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

VTEI / 2023 / 5

THEME

Water protection in the landscape

60 years ago in VTEI

The TECHNICAL INFORMATION FROM THE FIELD OF WATER MANAGEMENT (TECHNICKÉ INFORMACE Z OBORU VODNÍHO HOSPODÁŘSTVÍ) journal, in its third issue of 1959, addressed a very interesting issue. It was about possible ways of repelling fish from the screens of hydroelectric power stations, in order to prevent unnecessary injury to fish, or even their killing.

Screens are installed in front of the inlets to hydroelectric power stations, which protect the turbines from damage by larger objects and prevent fish from entering the turbines, where they are often injured or killed. Since the installation of screens in the inlet profile results in losses in the head, and thus also on the production of electricity in the hydroelectric power station, there has been an effort for a long time to construct a device for repelling fish from the inlets to hydroelectric power stations, which would enable the use of only sparse screens with small losses.

Many experiments have been carried out in our country and abroad which have shown that high-speed turbines with a larger number of blades are most responsible for killing fish. According to the results of Ing. Raben, published in no. 3/1957 of the journal Die Wasserwirtschaft, the so-called critical impact speed (the product of the rotational speed and the diameter of the runner) is decisive for the assessment of the turbine from this point of view. If it were possible not to exceed these critical speeds when dimensioning the turbines, solving the problem would be greatly facilitated. Other possibilities are provided by the use of an electric field created by special electrodes before the inlet, or by ultrasound.

The rods of bar screens placed at the beginning of the inlet channel are used as electrodes. Suspended electrodes are also designed, which can be placed in any position. Ultrasonic fish repellency is still in the research stage. However, according to some experts, fish get used to ultrasound impulses over time and do not respond to them.

Although the repellent effect of ultrasound on fish has not yet been sufficiently investigated, it can be assumed that it could have its application in repelling fish only as a supplement to enhance the effect of an electrophysiological repellent device.

The ultrasonic generator is described in Engineering Constructions journal (Inženýrské stavby) No. 5757. This ultrasonic generator and exciters are still a development product, which is verified during measurements on dam sections.

When designing repelling devices, it is necessary to consider all the operating conditions of the hydropower station and the circumstances that occur during floods and ice flow, when damage or even destruction of the relevant device can easily occur.

From TGM WRI archives
VTEI Editorial office

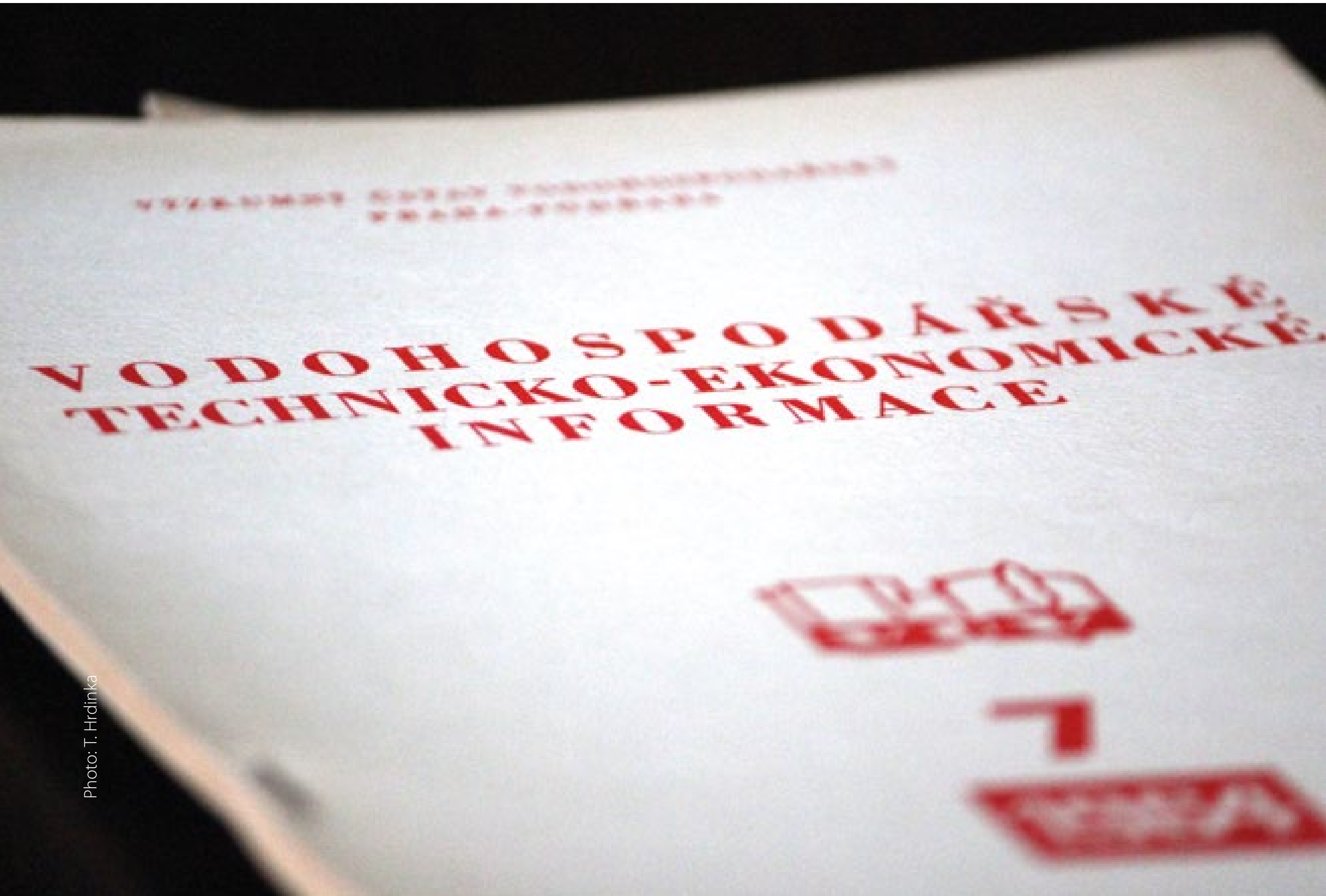


Photo: T. Hrdinka

Contents

Foto: J. Unucka

Dear readers,

welcome to the pages of the October edition of the VTEI journal, which is dedicated to one of the oldest fields of water management – hydrology. Although the October issue has a single theme, the individual articles are very varied.

The first article is focused on the study of the influence of small water reservoirs on overall hydrological balance. It summarizes the results of observations carried out by means of a floating evapotranspiration station located on Vavřinecký pond in Central Bohemia. During the three-year observation, total evaporation during the evapotranspiration season exceeded the amount of precipitation by more than 100 mm; this means, from the point of view of long-term balance, a decrease of water in the watercourse. You can find details about why the influence of small water reservoirs on the overall hydrological balance is not black and white in Adam Beran's contribution (TGM WRI).

The south of Europe was affected by extreme drought this year, along with large-scale fires in the Mediterranean and, in contrast, Slovenia and the Scandinavian countries faced extreme floods in August; therefore, the introduction or improvement of warning information systems is a pressing topic for discussion. From the hydrology point of view, it is the creation of tools for long-term prediction of the status of water resources and the state of drought. Our article provides information on the establishment of normative limits for water resources intended for the preparation of plans for managing drought and water shortages. These limits are analogous to flood levels and are used for operational drought management. Find more in the contribution from Adam Vizina et al. (TGM WRI).

The article by Jiří Prinz, Pavel Eckhardt, and Roman Kožín (TGM WRI) deals with areas protected for the accumulation of surface water from a hydrogeological point of view and, at the same time, presents important aspects of the protection of these areas as well as the importance of these areas for the sustainable use of water resources. As there are potentially negative effects of the construction of the planned reservoirs on groundwater; from a hydrogeological point of view, it is necessary to assess the given locations individually.

The study of morphological changes in watercourses and the application of its results is another topic that the authors address in this issue. The article by Petr Sklenář (TGM WRI) summarizes research on the origin and development of the watercourse morphology at the transition from a fortified riverbed with fixed banks and bottom to a riverbed that can be further morphologically transformed in a completely uncontrolled manner.

It is generally said that the future is uncertain; but how uncertain is the future of our watercourses? The analysis of flows and trends allows us to ask the following question: how much lower will flows in watercourses be by 2060 and how correct is to consider the change in potential evapotranspiration an increase in real evapotranspiration or a decrease in runoff? Find more in the article by Ladislav Kašpárek (TGM WRI).

For our interview in the October edition of VTEI, we have chosen a prominent figure in Czech and world climatology – Radim Tolaz, head of the climate change department of the Czech Hydrometeorological Institute and World Meteorological Organization (WMO) climate data expert. Our questions were directed not only at the "traditional" topic of climate change, but we also touched on his professional beginnings and private activities, for example writing the "Climate Ten Commandments of the Individual".

The article by Anna Hrabánková (TGM WRI), which closes this year's October issue, will provide readers with more detailed information about the *"Water Centre"* project; its aim is to find suitable measures to preserve water sources for water supply in areas where water supply is already running out or could run out in the future, specifically its part called "Water for people".

We hope you find the articles in the October issue of VTEI journal interesting and they provide you with useful information.

