself so significantly, and what did this change bring you?

The reason was a change in the leadership of the Ministry in 2020, which I think had different ideas about priorities in the area of sustainable water use and water resource protection, although I never learned the specific reasons and did not search for them. I took it as a fact that every management chooses an expert they trust for positions, which, as it turns out, also includes the position of Director General of the Directorate of Water Policy.

Since I devoted years of study and practice to water management, I did not leave the department bitter; on the contrary, I took advantage of the opportunity to continue working in the Directorate of Water Policy in the position of clerk, or the chief state adviser, often within the agenda of bilateral cooperation on border waters with neighbouring states, as well as the agenda associated with the development of inland waterways and navigation and, last but not least, the agenda related to the methodical guidance, management, and check of state-owned enterprises founded by the Ministry of Environment of the Slovak Republic.

In addition, from the position as chairman of the Slovak Navigation Congress (Slovenský plavebný kongres), I ensured cooperation with the Czech Navigation and Waterways Association, (České plavební a vodocestní sdružení, z. s.), which culminated in the preparation and holding of a regular conference with international participation – 31st Navigation Days (Plavebné dni) 2023.

Bojan Vranjkovič (Serbian ICPDR President for 2023) and Vladimír Novák (Slovak ICPDR President for 2024) during the handing over and taking over of the ICPDR presidency at the Embassy of the Republic of Serbia in Vienna in January 2024

In addition to the negatives, the change also brought me some positives, such as more time for myself and my family. For example, in a year and a half, I managed to reduce my weight from 113 kg to 89 kg, which at that time ultimately brought me an improvement in my health and especially my fitness.

You worked in the position of Director General of the Directorate of Water Policy of the Ministry of Environment of the Slovak Republic before. Were you able to follow up on your previous work?

In essence, I followed up on my previous activities, as the priorities and goals of water management remain unchanged in principle and are set for six-year planning cycles; however, it is possible to discuss the prioritization of individual measures, considering available financial resources and human resources for their implementation.

However, at the time of the inevitable consolidation of funds, it seems necessary to correctly set the just-mentioned prioritization of implementing the individual measures and also to motivate the team, which, compared to the times of the previous government, was reduced by six employees. When we realize the content and scope of the tasks of water management and protection of water resources in the Slovak Republic, 26 employees in reality and 28 officially may appear to be sufficient; however, we must remember that we are not only talking about ensuring activities under the responsibility of the central body of the state administration in the field of water, but also management, methodical guidance, and check of ministry institutes of the Slovak Hydrometeorological Institute, Slovak Water Research Institute, but also departmental state enterprises, such as Slovenský vodohospodársky podnik, š. p., and Vodohospodárska výstavba, š. p.

Last but not least, we are "dependent" on cooperation with other ministries; in particular, the Ministry of Transport and Construction of the Slovak Republic in matters of development and modernization of waterways and inland navigation, the Ministry of Economy of the Slovak Republic in matters of water energy use as a renewable source from hydro power stations, including small ones up to 10 MW, the Ministry of Agriculture and Rural Development of the Slovak Republic in matters of hydromelioration, the Ministry of Health in matters of public health, water suitable for bathing, and also the Ministry of the Interior in matters of flood protection and crisis management, as well as in matters of character and the course of the state border on watercourses etc.

What are the current priorities of the Slovak Republic regarding water protection?

The Slovak Republic fulfils its obligations in the sustainable use of water and in the protection of valuable water resources at the national level, as they result from its membership in the European Union, as well as to other Member States.

In addition, it ensures cooperation and coordination of individual activities at the bilateral and multilateral level. The priorities of the Slovak Republic are directly connected to the mentioned national, bilateral, and multilateral obligations and I am directly or indirectly responsible for their fulfilment.

Among the main priorities of the Slovak Republic are obligations related to the achievement of good water status, both groundwater and surface water bodies. For this, it is necessary to have responsibly managed transposition of the relevant directives, in particular the Water Framework Directive, the Flood Directive, the Directive on the Treatment of Municipal Waste Water, the Directive on the Protection of Water from Nitrate Pollution from Agricultural Sources, the Directive on the Protection of Groundwater from Pollution and Quality Deterioration, the Directive on the Management of the Quality of Water Intended for Bathing, the Directive on Environmental Quality Standards in the Field of Water Policy and, last but not least, the Directive on the Quality of Water Intended for Human Consumption.