We wish you a pleasant read and an inspiring discovery of the world of hydrology

VTEI Editorial office

Direct monitoring of water vapor from the free water level of the Vavřinecký pond and its influence on the hydrological balance

ADAM BERAN, VÁCLAV DAVID, RADOVAN TYL

Keywords: floating evaporimeter — Vavřinecký pond — water surface — evaporation — hydrological balance

ABSTRACT

With increased average air temperature, there is an increase in water vapour from a water surface. Between 2020 and 2022, evaporation from the water surface was observed with a floating evaporimeter at Vavřinecký pond in the Central Bohemian region. A floating evaporimeter monitors evaporation from the water surface along with basic meteorological quantities directly on the surface of the water reservoir, so its results should be more accurate than calculations based on data from nearby meteorological stations. The results show that in all three years evaporation exceeded precipitation by more than 100 mm between April and September. However, the issue of the influence of small water reservoirs on the hydrological balance is a very complex topic, where the assessment of negative and positive effects is not always black and white and requires detailed investigation.

INTRODUCTION

In the Czech Republic, average air temperature has been increasing in recent decades; over the past 60 years it has risen by more than 2 °C [1]. As the temperature increases, there is increased water evaporation from all surfaces of the Czech landscape, whether they are fields, forests, or water body. With stable balance, the loss of water through evaporation is compensated by precipitation totals; however, precipitation totals in the Czech Republic do not change much and remain (with various fluctuations) at the same level. Therefore, within the Czech Republic in areas with lower long-term precipitation totals (e.g. southern to central Moravia, Polabí, Poohří, the lower reaches of the Vltava), there is an increase in the negative difference between precipitation and evaporation. In these areas, total evaporation exceeds precipitation, and therefore they are in deficit in the long term.

In recent years, efforts have been made in the Czech Republic to propose and adopt adaptation measures that would support water retention in the landscape and reduce the overall water deficit. One of the discussed measures is the construction or renovation of small water reservoirs (SWR). According to ČSN 75 2410, these are reservoirs with a maximum depth of 9 m and a controllable volume of up to 2 million m^3 [2]. SWRs have the potential to improve the flow below the dam in the dry season, and raising the groundwater level around the reservoir can also be beneficial. However, the impacts on the hydrological balance can also be negative, especially due to inappropriate selection of SWR function or their location within the Czech Republic. If there is insufficient inflow into an SWR and an area is selected with a long-term negative moisture balance, there will be excessive water evaporation, and the effect on the watercourse hydrological balance may thus be negative.

It is possible to calculate water losses by evaporation for specific SWR; however, more accurate data can be obtained by direct monitoring using an evaporimeter. TGM WRI has been dealing with direct evaporation monitoring since the 1950s [3]. In recent years, floating evaporimeters have been used to determine evaporation from water bodies; they are placed directly on the their surface, and thus can most precisely measure the meteorological conditions in a reservoir.

This article describes the results of evaporation measurement with a floating evaporimeter from the Vavřinecký pond water surface between 2020 and 2023 and its effect on the overall hydrological balance. In the conclusion, the pros and cons are discussed of using SWR as an adaptation measure supporting water retention in the landscape.

METHODOLOGY

Project *„The influence of small water reservoirs on the groundwater level and hydrological balance with emphasis on dry periods“* (TITSMZP809)

The effect of evaporation from the water surface on the overall SWR hydrological balance was addressed between 2019 and 2022 within the programme of the Technology Agency of the Czech Republic (TA CR) Beta2 *„The influence of small water reservoirs on the groundwater level and hydrological balance with emphasis on dry periods“* for the Ministry of the Environment (MoE). The main goal of the project was to assess the impact of SWR on the hydrological balance and its components at different spatial scales. The analysis was carried out in the SWR vicinity, in source catchments, and in catchments with systems of ponds and SWR. Hydrological balance was mainly assessed with regard to the influence of SWR on groundwater level, evaporation, and runoff. The activities were based on direct monitoring of selected hydrological quantities at the SWR, from analyses of the SWR vicinity through remote sensing data, estimation of the components of the hydrological balance by hydrological models together with a description of uncertainties, estimation of the physical-geographical characteristics of the SWR and affected basins, and from a regional analysis of the SWR characteristics [4].

Project *„Water centre“* (SS02030027)

After the completion of the above-mentioned project, the research on direct monitoring of evaporation from the water surface at Vavřinecký pond was transferred to the work package WP3 „Adaptation measures on surface water and groundwater in deficit areas“, which is part of the research project SS02030027 *„Water systems and water management in the Czech Republic in conditions of climate change (Water Centre)“* addressed within the Programme of applied research, experimental development and innovation in the field of the environment – Environment for life (Sub-programme 3 – Long-term environmental and climate perspectives) administered by the TA CR. The work package aims to assess possible adaptation measures for the deficit areas of the Czech Republic with regard to expected climate change scenarios. The investigated possible adaptation measures include water transfer, artificial infiltration, protection and support of groundwater sources, change in handling or increase of storage space of existing water/dry reservoirs, construction or restoration of SWR, support of natural infiltration through water retention in the landscape, and establishing protected sites for surface water accumulation. Accurate determination of water surface evaporation plays a role in designing or restoring SWR as an adaptation measure.

Vavřinecký pond

Vavřinecký pond is located in Central Bohemia upstream of the Výrovka (49.4 river km), about 3 km north of Uhlířské Janovice in the Kutná Hora district. With a surface area of about 71 ha and a volume of over 1 million m^3, it is one of the largest SWR in Central Bohemia as well as the whole of the Czech Republic. It is fed by the Výrovka stream flowing from Uhlířské Janovice and the Ostašovský stream flowing from the southwest. The catchment area for the dam is 60 km^2.

The site is located in the hydrogeological district of 6531 Kutná Hora crystalline basement. It is a typical environment of a hydrogeological massif with occurrence of fissure-permeable rocks. Precipitation infiltration occurs almost on the whole area, with the exception of areas with loess, poorly permeable rocks, where infiltration is very limited. Natural sources of groundwater are below average; values of specific underground runoff are given by Krásný et al. [5] around 1.5–2 l/s/km^2, while the CGS balance calculations from 2006 give a value of 2.19 l/s/km^2, which corresponds to infiltration at the level of roughly 8 % of total precipitation. Long-term more recent values of natural resources for 1981–2019 are given by Kašpárek et al. [6], whose calculations based on hydrological methods for hydrogeological region (HGR) 6531 correspond to a value of 1.5 l/s/km^2; therefore, in the given HGR, there is a reduction of natural resources compared to older data, mainly due to the dry period 2014–2019.

Floating evaporimeter

An evaporimeter floating on a water surface can best simulate the meteorological conditions of a given water reservoir. It measures water temperature precisely compared to classic field evaporimeters, in which the water heat up faster in the spring and cool down faster in the autumn. Due to their large volume, water bodies have a certain inertia, thanks to which the temperature is more constant than in the measuring vessel itself. In the same way, the monitoring of evaporation directly on the water surface is more representative with regard to other conditions influencing this process, such as insolation and, above all, wind speed.

The floating evaporimeter used on the Vavřinecký pond (*Fig. 1*) consists of a supporting structure including floats and breakwaters, which includes a measuring vessel with a diameter of 620 mm. The device is powered by a battery charged by 2 solar panels (20W each). The container is equipped with a two-way pump that fills/drains water into/out of the evaporation measurement container in the event of a level change from the reference value by 5 cm.

Sensor equipment:

- H7-G-TA4-NZ – universal multi-channel monitoring unit with GSM/GPRS module (FIEDLER)
- Accurate evaporimeter level sensor, range 0–400 mm
- RVT13/RK – relative air humidity and air temperature sensor
- WD360 – wind direction sensor
- WS103 – all-metal anemometer
- PT100-KP – water temperature sensor, four-wire connection
- RDH11 – rain detector with controlled heating
- NR LITE2 – Kipp & Zonen Net Radiometer

Fig. 1. Floating evaporimeter (FIEDLER)

DATA

Data is recorded at 10-minute intervals and sent to the server 3 times a day (at 1:00, 7:00, and 19:00) based on GSM data transmission. Evaporation and precipitation are measured on the basis of a 1-minute recording of the water level in the evaporative container in combination with a rain detector (in the case of rain detection, the level increase is caused by precipitation) and information about water intake/discharge into/out of the container. Average daily values of meteorological quantities are calculated as an average of 10-minute measurements on a given day. Evaporation and precipitation values are derived from 1-minute records.

Monitored meteorological quantities – evaporation [mm], precipitation [mm], solar radiation [W/m^2], air temperature [°C], water temperature in the evaporimeter [°C], water temperature at depths 0.5–1–1.5–2–2.5 m [°C], wind speed [m/s], instantaneous wind speed [m/s], wind direction [0–360°], relative humidity [%].

Meteorological data was recorded by a floating evaporimeter; data from the CHMI measurement network from station P3STAN01 Vavřinec, Žíšov was used for verification. The gauging stations at the inflow and outflow (*Fig. 2*) were established as part of the TITSMZP809 project in 2019 and record the water level at the tributary – Ostašovský stream, Výrovka, and the outflow – Výrovka below the dam of Vavřinecký rybník in a minute step. As part of the project, shallow (depth up to 9 m) monitoring wells were established to monitor the groundwater level in the vicinity of the pond (50–300 m).

Fig. 2. Monitoring sensor location at Vavřinecký pond

RESULTS

In the measuring season from 1st April to 30th September 2022, total evaporation from the water surface was measured at 678.4 mm, while precipitation total was 582.4 mm. Average air temperature was 15.81 °C. The changes in air temperature, solar radiation, evaporation from the water surface, and precipitation is shown in the graphs in *Figs. 3* and *4*.

A comparison of total evaporation and precipitation in the last three years, when the floating evaporimeter was used, is shown in *Tab. 1* together with data on the difference between precipitation and evaporation. The representation of evaporation in mm and at the same time in m^3 in a daily step between 2019 and 2022 is shown in *Fig. 5*. The measured data clearly illustrate the fact that the water area of 71 ha means a significant loss of water from the watercourse in the summer months precisely due to evaporation. Every millimetre of vapour means a loss of 710 m^3 of water. With an average daily evaporation of 3.7 mm in 2022, this represents an average daily water loss of 2,627 m^3. The highest daily evaporation over the past three years was measured at Vavřinecký pond on 19th June 2022, namely 10 mm, which means a daily loss of water due to evaporation from the surface of 7,100 m^3 in a single day. It should be mentioned that the change in surface area during water loss, which is negligible for losses of several centimetres, was not taken into account.

Fig. 6 shows a comparison of daily evaporation with current outflow from the pond and also with the value of average long-term outflow Qa = 0.3 m^3/s and with the value of Minimal Ecological Flow (MEF) = 0.047 m^3/s. In 2020, there was one case where the current outflow from the pond decreased below the value of the minimum residual flow. This situation occurred at the end of the season (in September), when precipitation totals and inflow into the reservoir were missing. The outflow was increased by water supply in the pond. In 2022, several days were recorded when evaporation from the water surface exceeded the value of minimum residual flow, and even the current value of outflow from the pond. This is best observed around 19th June 2022, when the water vapour was extreme.

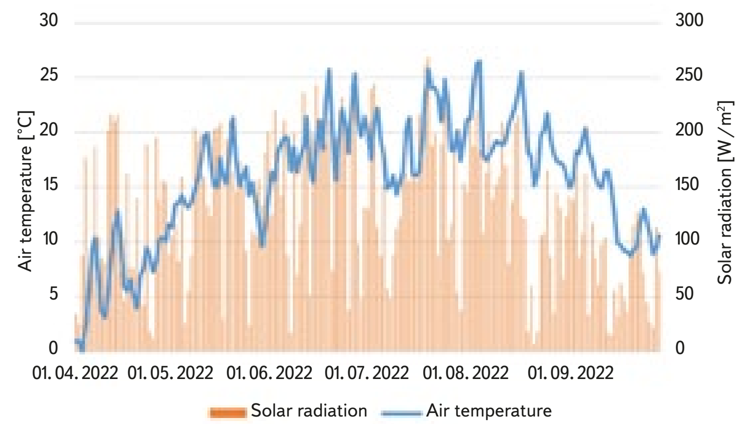


Fig. 3. Air temperature and solar radiation at Vavřinecký pond, 1st April 2022 – 30th September 2022

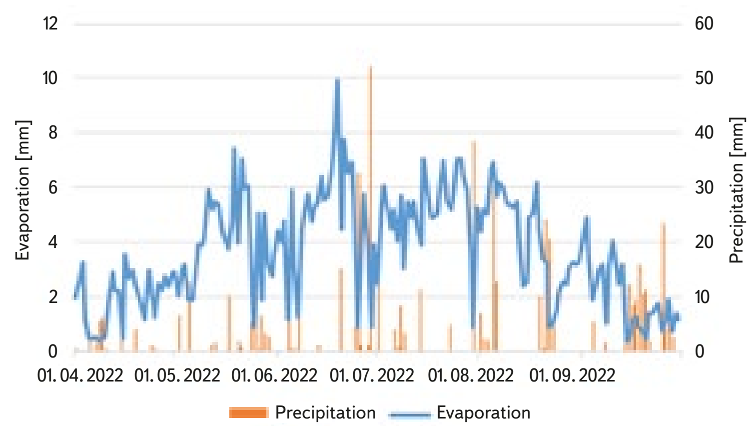


Fig. 4. Water surface evaporation and precipitation totals at Vavřinecký pond, 1st April 2022 – 30th September 2022

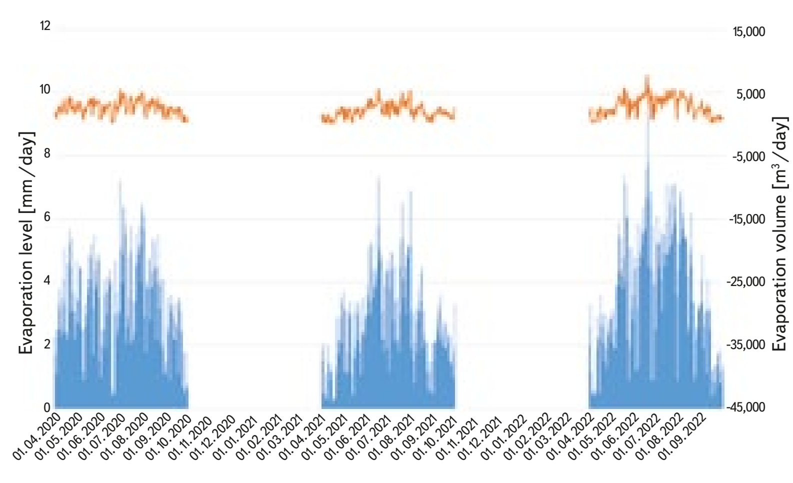


Fig. 5. Water surface evaporation at Vavřinecký pond, 1st April 2020 – 30th September 2022

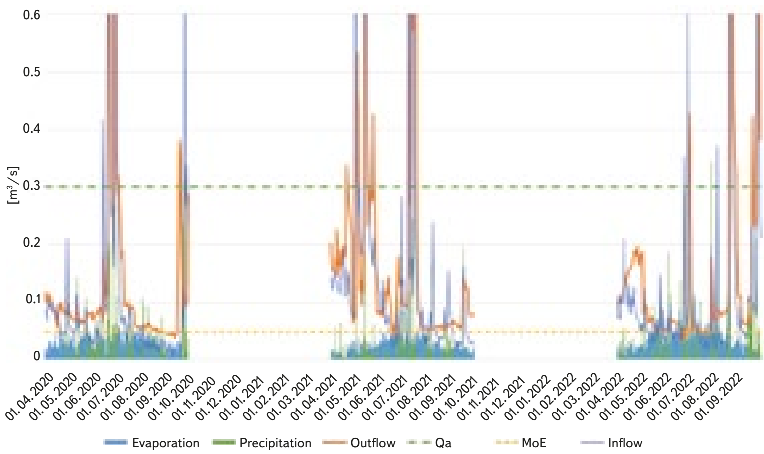


Fig. 6. Volume of water level evaporation compared to the precipitation, inflow and outflow characteristics at Vavřinecký pond, 1st April 2020 – 30th September 2022

Tab. 1. Comparison of water level evaporation and precipitation in 2020–2022 (April–October)

	Evaporation [mm]	Precipitation [mm]	Difference [mm]
2020	615.5	464.1	-151.4
2021	495.2	397.6	-97.6
2022	678.4	582.6	-95.8

CONCLUSION

Water surface evaporation is an important factor affecting the hydrological balance of a basin. Vavřinecký pond is a reservoir with a relatively large water surface area, which increases loss of water through evaporation and, during dry periods, a situation can arise when the influence of evaporation negatively affects the hydrological balance. During the monitored period, from April to September, total evaporation from the water surface ranged from 500 to 680 mm, with precipitation from 400 to 580 mm. In 2020, the water surface evaporation was higher then precipitation by 150 mm, and by 100 mm in 2021 and 2022; in terms of water volume, that is more than 70,000 m^3 of water.

During the monitoring, only exceptionally did the values of the outflow from the pond decreased below the value of the minimum residual flow. Outflow was replenished in periods of low water at the expense of water supply in the pond. In 2022, there were also individual cases of water surface evaporation being greater than outflow from the pond.

This paper summarizes monitored evaporation data obtained by monitoring with a floating evaporimeter, placed on the surface of Vavřinecký pond from 2020 to 2022. Floating evaporimeters can more accurately monitor conditions on water bodies, in particular water temperature, solar radiation, and wind speed. Evaporation from the water surface is a negative factor from the point of view of watercourse balance within the hydrological balance. However, only on the basis of evaluation of the amount of precipitation and evaporation, it cannot be claimed that SWR have a negative impact on their surroundings. The SWR influence on the hydrological regime is very complex, as well as the influence of SWR through individual hydrological processes. Although it negatively affects the watercourse balance, water loss by evaporation also has a positive effect in the form of cooling the air due to the effect of energy consumed for the change in the state of matter during evaporation, which results in a positive influence on the microclimate. Undoubtedly, the increase in underground water reserves due to backwater in reservoirs can be considered a positive local influence of SWR. Last but not least, it is necessary to mention the possibility of the transformation of flood waves during significant rainfall-runoff events.

Positive and negative effects of SWR on the hydrological regime are described in the summary report of the project TITSMZP809 [4]. As the research carried out within the project shows, SWR influence the regime of both surface and sub-surface waters. The construction of SWR is often seen as a possible element of protection against the impacts of climate change; however, it is important to remember that water management elements affect different processes in different ways, both positively and negatively. Therefore, when restoring or proposing new SWRs, all possible impacts should be properly assessed. In terms of the effect of evaporation, the location of SWR within the Czech Republic in areas with a stable precipitation-evaporation balance is important, and the function of an SWR is also important. The methodological procedure for assessing the impacts of SWR on the hydrological balance and water resources deals with the procedure for designing or restoring SWR [7].

Acknowledgements

This paper was created as part of the projects TITSMZP809 "The influence of small water reservoirs on the groundwater level and hydrological balance with emphasis on dry periods" and "Water systems and water management in the Czech Republic under conditions of climate change (Water Centre)" financed by the Technological Agency of the Czech Republic.

The authors thank the employees of Rybářství Chlumec for their willingness and cooperation in monitoring the Vavřinecký pond with a floating evaporimeter.