Responsibly managed transposition of the aforementioned directives into the national legislation of the Slovak Republic, in particular the Water Act, Act on Public Drinking Water Systems and Public Sewerage Systems, the Flood Protection Act and others, as well as their implementing regulations, provides space for the implementation of measures necessary to achieve individual goals to correspond to the mentioned priorities. Individual measures are proposed separately for surface water and groundwater bodies, both in terms of their quantity and quality.

Basic measures include not only legislative ones, but also measures related to the optimization of financial and human resources and, last but not least, technical and ecological measures. I would emphasize water monitoring as one of the basic measures, the results of which are an essential basis for determining individual basic and additional technical measures. This is related to setting of models and funding sources (from the state budget or European Union funds, or any other sources) on which, among other things, the quantity and quality of human resources depend not only for science and research, but also for planning, projecting, implementation, or the operation of individual measures.

Basic and additional measures in the Slovak Republic are summarized in the Programme of Measures, which forms an annex to the Water Plan of the Slovak Republic. It is being developed for a period of six years; its third update for 2022–2027 is currently available and consists of the Danube Basin Management Plan and the Vistula Basin Management Plan. In addition to the Water Plan, the measures are also found in other strategic, planning, and conceptual documents and their updates; in the Slovak Republic, for example, in Flood Risk Management Plans in Sub-Basins of the Slovak Republic, in Plan for the Development of Public Water Supply and Sewerage Systems for the Slovak Republic, but also in Concept of Water Policy until 2030 with an Outlook to 2050, or in the Action Plan for Dealing with the Consequences of Drought and Lack of Water – H_2ODNOTA JE VODA (Water is the Value).

So, in conclusion, I will summarize that the priorities of the Slovak Republic, in addition to protecting the quality of water resources and ensuring biodiversity through the protection of habitats and ecosystems, are currently mainly focused on ensuring the supply of drinking water to the population, the drainage of agglomerations, but also on ensuring the protection of the population against floods, as well as on providing sufficient water according to priorities for its individual users continuously and especially during the dry season (water for drinking purposes, water for agriculture, water for industry, cooling water for nuclear power plants, water for the use of hydropower potential, water for navigation, water for recreational purposes, water for fish breeding, etc.).

This year, the Slovak Republic chairs the largest commission focused on the protection of watercourses, the International Commission for the Protection of the Danube. You yourself hold the position of its President. With what goals did you enter this position?

Yes, it is true that the Slovak Republic has the honour of chairing the International Commission for the Protection of Danube Waters (ICPDR) in 2024. This year is special because we celebrated the 30th anniversary of the Convention on Cooperation in the Protection and Sustainable Use of the Danube River, which was signed on 29th June 1994 in Sofia and, at the same time, the 20th anniversary of the establishment of 29th June as Danube Day.

I am personally honoured that in the year of my 50th birthday I can represent the Slovak Republic during the presidency of the ICPDR as its president.

(*Editor's note: you can read more about the goals of the Slovak Republic in the ICPDR in a separate article about the presidency of the Slovak Republic in the ICPDR after this interview.*)

You also hold other important positions. You are, for example, the government representative for water management issues on border waters

with neighbouring states. What current issues are on the agenda with the Czech Republic?

It has been the floods during September 2024, which mainly affected Central Europe and, in addition to the Slovak Republic, affected the Czech Republic in an incomparably more destructive form, as well as Poland and Lower Austria.

As part of the flood in question, there was a regular exchange of information and coordination of the implementation of necessary measures, or securing and rescue work, especially on the joint section of the Morava river along the Slovak-Czech border. The cooperation was carried out through the Slovak-Czech Border Water Commission and the technical issues working group established by it, as well as through communication between the Morava managers and the hydrometeorological institutes on both sides in accordance with the intergovernmental agreement on cooperation on border waters, i.e. Directive on the warning and notification service on border waters. The situation will be evaluated and recorded in the Protocol from the next, 25th meeting of the Slovak-Czech Border Water Commission, which will take place in 2025 in the Czech Republic. The knowledge gained will be used in the possible optimization of cooperation in the mentioned area.