This paper was presented at the Rybníky 2023 *conference on 15th June 2023.*

References

[1] ŠTĚPÁNEK, P., TRNKA, M., MEITNER, J., DUBROVSKÝ, M., ZAHRADNÍČEK, P., LHOTKA, O., SKALÁK, P., KYSELÝ, J., FARDA, A., SEMERÁDOVÁ, D. *Očekávané klimatické podmínky v České republice.* Brno: Global Change Research Institute of the Czech Academy of Sciences, 2019.

[2] ČSN 75 2410 *Malé vodní nádrže*, April 2011.

[3] BERAN, A., KAŠPÁREK, L., VIZINA, A., ŠUHÁJKOVÁ, P. Ztráta vody výparem z volné vodní hladiny. *Vodohospodářské technicko-ekonomické informace.* 2019, 61(4), pp. 12–18. ISSN 0322-8916.

[4] DAVID, V., ČERNOCHOVÁ, K., KRÁSA, J., BERAN, A., DATEL, J. V., KOŽÍN, R., TYL, R., JEDLIČKA, M., KUKLA, P. et al. *Shrnutí posouzení vlivu malé vodní nádrže na složky hydrologické bilance malého povodí.* Prague: CTU, 2023.

[5] KRÁSNÝ, J., DAŇKOVÁ, H., KNĚŽEK, M., KULHÁNEK, V., SKOŘEPA, J., TREFNÁ, E. *Vysvětlivky k základní hydrogeologické mapě ČSSR 1 : 200 000, list 13, Hradec Králové.* 1st edition. Prague: Ústřední ústav geologický, 1982. 159 p.

[6] KAŠPÁREK, L., KOŽÍN, R., DATEL, J. V., PELÁKOVÁ, M. Odhad přírodních zdrojů podzemní vody v hydrogeologických rajonech v České republice v měnících se klimatických poměrech 1981–2019. *Vodohospodářské technicko-ekonomické informace.* 2022, 64(5), pp. 4–13. ISSN 0322-8916.

[7] BERAN, A., DATEL, J. V., DAVID, V., VIZINA, A., TREML, P., KOŽÍN, R., TYL, R. *Metodický postup pro posouzení dopadů malých vodních nádrží na hydrologickou bilanci a vodní zdroje.* Prague: TGM WRI, p. r. i., 2022.

Authors

Ing. Adam Beran, Ph.D.[1]
✉ adam.beran@vuv.cz
ORCID: 0000-0002-8800-5599

Ing. Václav David, Ph.D.[2]
✉ vaclav.david@fsv.cvut.cz
ORCID: 0000-0002-7792-9470

Ing. Radovan Tyl, Ph.D.[3]
✉ radovan.tyl@chmi.cz
ORCID: 0000-0002-5270-3248

[1]T.G. Masaryk Water Research Institute, Prague
[2]Czech Technical University in Prague, Faculty of Civil Engineering, Prague
[3]Czech Hydrometeorological Institute, Prague

This article was translated on basis of Czech peer-reviewed original by Environmental Translation Ltd.

DOI: 10.46555/VTEI.2023.07.001


Photo: J. Unucka

Drought warning system and local threshold limits

ADAM VIZINA, PETR PAVLÍK, IRINA GEORGIEVOVÁ, MARTIN PECHA, MARTIN HANEL, MARTINA PELÁKOVÁ, MIROSLAV TRNKA, RADEK ČEKAL, EVA MELIŠOVÁ, RADEK VLNAS

Keywords: drought — hydrological drought — surface water — groundwater — warning — prediction — climate change — water scarcity — HAMR Information System (HAMR IS) — *„PERUN"* project

ABSTRACT

Droughts and floods are extreme hydrological phenomena that are currently increasing in frequency due to the growing impact of climate change, and can have significant effects on our lives. Within the "*PERUN*" research project, an assessment of drought conditions and their development in the Czech Republic is being developed, along with the innovation of the warning system by the Czech Hydrometeorological Institute (CHMI). Drought is a natural phenomenon characterized by a gradual onset, long duration, and low dynamics, which requires a specific approach. The amendment to the Water Act introduces the obligation of regular reporting on drought and the establishment of a predictive service to be conducted by CHMI. Tools are being developed for long-term prediction of water resource conditions and a methodology for drought and water scarcity management plans. These plans aim to ensure water supply, protect the environment, and minimize the economic impacts. The decision-making body for issuing measures based on the drought plans is the Drought Commission, which operates at the regional level. The warning information is available on the HAMR web portal, which also displays local threshold limits for individual water resources.

INTRODUCTION

Droughts and floods are extreme hydrological phenomena that are a natural part of our environment. However, with the increasing impacts of climate change, the frequency of these phenomena is increasing and they can significantly affect our lives. It is essential to be prepared for changes in the temporal and spatial extent of extreme hydrological events in order to minimize their negative consequences [1–4].

Drought is considered a natural phenomenon and refers to a temporary decrease in water availability. It is characterized by gradual onset, long duration, and low dynamics. It often affects large areas. Although the immediate danger of drought is minimal compared to other hydrometeorological phenomena, notifying its status and development requires a specific ongoing approach.

The one of goal of the "*PERUN*" research project is to create a methodology for assessing the status and development of drought in the Czech Republic and to innovate the CHMI warning system. "*PERUN*" is Prediction, evaluation and research of the sensitivity of selected systems, the influence of drought and climate change in the Czech Republic; it is co-financed with the support of the Technology Agency of the Czech Republic. This article includes the assessment of drought in surface water and groundwater in order to meet the requirements of an amendment to the Water Act (Act No. 544/2020 Coll.).

Until 2021, there was no official warning system that would systematically and regularly warn of the emergence and further development of drought in the Czech Republic. The amendment to the Water Act introduced the obligation to provide regular information about drought and the introduction of a prediction service. According to this amendment, CHMI must inform regions and Municipalities with Extended Powers (MEP) in a clear and comprehensible manner about the risk of the occurrence and development of drought. This will then enable effective decision-making on possible measures. For the general public, this information must be integrated with the existing phenomena, but this is somewhat complicated due to the specific nature of this specific phenomenon.

According to the amendment to the Water Act, the key research activity is currently the creation of tools for long-term prediction of the status of water resources and the subsequent interpretation of the obtained data when planning measures for managing drought and water scarcity. At the beginning of 2023, the Ministry of Agriculture (MoA) and the Ministry of the Environment (MoE) issued a joint methodology [5], which includes procedures for creating plans for dealing with drought and water scarcity, developed at the regional level. During 2023, a national plan is being created. The aim of the both the national and regional plans is to ensure sufficient water for basic needs, protect the environment from the negative effects of drought, and minimize the economic impact of drought and water scarcity. The plan contains information on the identification of water resources, drought risks, and their possible impact. The main part of the plan includes drought management procedures and water scarcity measures.

The decision-making body for issuing measures based on drought plans in the event of water scarcity is the Drought Commission. The Drought Commission meetings are already taking place at the regional level, and CHMI representatives are also participating in them [6]. Warning information is available on the HAMR information system portal [7], which also shows the local threshold limits [8].

METHODOLOGY AND MATERIAL

HAMR

The development of the HAMR system tool [9] is financed by the MoE along with other activities dealing with the impact of drought, adaptation measures, monitoring, and climate change (more at www.suchovkrajine.cz). Drought is divided into meteorological, agronomic, hydrological, and socioeconomic. From this comes the very name of the HAMR (Hydrological, Agronomic, Meteorological, and Retention) system (*Fig. 1*). Each component is represented by a mathematical model based on physics (SoilClim [10], Bilan [11, 12], and Wateres [13]) and is subsequently evaluated according to the calculated indicators.

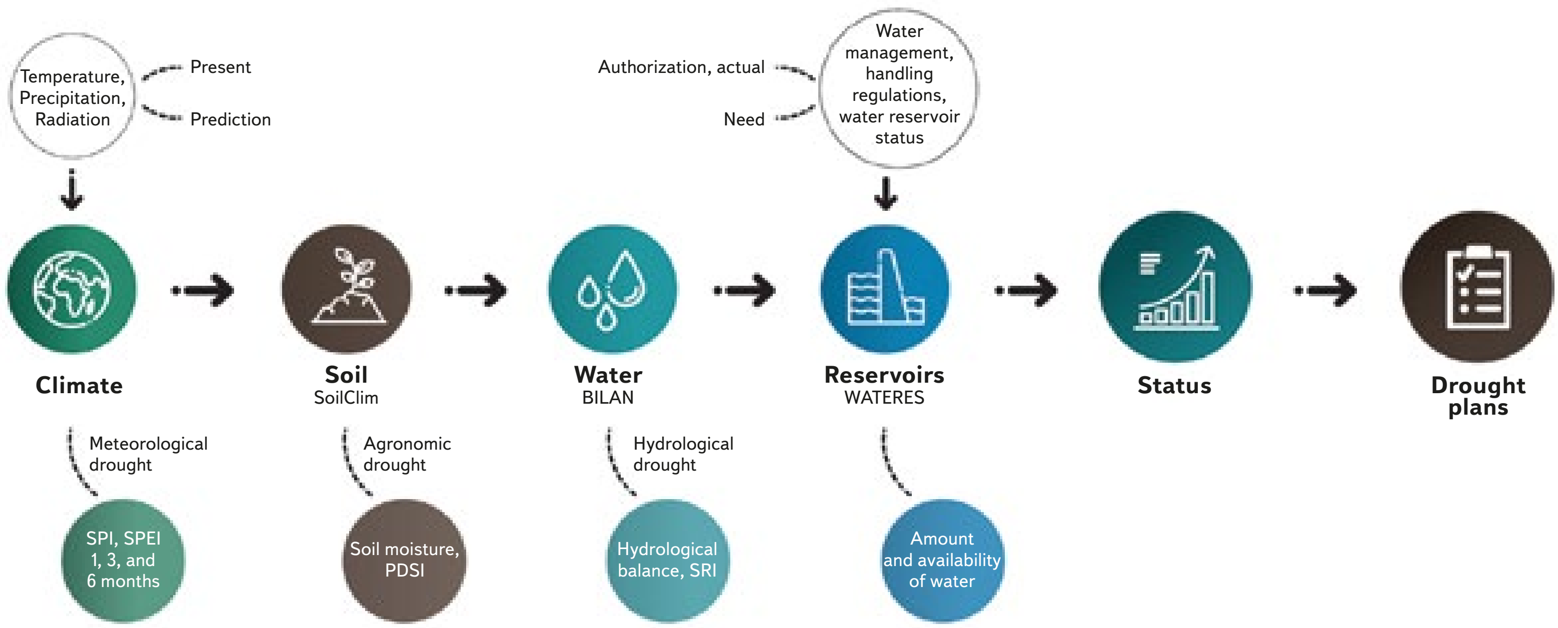


Fig. 1. HAMR system

In order to assess the current status and in particular to predict the development of drought in the Czech Republic, during 2022, a methodology was created at the CHMI, which includes predictions for three types of drought: drought in surface water; drought in groundwater; and hydrological drought (drought in both groundwater and surface water). Individual types of drought are identified for MEP territorial units [6].

Data for the warning system

135 reference discharge gauging sites (out of about 520) were selected for the evaluation of drought in surface waters according to the set criteria. The reference gauging sites were selected according to their representativeness for the relevant administrative MEP district. The aim was to select sites with a smaller catchment area, which better reflect the runoff conditions of the given MEP. Some reference sites are located in the territory of surrounding MEP, mainly due to less coverage by gauging sites with a smaller catchment area. Each MEP is assigned one reference gauging site, ideally within the given MEP. If there is no suitable site in the MEP, the most suitable site from the nearby area is selected. Some sites are thus representative of several MEP, especially in areas with a sparser river network.

Determining the risk of drought in surface waters is primarily based on the data of the reference gauging site assigned to the given MEP. However, values from surrounding reference sites and unaffected sites are also taken into account, especially in boundary situations where the flow-rate averages are close to the 355-day flow level (Q_{355d}) for 1991–2020 [6].

Assessing the risk of drought in surface waters is primarily based on the data of the reference gauging site assigned to the given MEP. Every week, average water bearing values in the reference gauging sites for the past week and the current hydrometeorological situation are taken into account. If mean daily discharges are predicted to drop to or below the Q_{355d} level, a surface water drought hazard is indicated for that MEP.

The resulting information on the danger of drought in the coming week in surface waters for the relevant MEP is created every Tuesday afternoon based on the synthesis of calculations and the expected hydrometeorological situation. This prediction is subsequently published on the HAMR system website in *Warning information* section in a separate map called „Surface waters".

The CHMI groundwater monitoring network, which includes 874 shallow wells, 440 deep wells, and 317 springs, is used to assess the drought in groundwater. Shallow wells measure the groundwater level in Quaternary sediments with a free water level, while deep wells measure the groundwater level of underlying structures without the influence of blanket formations. Springs represent the natural outflow of groundwater.

A set of 332 features were selected for drought assessment, of which 251 are shallow wells, 75 are deep wells, and 6 are springs. When selecting the features, location within the MEP and the monitored aquifer [6] were taken into account. Most features have been monitored since 1991. Each MEP has at least one assigned object, and if no suitable object was found in its area, the closest feature monitoring the same hydrogeological structure was selected. The average weekly level in the well or the average weekly yield of the spring is decisive for the assessment of drought. If the value for at least one feature falls below the 95% quantile for the reference period, the risk of drought in the MEP groundwater is indicated. The assessment takes place every Monday and the results are published on Wednesday in the „Groundwater" map in the HAMR system.

Local threshold limits

The local threshold limits (LTL) for water resources in order to prepare plans for managing drought and water scarcity [14] supplement the *Methodology for the preparation of plans for managing drought and the state of water scarcity*, which was issued by the MoA and the MoE in 2021. Planning measures for managing drought and water scarcity is the responsibility of the regional authorities according to Section 87c of the Water Act, in cooperation with the relevant basin managers and CHMI. LTLs are set for water resources that are important to a given region.

The LTL is reached when there is a high probability of insufficient yield or quality of the water resource due to drought, and at the same time there is a sufficiently long period of time before the resource will no longer be able to meet the needs of water users. LTLs are analogous to flood stages and serve to operationally implement drought management measures. LTLs can have multiple values throughout the year in accordance with the hydrological cycle and changing demands on water resources. They are derived from the moment when the resource fails to fulfil its function in relation to drought, either due to lack of water or poor quality.

LTLs complement information on the danger of drought provided by CHMI. They represent local information about the reaction of a specific water resource to an adverse hydrological situation. The methodology for drought plans describes a basic approach to determining LTL, and the handbook [14] contains examples for different types of water resources with different levels of input data detail. The aim of the handbook was to provide drought planners with possible approaches and inspiration in setting LTLs for the region's strategic water resources. However, it cannot take into account all the facts in the real environment, which is why individual developers of regional plans chose different strategies when determining the LTL, which are described in the plans themselves. The determination of the LTL of the water resource was to take place in cooperation with a consultation team that includes operators, water users, basin managers, regional authorities, writers of drought plans, and other relevant entities, in four steps [14]:

- Selection of key quantities with systematic monitoring of water resource functioning during long-term drought.
- Determination of the limit level of this quantity, which indicates exhaustion of the available amount of water in the resource or the limit for water treatment in connection with drought, at which all water requirements, including environmental requirements, cannot be ensured.
- Proposal of an advance of time for reaching the LTL, which is the period between exhaustion of the available amount of water in the resource or the limit for water treatment and the achievement of the LTL.
- Derivation of the level of the selected quantity that precedes exhaustion of the available amount of water in the resource or the limit for water treatment with a reasonable advance of time.

Data for local threshold limits are mostly provided by the CHMI or the operators themselves. This data is the basis for displaying the LTL in the HAMR system and is available on the system's website [8].

RESULTS

The resulting information (warning) on the status and development of the hydrological drought is generated every Tuesday afternoon by combining both types of drought for individual MEPs; it is visualized on a separate map in the HAMR system in the *Warning Information* section on Wednesday mornings. In the event that none of the mentioned types of drought is indicated for the respective MEP according to the reference profiles, these MEPs are coloured green on the resulting information map. If only one type of drought is indicated, either in groundwater or surface water, the respective MEPs are coloured yellow. If a dry period is indicated in both types of water (underground and surface), such an area is coloured orange in the resulting information map (*Fig. 2*). The MEP is then informed by e-mail.

As a supplement to the information system, a map (*Fig. 3*) was created comparing seven-day flow-rate averages in the reference gauging sites with M-daily discharges for the new reference period 1991–2020 for individual MEPs. This map serves as an indicator of the possible reaching of a drought level (Q_{355d}) in the near future, especially if the seven-day average flow-rate is near the 330-day flow level (Q_{330d}).

At the same time, this map clearly shows where low surface water levels have dropped so much that seven-day average water levels have fallen as low as Q_{364d}. This supplementary map is regularly created during Tuesday and published in the HAMR system on Wednesday morning at the latest, first in the *Warning information* section and then in the *Surface waters* section, where it is possible to display the average water bearing values for the previous week.

The determined local threshold limits are displayed in the HAMR application in the map window, where the current status is indicated, i.e., whether the LTLs are exceeded or not. The app displays LTLs for surface water, groundwater, and water reservoirs where LTLs are often set. Within the system, it is also possible to display time series of the selected quantities, if they are available. The LTL application was launched in September 2023 and is shown in *Fig. 4*.

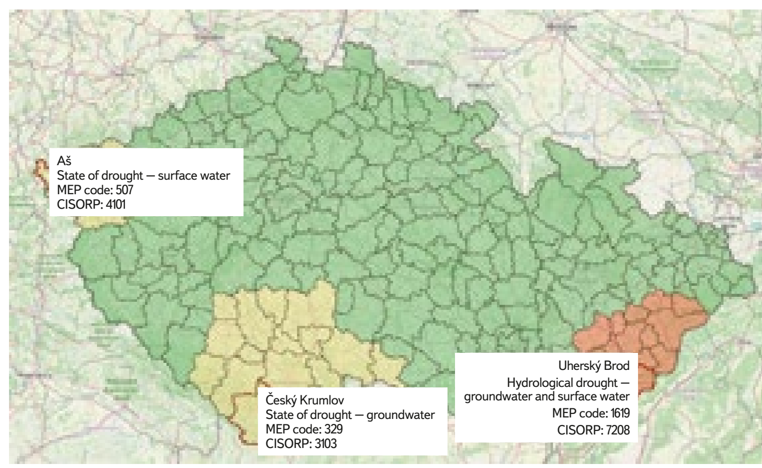


Fig. 2. Demonstration of drought prediction in the Czech Republic for Municipalities with Extended Powers [5]