In the long term, we are trying to cooperate, or to provide relevant documents to the ministries of finance on both sides, in order to settle the property of the managers of border watercourses important from the water management point of view. The question of the fixed or movable state border on border waters also remains open.

In conclusion, I must mention the continuous exchange of information and data in the field of hydrology and water quality protection, but also the implementation of individual technical measures related to the development of waterways and navigation.

Cooperation with other countries is also interesting. Thanks to your long-term involvement in border waters, can you compare the specifics of these negotiations?

The fundamental difference in the negotiations of individual Commissions for Border Waters with neighbouring states compared to the Slovak-Czech Border Water Commission, but also in the negotiations of individual working groups established within the said commission, is the fact that we still do not need an interpreter, which accelerates the negotiations and brings a different atmosphere to them. With this statement, I would close the question for the time being, as the details and specifics of the negotiations of the Border Water Commission with individual neighbouring states would require a separate interview. -:)

Tell the readers about your visions, your plans or a specific project that you would like to implement.

Of course, each of us has some "secret dreams". I must say that I envy the generations that established and built things and whose results still serve us today. Therefore, I would be happy if I could be part of a team that can manage and ensure the construction of either single-purpose or multi-purpose water structures for the society, which will provide prosperity for the entire society and ensure sufficient water that can be used in the dry season, and at the same time ensure the protection of life and property of citizens during floods. However, considering the current situation in the society, this is more of a long-term plan.

From a medium-term point of view, I consider it necessary to contribute with correct proposals and information for the Ministry to the financial and personnel stabilization of state enterprises, which ensure the management of watercourses and water structures owned by the state.

Finally, I will mention short-term "projects", or visions, and these are, on the one hand, the necessity of stabilizing and rejuvenating the Directorate of Water Policy team, as in the previous period, several job positions were scrapped, while several employees are in pre-retirement and retirement age. I believe that, in cooperation with my colleagues, I will also succeed in the update of the Water Policy Concept of the Slovak Republic until 2030, with an outlook to 2050, so that the measures that were included by political decision and without relevant assessment are removed from it. Among other things, this would also open up space for the implementation of the aforementioned long-term "project", or vision.

In conclusion, I would like to make a wish for society to return to pragmatism in decision-making and suppress ecological extremism insulting water managers, respectively civil engineers as representatives of the "concrete lobby" and so on.

It is no secret that you have a son. Will he follow in his father's footsteps?

As they say, "never say never", but considering the above and the current situation, I dare say that "the apple does not fall far from the tree" will not apply in this case. My son will finish his studies at the eight-year secondary school this school year, and there is no indication yet that he will pursue after graduation the field of water management, which of course I will not begrudge him in any way.

Anyway, I will cheer him on and support him in his further progress, regardless of the field he chooses; after all, no one forced me to study the chosen field either.

Director General, thank you very much for your time for our interview.

Ing. Josef Nistler

Ing. Vladimír Novák

Ing. Vladimír Novák was born on 31 May 1974 in Bratislava. He studied hydraulic engineering at the Faculty of Civil Engineering of the Slovak Technical University in Bratislava. He is an expert in water management. On the basis of a government resolution, he was appointed to the position of representative of the Slovak government for cooperation on border waters with neighbouring states (the Czech Republic, Ukraine, Hungary, and Austria) and to the position of chairman of the Slovak part of the Slovak-Polish Border Water Commission. He was first director of the Waterborne Transport Development Agency (from 2011). As a member of the Slovak government delegation, he also participated and participates in the negotiations with the Hungary government delegation, the goal of which is to end the long-term discussions to find a definitive joint solution to the open questions related to the System of Water Works named Gabčíkovo-Nagymaros. His work is also connected with the representation of Slovakia in multilateral platforms, such as informal meetings of the Water and Marine Directors of the European Union and activities in the Priority Area 4 (PA4) "Maintain and Restore the Quality of Waters" of the European Strategy for the Danube Region (EUSDR). He is currently Director General of the Directorate of Water Policy of the Ministry of Environment of the Slovak Republic, International Commission for the Protection of the Danube River (ICPDR) President for 2024, a water management expert in the permanent border commissions for issues of the character and laying out of the state border and, last but not least, the long-term chairman of the Slovak Navigation Congress.