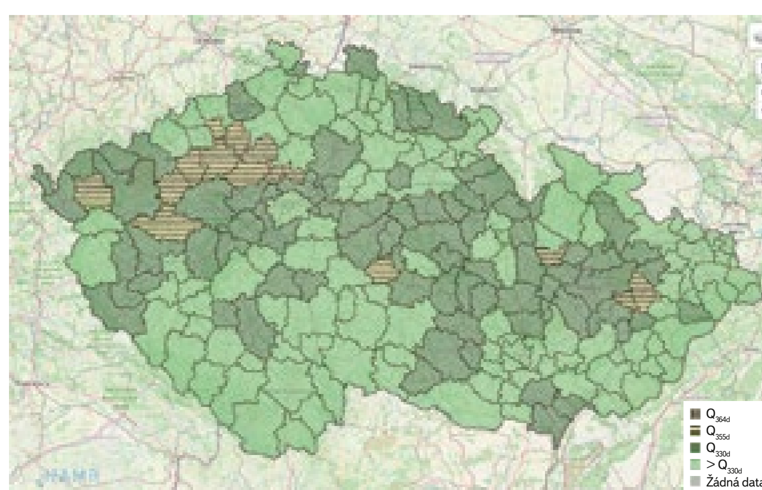


Fig. 3. Example of a complementary map of 7-day flow-rate averages in comparison to selected quantiles taken using flow duration curves of mean daily discharges, 1991–2020

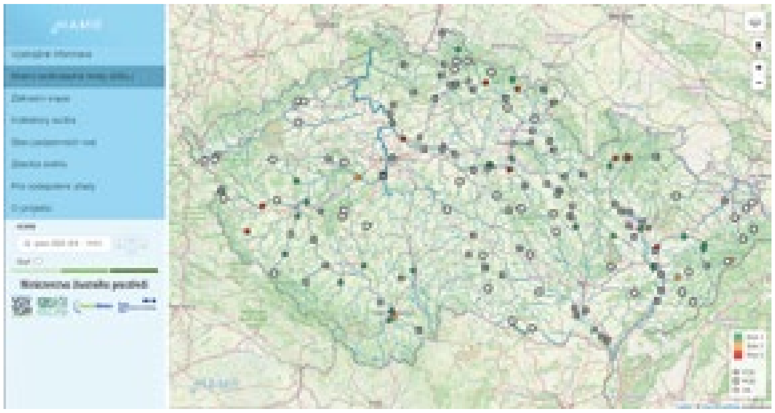


Fig. 4. Mapping application for displaying local threshold limits

CONCLUSION

Since September 2022, CHMI has been evaluating and predicting the status of hydrological drought in the Czech Republic every week. The outputs are fully available from the turn of September and October on the IS HAMR website in the *Warning Information* section. During the winter season 2022/2023, an evaluation took place of the test operation and verification of reference discharge gauging sites of surface water and groundwater features for individual MEP. Based on this testing, minor changes were made in the selection of representative features before the new growing season. The information system on the status and development of the drought in the Czech Republic was fully included in the CHMI operation from the beginning of the growing season in 2023. During September 2023, an application was launched in the HAMR system to display and evaluate the set local threshold limits for water resources, which are based on individual regional plans, prepared mainly in 2022.

Acknowledgements

This research was partially financed by the Technology Agency of the Czech Republic within the framework of the „Environment for Life" programme (Programme of applied research, experimental development and innovation in the field of the environment) and the project „PERUN (SS02030040) – Prediction, evaluation and research for understanding national sensitivity and impacts of drought and climate change for Czechia (https://www.perun-klima.cz/)".

References

[1] FISCHER, M., PAVLÍK, P., VIZINA, A., BERNSTEINOVÁ, J., PARAJKA, J., ANDERSON, M., TRNKA, M. et al. Attributing the Drivers of Runoff Decline in the Thaya River Basin. *Journal of Hydrology: Regional Studies*. 2023, 48, 101436.

[2] POTOPOVÁ, V., TRNKA, M., VIZINA, A., SEMERÁDOVÁ, D., BALEK, J., CHAWDHERY, M. R. A., MUSIOLKOVÁ, M., PAVLÍK, P., MOŽNÝ, M., ŠTĚPÁNEK, P., CLOTHIER, B. Projection of 21st Century Irrigation Water Requirements for Sensitive Agricultural Crop Commodities across the Czech Republic. *Agricultural Water Management*. 2023, 262, 107337.

[3] TRNKA, M., BRÁZDIL, R., VIZINA, A., DOBROVOLNÝ, P., MIKŠOVSKÝ, J., ŠTĚPÁNEK, P., HLAVINKA, P., ŘEZNÍČKOVÁ, L., ŽALUD, Z. Droughts and Drought Management in the Czech Republic in a Changing Climate. *Drought and Water Crises: Integrating Science, Management, and Policy*. 2017, pp. 461–480.

[4] MELIŠOVÁ, E., VIZINA, A., HANEL, M., PAVLÍK, P., ŠUHÁJKOVÁ, P. Evaluation of Evaporation from Water Reservoirs in Local Conditions at Czech Republic. *Hydrology*. 2021, 8(4), 153.

[5] MoE, MoA. *Metodika k přípravě plánů pro zvládání sucha a stavu nedostatku vody*, 2021. Available at: https://eagri.cz/public/web/file/679559/metodika_plan_sucho.pdf

[6] PECHA, M., ČEKAL, R., LEDVINKA, O., LAMAČOVÁ, A., VLNAS, R., VIZINA, A., GEORGIEVOVÁ, I., PAVLÍK, P. et al. Informační systém o stavu a vývoji sucha na území České republiky. *Meteorologické zprávy*. 2022, 75(6), pp. 165–169.

[7] https://hamr.chmi.cz/hamr-JS/vystraha.html

[8] https://hamr.chmi.cz/hamr-JS/msl.html

[9] VIZINA, A., HANEL, M., TRNKA, M., DAŇHELKA, J., GREGORIEOVÁ, I., PAVLÍK, P., HEŘMANOVSKÝ, M. HAMR: Online Drought Management System–Operational Management during a Dry Episode. *Vodohospodářské technicko-ekonomické informace*. 2018, 60(5), pp. 22–28.

[10] HLAVINKA, P., TRNKA, M., BALEK, J., SEMERÁDOVÁ, D., HAYES, M., SVOBODA, M., EITZINGER, J., MOŽNÝ, M., FISCHER, M., HUNT, E., ŽALUD, Z. Development and Evaluation of the SoilClim Model for Water Balance and Soil Climate Estimates. *Agricultural Water Management*. 2011, 98(8), pp. 1 249–1 261.

[11] MELIŠOVÁ, E., VIZINA, A., STAPONITES, L. R., HANEL, M. The Role of Hydrological Signatures in Calibration of Conceptual Hydrological Model. *Water*. 2020, 12(12), 3401.

[12] VIZINA, A., HORÁČEK, S., HANEL, M. Nové možnosti modelu Bilan. *Vodohospodářské technicko-ekonomické informace*. 2015, 57(4–5), pp. 7–10.

[13] GEORGIEVOVÁ, I., HANEL, M., PAVLÍK, P., VIZINA, A. Streamflow Simulation in Poorly Gauged Basins with Regionalised Assimilation Using Kalman Filter. *Journal of Hydrology*. 2023, 620, 129373.

[14] NESLÁDKOVÁ, M., PELÁKOVÁ, M. *Stanovení místních směrodatných limitů pro vodní zdroje k přípravě plánů pro zvládání sucha a stavu nedostatku vody: Pracovní pomůcka pro zpracovatele plánů pro zvládání sucha a stavu nedostatku vody podle § 87b až § 87d zákona č. 254/2001 Sb., o vodách a o změně některých zákonů*, 2021.

Authors

Ing. Adam Vizina, Ph.D.[1,2]
✉ adam.vizina@vuv.cz
ORCID: 0000-0002-4683-9624

Ing. Petr Pavlík [1,2]
✉ petr.pavlik@vuv.cz
ORCID: 0000-0002-6138-1156

Ing. Irina Georgievová[1,2]
✉ irina.georgievova@vuv.cz
ORCID: 0000-0002-5760-6471

Ing. Martin Pecha[3]
✉ martin.pecha@chmi.cz
ORCID: 0000-0003-0294-8981

Prof. Martin Hanel, Ph.D.[1,2]
✉ martin.hanel@vuv.cz
ORCID: 0000-0001-8317-6711

Ing. Martina Peláková[1]
✉ martina.peláková@vuv.cz
ORCID: 0000-0003-0485-1542

Prof. Miroslav Trnka, Ph.D.[4]
✉ mirek_trnka@yahoo.com
ORCID: 0000-0003-4727-8379

RNDr. Radek Čekal[3]
✉ radek.cekal@chmi.cz

Ing. Eva Melišová, Ph.D.[1]
✉ eva.melisova@vuv.cz
ORCID: 0000-0001-5677-2673

Ing. Radek Vlnas[3]
✉ radek.vlnas@chmi.cz
ORCID: 0009-0008-1196-6261

[1]T. G. Masaryk Water Research Institute, Prague
[2]Czech University of Life Sciences, Prague
[3]Czech Hydrometeorological Institute, Prague
[4]CzechGlobe – Global Change Research Institute of the Czech Academy of Sciences, Brno

This article was translated on basis of Czech peer-reviewed original by Environmental Translation Ltd.

DOI: 10.46555/VTEI.2023.07.004

Photo: 123rf.com

Protected areas for surface water accumulation from a hydrogeologist's the point of view – the effect of possible realization of surface water accumulation on hydrogeological conditions

JIŘÍ PRINZ, PAVEL ECKHARDT, ROMAN KOŽÍN

Keywords: water resources – surface water accumulation – potable water supply – hydrogeology – groundwater level – GIS

ABSTRACT

Suitable areas for the accumulation of surface water have been defined in the Czech Republic, potentially serving mainly for the supply of potable water and for mitigating the adverse effects of floods and drought. The sites are listed in the General Scheme on the Accumulation of Surface Water, which was obtained by the Ministries of Agriculture and the Environment following the previous long-term territorial protection of prospective water reservoirs. Before any decision to build these reservoirs, it is necessary to assess the project from various points of view. This article presents an evaluation of selected sites from a hydrogeological point of view. Among other things, it deals with the analysis of the location of potential reservoirs in the hydrogeological environment, the effect on the quantity and quality of groundwater, and the potential impact on the used groundwater resources. After the construction of the reservoirs, the groundwater level of the shallow aquifer will rise, and consequently, groundwater storage will also increase. However, it is necessary to assess the sites individually; there are often potentially negative effects of future reservoirs on groundwater.

INTRODUCTION

Surface water accumulation, whether natural or artificially constructed, have a significant effect on the circulation of groundwater in their vicinity. An increase in the level of the erosion base leads to a rise in the groundwater level in the vicinity of a reservoir – at a greater extent above the reservoir dam. The presented article deals with the potential influence of the areas defined in the General Scheme on the Accumulation of Surface Water [1] (hereinafter referred to as General LAPV) on hydrogeological conditions and groundwater resources. Currently, 96 sites are protected by the General LAPV. The development of the number of protected areas for surface water accumulation (LAPV) and their potential for mitigating the effects of climate change is summarized, for example, by [2, 3]. General LAPV is the basis for the proposal of the territorial development policy and spatial planning documentation. It is not a plan for the construction of water reservoirs, but a basis for spatial planning, so as not to prevent or substantially complicate any implementation in the future [1].

The aim of the article is to inform about the treatment of LAPV hydrogeological issues within the Research Project SS02030027 – *„Water systems and water management in the Czech Republic in conditions of climate change (Water Centre)"*. In this phase, basic hydrogeological data ('passports') on individual sites are being processed. This paper presents three examples of sites for different hydrogeological environments. Due to the difficulty in preparing any future reservoirs, a more detailed survey will only be undertaken in the event of a decision on their actual construction. Mathematical modelling, regime measurement, and geophysical survey can be used as appropriate tools for assessing the influence of valley reservoirs. A detailed geological survey would then take place before construction itself.

GIS tools [6] with available basic data on the location of these areas are a suitable tool for the preliminary assessment of selected sites and the acquisition of data for deciding on the possible implementation of a hydraulic structure. As part of the *„Water Centre"* project, spatial data and basic data are obtained for each site; at some of the sites, flow and other parameters are monitored.

Location of LAPV from a hydrogeological point of view

Protected areas for surface water accumulation (LAPV) were initially selected mostly on the basis of criteria other than the hydrogeological ones. For example, the morphological point of view (possibility of an effective construction of a dam) was important, which is, however, closely related to geological conditions. An overview of the hydrogeological situation of the LAPV location in the Czech Republic is shown in *Fig. 1*.

More than half of the Czech Republic (about 57 %) is made by hydrogeological massif [4]. It includes crystalline rocks, as well as sediments of the Proterozoic and older Palaeozoic, and Culm rocks. They usually only have a limited circulation of groundwater, mainly tied to the sub-surface layer of the Quaternary cover and semi-open bedrock. The vast majority of LAPV (80 %) is located within the hydrogeological massif. Therefore, the percentage representation of LAPV in the massif

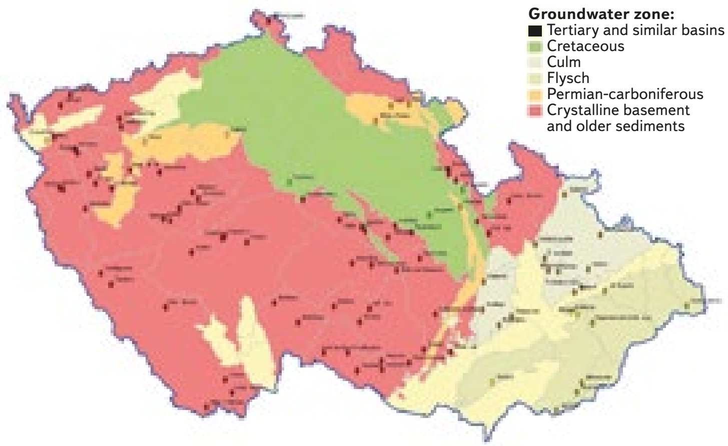


Fig. 1. Groups of hydrogeological regions of the base layer of the Czech Republic with the location of protected areas for surface water accumulation (according to Decree No. 5/2011 Coll.)

significantly exceeds its areal extent. LAPVs have been delineated in both crystalline and older Palaeozoic or Culm rocks. For example, over 14 % of all sites are found in Culm rocks. A total of 76 sites for reservoirs with an average volume of 21.2 million m^3 (with an average dam height of 38 m) and a total catchment area of 8,715 km^2 have been selected in the hydrogeological massif.

In the Bohemian Massif, solid carbonate rocks also occur, especially limestone and crystalline limestone, which, in addition to fissure permeability, often have karst permeability. These tend not to be suitable for reservoir locations due to the possible leakage of water through karst systems. Thus, there are no LAPVs in these rocks.

The rocks of the flysch zone of the Western Carpathians also have the character of a hydrogeological massif; they form a strip of land along the eastern border of the Czech Republic and cover over 8 % of the country. 8 % of LAPV sites were proposed here, which corresponds to the spread of these rocks in the Czech Republic. In total, eight reservoir sites have been selected here, with an average volume of 8.7 million m^3 (with an average dam height of 31 m) and a total catchment area of 251 km^2.

In a smaller number of the sites, the subsoil is made up of sedimentary rocks, which, in addition to the majority of fissure permeability, also have pore permeability. In the case of the reservoir construction and in the longer term, there will be an increase in static groundwater supply in the vicinity of these sites. The impact of valley reservoirs will be mostly local, caused by an increase in the erosion base above the dam.

Permian-carboniferous basins and occurrences occupy an area of about 5.8 % of the Czech Republic. In addition to fissure permeability, Permian-carboniferous rocks also have pore permeability. 6 % of LAPV sites are located on these rocks, which corresponds to the widespread distribution of this hydrogeological environment. In total, six sites for reservoirs have been selected in the Permian-carboniferous rocks, with an average volume of 6.8 million m^3 (with an average dam height of 26 m) and a total catchment area of 251 km^2.

In terms of water management, the Czech Cretaceous Basin is the most important hydrogeological structure in the Czech Republic. Although it covers over 15 % of the country, only 3 % of LAPV was located in the groundwater zones of the Czech Cretaceous Basin. At the other five sites, the Cretaceous groundwater zones are affected by the protected area marginally (LAPV Doubravčany, Hořička, Ostružno, Rychmburk, and Albrechtice). The significantly lower suitability of this structure for LAPV is caused, among other things, by morphological conditions, the high permeability of the rocks, and the existence of important sources of (ground)water. The construction of reservoirs could therefore be aimed at the artificial infiltration of surface water into the rock environment instead of creating surface water accumulation (e.g. [7]). In total, three sites for reservoirs have been selected in the Czech Cretaceous Basin, with an average volume of 13.6 million m^3 (with an average dam height of 27 m) and a total catchment area of 458 km^2.

In the rocks of the Cenozoic basins (with Tertiary and Upper Cretaceous filling), LAPVs are very sporadic, partly for similar reasons as in the Czech Cretaceous Basin. Neither the South Bohemian basins nor the Mostecká (North Bohemian) and Sokolovská basins have any defined LAPV. It should be noted that the large water bodies created in recent decades in the Mostecká and Sokolovská basins are not LAPV, but are formed by flooding of surface mines. One LAPV site is linked to the Tertiary Cheb basin (more detail in *Fig. 4*); the same applies for the Vídeňská basin. Only two LAPV sites are linked to Tertiary filling regions of the Carpathian depression (Blazice and Radkovy). In total, three sites for reservoirs have been selected here, with an average volume of 11.8 million m^3 (with an average dam height of 23 m) and a total catchment area of 79 km^2.

Quaternary sediments on the surface represent the most widespread geological unit in the Czech Republic. Particularly in the case of hydrogeologically important accumulations of highly permeable Quaternary sediments, these areas were separated into groundwater zones of the upper layer. Only at two LAPV sites do the floodplains of the reservoirs extend into the upper groundwater zone of the Quaternary sediments (Tuřany in the Ohře basin and Rybník water reservoir in the Odra basin). The influence of these valley reservoirs on groundwater circulation will be positive. Due to the higher permeability of the rock environment, there can be a relatively intensive spontaneous infiltration of surface water into groundwater and an increase in the groundwater level in the vicinity. However, an increase in the groundwater level can also have negative effects, such as the emergence or increase of the risk of slope instability and waterlogging of agricultural land.

Municipalities affected by drought and LAPV

Approximately one third of the LAPV was defined in the cadastral area of municipalities affected by drought, where the possible construction of water reservoirs could contribute to improving the situation. *Fig. 2* shows the map of LAPV and municipalities affected by drought..

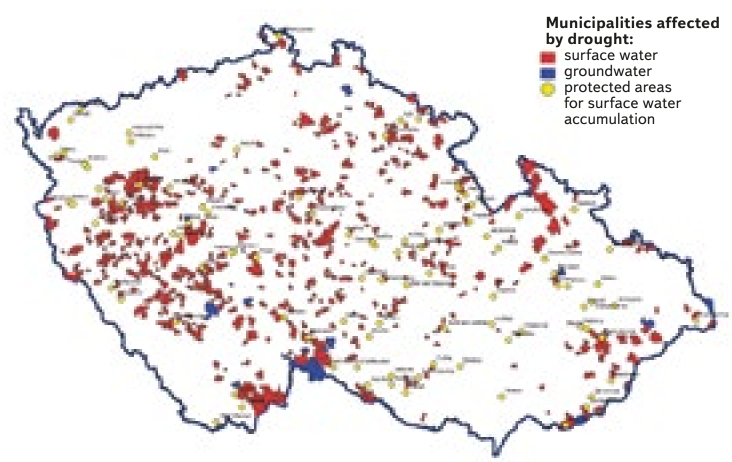


Fig. 2. Cadastral area of municipalities affected by drought from the point of view of potable water supply (issue in the entire municipality) in the Czech Republic with LAPV sites (HEIS, 2020)

The map in *Fig. 2* clearly shows that issues occur mainly in connection with groundwater. Therefore, it is also necessary to address the question of whether and to what extent the implementation of LAPV reservoirs could contribute to improving the quantitative state of groundwater in times of drought, as well as its possible use by municipalities.