Presidency of the Slovak Republic in the International Commission for the Protection of the Danube River

In 2024, the Slovak Republic is chairing the International Commission for the Protection of the Danube River (ICPDR).

The Presidency is based on the rotation of the 14 Danube states and the European Commission, which are signatories of the Danube River Protection Convention. Hence, the Slovak Republic is the presiding state once every 15 years.

As part of the Slovak presidency, the Deputy Prime Minister and Minister of the Environment of the Slovak Republic appointed Ing. Vladimír Novák, Director General of the Directorate of Water Policy, to be its president. The ICPDR reported on this at the 14th regular meeting of the heads of the ICPDR delegations, which took place in December 2023 in Vienna.

The Convention on Cooperation in the Protection and Sustainable Use of the Danube was signed on 29th June 1994 in Sofia, Bulgaria. In 2024, we are therefore commemorating 30 years of successful cooperation between the Danube countries. In 2024, we are also commemorating another anniversary – 20 years since the declaration of International Danube Day on 29th June (date of signing the Convention).

The Convention on Cooperation in the Protection and Sustainable Use of the Danube created basis for future cooperation of the Danube countries, especially in the implementation of the EU Water Framework Directive and Directive on the Assessment and Management of Flood Risks (Floods Directive). In this context, the ICPDR develops support activities and measures in the Danube river basin, coordinates the implementation of EU directives, creates a platform for the ongoing exchange of experience, and facilitates cooperation between EU and non-EU countries. In February 2022, all signatory states of the Convention signed the Ministerial Danube Declaration, in which they commit to achieving good water status, increasing the safety of residents against floods and droughts, as well as returning the Danube iconic fish – the sturgeon – to its waters.

On 25th and 26th June 2024, the Directorate of Water Policy of the Ministry of Environment organized a two-day meeting of the Permanent Working Group, which discussed the fundamental direction of the ICPDR's activities. On behalf of the Ministry of Environment of the Slovak Republic, the meeting was opened by the president of ICPDR for the 2024, Ing. Vladimír Novák.

Furthermore, the Directorate of Water Policy of the Ministry of Environment of the Slovak Republic organized the meeting of the Monitoring & Assessment Expert Group (MA EG) in Bratislava on 25th and 26th September 2024, in the premises of the Water Research Institute (VÚVH) as well as online.

On 24th September 2024, the so-called JDS5 Biology Core Group and JDS5 Chemical Core Group working meetings were organized with the aim of organizing the Joint Danube Survey (JDS5) in 2025; its main goal is proposing a programme for the field of biology and chemistry. The organization and premises will be provided by VÚVH.

The priorities of the Slovak ICPDR presidency in 2024 are mainly the following:

— Support for processing the ICPDR Interim Report on the Joint Programme of Measures, or implementation of Danube Basin Management Plans. The Interim Report will be prepared in the form of examples of successful implementation of the EU Water Framework Directive and Floods Directive. The deadline for approval of the Interim Report is December 2024.
— Support for Joint Danube Survey 5 (JDS5) – this is the fifth cycle of the joint survey of the Danube. Previous surveys were carried out in 2001, 2007, 2013, and 2021. The JDS is the most comprehensive surface water monitoring research project in the world, harmonizing water monitoring practices in the Danube countries to support compliance with the Water Framework Directive. Scientific research teams from all Danube countries are participating in the survey. JDS helps to cover the information gaps necessary for updating the management plan of the Danube basin administrative area. An important role is played by VÚVH – Water Research Institute with its expert staff and laboratory equipment. The Slovak Hydrometeorological Institute (SHMÚ), which provides in-kind support for the TransNational Monitoring Network for all Danube countries, is also cooperating in the survey. There will be new challenges for monitoring in JDS5: eDNA will be used to assess biodiversity elements, sturgeon will be monitored. Preparation for JDS5, which is expected to take place in spring 2025, is being carried out throughout 2024.
— Support for the organization of the ICPDR Sustainable Hydropower Workshop, which took place on 4–5th June 2024 in Vienna. In 2011, the ICPDR published the Main Principles for the Integration of Environmental Aspects of Hydropower Use, which the Danube countries committed to incorporate into their national policies. The aim of the workshop was to present new challenges in the field of renewable energy sources and the adoption of the EU RePower regulation in 2021 in the countries of the Danube basin. Hydropower stations offer the possibility of reducing greenhouse gas emissions; however, at the same time they have negative impact on river ecology. The workshop was a dialogue between water managers and power engineers to ensure balanced and integrated development, which dealt with the potential conflict of interests from the beginning.
— Accompanying events on the occasion of Danube Day on 29th June 2024, due to the celebration of the 20th anniversary of the declaration of Danube Day. This international day was announced on the occasion of the 10th anniversary of the signing of the Convention on Cooperation in the Protection and Sustainable Use of the Danube.
— Presentation of activities within the "*LIFE Living Rivers*" project, which aims to restore rivers. The Directorate of Water Policy of the Ministry of the Environment of the Slovak Republic is cooperating in the project, and the main partner is VÚVH. It was assumed that representatives of the Danube countries would be invited to one of the workshops in 2024. This is a contribution to the implementation of the Water Plan of Slovakia as well as the EU Water Framework Directive the EU Nature Restoration Law, the obligation to restore rivers and ensure free-flowing sections of rivers.

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This informative article has not been peer-reviewed.
ISSN 0322-8916 (print), ISSN 1805-6555 (on-line).

Photo: 123rf.com

17th conference Radionuclides and ionizing radiation in water management

The annual conference *Radionuclides and ionizing radiation in water management* took place on 21st and 22nd May 2024 at the Clarion Hotel in České Budějovice. The expert guarantor was Ing. Barbora Sedlářová (TGM WRI) and the organizational guarantor was Jan Kříž (ČVTVHS, z. s.). The conference was attended by 63 experts, of which 58 from the Czech Republic and 5 from Slovak Republic.

In the introductory lecture, Ing. Jan Varmuža (State Office for Nuclear Safety, SÚJB) informed about the amendment of the Atomic Energy Act from the point of view of monitoring radiation in surface waters. In the following presentation, RNDr. Jana Slimáková, Ph.D. (Public Health Authority of the Slovak Republic), summarized the experience of monitoring radiation in Slovac Republic. This was followed by a lecture on the amendment of the Atomic Energy Act from the point of view of monitoring tritium in waters, presented by Dr. Ing. Milan Hort (SÚJB). Then, Ing. Marcela Velkoborská (SÚJB) continued with information regarding the amendment of the relevant decrees on legislation for requirements for the supply and treatment of groundwater.

The following part dealt with the measurement and evaluation of the content of natural radionuclides with a possible increased content of natural radionuclides produced in groundwater treatment plants. The issue of refining the estimation of uranium-234 content was presented by Ing. Tereza Doksanská (National Radiation Protection Institute, NRPI) and practical experience and suggestions for revising the SÚJB recommendations were summarized by Ing. Tomáš Bouda (ALS Czech Republic). The next topic was deep radioactive waste repository in terms of characterizing suitable locations by determining the activities of long-lived radionuclides in groundwater. The topic was presented by Mgr. Michal Fejgl, Ph.D. (NRPI). Ing. Hana Sýbková (National Institute for NBC Protection) reported on the evaluation of the leaching of radioactive elements from rock material from uranium mining dumps used for motorway construction. Recently, a lot of attention has been paid to the issue of early detection of a possible radioactive event. Therefore, in his contribution, M.Sc. Michal Fejgl, Ph.D. (NRPI), presented the results of a currently developed device enabling the continuous determination of gamma activity in rainwater.

The next part dealt with the occurrence of artificial radionuclides in surface waters. RNDr. Diana Marešová, Ph.D. (TGM WRI), summarized findings on existing data on tritium volume activities and on their development in precipitation and surface waters in the Vltava and Elbe basins. Mgr. Enrico Mariaca (Water Research Institute, VÚVH) continued with information about volume activities in border watercourses in Slovakia. Ing. Eva Juranová, Ph.D. (TGM WRI), presented findings from the monitoring of carbon-14 in surface waters in the vicinity of the Dukovany and Temelín nuclear power stations. Other contributions dealt with the determination of long-lived radionuclides using Accelerator Mass Spectrometry (AMS), which can be used as a tracer of human nuclear activity. A lecture by Ing. Tomáš Prášek (Department of Nuclear Chemistry, FNSPE CTU) presented the initial measurement of uranium-236 in environmental samples. Ing. Edita Červenková (Department of Nuclear Chemistry, FNSPE CTU) reported on the determination of iodine-129 in river water as a tracer of nuclear accidents and on the effect of reprocessing spent nuclear fuel on the environment. The use of iodine-129 as an oceanographic tracer was presented by Ing. Miriam Mindová (Department of Nuclear Chemistry, FNSPE CTU). Ing. Jakub Sochor (Department of Nuclear Chemistry, FNSPE CTU, Faculty of Environmental Technology, UCT Prague) outlined the possibility of using ionizing radiation to solve the issue of degradation of antibiotic resistance genes in water. In conclusion, RNDr. Tomáš Soukup (Czech Metrology Institute) summarized the determination of radioactive indicators from the point of view of metrology, and Ing. Lenka Fremrová (Sweco Hydroprojekt, a. s.) prepared an overview of standards for the determination of radioactive substances in water and other related standards. The conference proceedings are available at: www.vuv.cz/wp-content/uploads/2024/05/Radionuklidy-2024_Sbornik.pdf.

The conference offered a platform for sharing professional experience, presenting the latest findings from research, and the possibility of establishing new collaboration between radiation safety and water management experts. The participants appreciated the wide range of topics discussed and the quality of presentations, which contributed to a better understanding of the issue of radionuclides in the environment. At the end of the meeting, it was recommended to organize the 18th conference on *Radionuclides and ionizing radiation in water management* in 2026.

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This informative article has not been peer-reviewed.

ISSN 0322-8916 (print), ISSN 1805-6555 (on-line).


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Photo: 123rf.com

VTEI/2024/6

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A scientific bimonthly journal specialising in water research. It is included in the List of peer-reviewed non-impacted periodicals published in the Czech Republic

Volume 66

VTEI.cz

Published by: Výzkumný ústav vodohospodářský T. G. Masaryka, veřejná výzkumná instituce, Podbabská 2582/30, 160 00 Praha 6

Editor in chief:
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Sources of photographs for this issue:
VÚV TGM, 123RF.com, doc. RNDr. Jan Unucka, Ph.D., archiv MŽP SR, Artificial Intelligence

Graphic design, typesetting and printing:
ABALON s. r. o., www.abalon.cz

Number of copies: 400.
Since 2022, the VTEI journal has been published in English at https://www.vtei.cz/en/

The next issue will be published in February 2025.
Instructions for authors are available at www.vtei.cz

VTEI is part of Scopus and DOAJ databases.

ISSN 0322-8916
ISSN 1805-6555 (on-line)
MK ČR E 6365

THE HVOZDNICE AMONG THE TREES

The Hvozdnice river is one of the most important tributaries of the Moravice River, which flows into Opava just a few kilometres after it. The spring can be found north of the Slezská Harta waterworks at an altitude of 690 m. Its total length is 36 km and the catchment area is 164 km^2. The river flows through the romantic region of the abandoned slate mines of Nízký Jeseník, with villages such as Jakartovice and Mladecko. Slate from the Nízký Jeseník Culm are generally considered to be of the highest quality; they decorate, among other things, sacred buildings in Wrocław and towns in Saxony. Abandoned surface mines and tunnels give this landscape an unusual romantic touch; moreover, these landscape enclaves are a living textbook of botany, zoology, and forestry. Current succession stages are often made up of pioneer trees of birch and pine. These secondary forest-free areas are also centres of occurrence of rare species of plants and animals. Charismatic species include our largest owl – the eagle owl *(Bubo bubo)*, as well as pygmy owl *(Glaucidium passerinum)*, which together with scops owl *(Otus scops)* are the smallest owls in the Czech countryside. Historically, a whole cascade of water mills functioned on the Hvozdnice, one of which gave the village its name – Pilný Mlýn (Busy Mill). Before the confluence with the Moravice, near the villages of Štáblovice and Slavkov, the Hvozdnice is lined with some of the few preserved remnants of alluvial forest in the Opava region.

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

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