In sites of hydrogeological massif, where a substantial part of the LAPV is located, usually only the shallow groundwater cycle of groundwater from the collection facilities is used. The most abundant ones are often located near watercourses. In recent years, as the demand for local resources for municipalities and individual houses has increased, the number of deeper hydrogeological wells that use groundwater from the fissure system has also increased. The influence of valley reservoirs on groundwater circulation will mostly be significant only within the framework of shallow groundwater cycle.

General hydrogeological changes caused by construction of water reservoirs

From a general point of view, when a surface water reservoir is built and filled, the groundwater level of a shallow aquifer in a given area increases.

Groundwater storage is created by the infiltration of rainwater and its accumulation in the rock environment. In places of erosion base, the rock environment is naturally drained into surface streams. By changing the height level of the erosion base, e.g. by building a hydraulic structure, the runoff conditions will change. In the case of suitable conditions, partial infiltration of surface water into groundwater can occur.

By building dams and flooding the floodplain of watercourses, the level of groundwater and surface water will be connected, however, with a certain delay depending on the distance from a water reservoir.

In general, we can say that the construction of a hydraulic structure and its flooding will have a positive effect on the groundwater status both above the dam (by raising the level of the shallow groundwater cycle) and below the dam (by stabilizing surface runoff). Previous experience shows that even a small increase in the surface water level (e.g. by building a weir [5]), has a positive effect on the increase in the groundwater level in the watercourse vicinity.

The yield of natural groundwater resources will remain similar because permeability is determined by the nature of the rock environment. However, the possible accumulation of surface water will – under suitable conditions – fulfil the function of an additional water source (for infiltration of precipitation) by surface water overflowing into groundwater.

Mathematical modelling can also be used for a comprehensive evaluation of changes in the groundwater flow regime after the hydraulic structure construction. It is also possible to simulate different modes of future use with a mathematical model. The groundwater flow model, together with the rainfall-runoff model, will create a comprehensive picture of the effect of a hydraulic structure on water cycle in the given site. However, the processing of mathematical models is time- and financially demanding, and together with the necessity of updating for changing climatic conditions, it is advisable to proceed to this step only after the decision on implementation of the hydraulic structure has been made.

Examples of individual LAPVs and their specific hydrogeological issues

LAPVs were spatially defined and given basic characterization. As part of basic data collection of individual sites, in addition to the basic geological and hydrogeological conditions, the area protection, groundwater resources, and possible risks were identified and briefly described. Some of them are subject to hydrological monitoring – measurement of flows and conditions on watercourses. In order to capture the specific hydrogeological issues of individual LAPVs, steps were taken to compile hydrogeological passports. An example of such a passport is shown in *Fig. 4*. In the following text, we present three examples of LAPV in different hydrogeological environments and their selected specific hydrogeological issues.

Example of LAPV in hydrogeological massif – Pěčín on the river Zdobnice

The most common hydrogeological environment where LAPVs are located is hydrogeological massif. The groundwater cycle here is mainly tied to the zone of sub-surface semi-opening of bedrock and Quaternary sediments. An example of LAPV in a hydrogeological massif is Pěčín on the river Zdobnice, in Orlické mountains. Pěčín reservoir is designed, among other things, to supply the inhabitants of the Hradec Králové region with potable water. In the case of Pěčín, a more detailed geological survey focused on the construction of a water reservoir had already been carried out in the 1980. As part of the filling of the reservoir, groundwater level of the shallow aquifer will rise in the now unsaturated backwater area and in its surroundings, and thus groundwater storage will also increase [8].

One of the attractions of LAPV Pěčín is the old mine works (*Fig. 3*) and the planned tailings heaps at the bottom of the future reservoir. Despite documented (sporadic) occurrence of sulphide ore minerals on these heaps, these old environmental loads should not threaten surface water quality of the planned reservoir.

Fig. 3. Adit (exploration gallery) in Zdobnice valley (LAPV Pěčín)

Example of LAPV basic data on Tertiary and Quaternary sediments – Tuřany in the Cheb basin

LAPVs are located only very rarely in Tertiary sediments and Quaternary zones of the upper layer. An example of such a site is Tuřany on the Šitbořský stream in the Tertiary Cheb basin.

The high permeability of Quaternary sediments in particular when the area is flooded after the construction of the planned reservoir can cause intensive infiltration of surface water into groundwater and their outflow outside the site of interest. Hydrogeological details of the site are given in the hydrogeological passport in *Fig. 4*.

Site name: **Tuřany**
Watercourse: **Šitbořský potok**

Groundwater zone – number: 2110
Groundwater zone – name: Cheb basin
Morphology, width of the valley floodplain: Shallow valley – the dam will completely flood the floodplain sediments

Geological and lithological characteristics

The predominant rock type in the site is the sedimentary rocks of the Cheb basin. There are lacustrine sediments of the cypress formation: claystones, clays and pelagic carbonates, sands in the coastal zone. They are followed by sedimentary sequence of the Wildstein Formation, from clays to sands and gravel-sands at the end of the youngest stage. Relics of river terraces (Mindel-Riss age) are preserved here. The Quaternary cover consists of a layer of fluvial and deluvio-fluvial sediments, with a thickness of up to 6 m in the vicinity of a watercourse. East of the Šitbořský stream, there are loess and loess loam in the overlying rock of Neogene sediments.

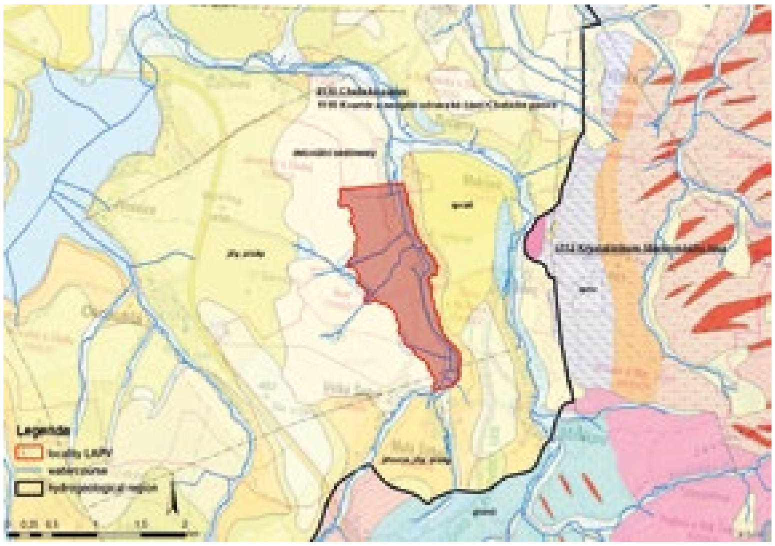


Fig. 4. An example of a hydrogeological passport of a locality LAPV (Tuřany in Cheb basin)

The site on a geological map (Source: mapy.geology.cz), including groundwater zones:

Tectonics

The most significant tectonic fault in the vicinity is the Mariánské Lázně complex, running about 1,500 m east of the Šitbořský stream in a north-south direction. At the southern end of the predicted floodplain, a fault runs in a SW-NE transverse direction.

Hydrogeological characteristics

The site is located in the groundwater zone of the base layer 2110 Cheb basin and the groundwater zone of the upper layer 1190 Quaternary and Neogene of the Odravian part of the Cheb basin. The sedimentary sequence of the Cheb basin creates conditions for the alternation of insulators and flow collectors, especially in the sediments of the Wildstein Formation, $T = 2 \times 10^{-4}$ to 1×10^{-3} m^2/s. The sediments of the cypress formation form a regional insulator, but in the Cheb basin, in contrast to the Sokolov basin, they are more permeable, $T = 5 \times 10^{-5}$ to 3.5×10^{-3} m^2/s. In the vicinity there are spatially limited, pore permeable collectors tied to river terraces, $T = 1 \times 10^{-4}$ to 1×10^{-3} m^2/s. The direction of groundwater outflow is northwest to north – to the erosion base formed by the Ohře.

Groundwater collection

Groundwater resources in the immediate vicinity of the site are not registered. The site is located in the Nebanice 2nd degree protection zone for vulnerable water resource. Its collection facilities are located on the opposite bank of the Ohře, so their influence is improbable. Building a water reservoir will increase the groundwater level in the vicinity and infiltration into the permeable layers of the rock environment.

Verification of the presence of old environmental loads

In the Šitbořský stream basin and its tributaries, two sites are recorded that can negatively affect groundwater and surface water quality. The first is a former petrol station in the village of Malá Šitboř (risk of oil pollution) and the second is an agricultural facility south of the village of Tuřany (risk of oil pollution). Both sites are registered in the Contaminated Sites Registration System database (SEKM).

Verification of protective zones of water resources, protection areas, geohazards, undermining

The site is located in the protection zone of natural healing resources: IIb – Františkovy Lázně and Mariánské Lázně, and in the protection zone of groundwater resources of the 2nd degree – Nebanice underground resource. The site is a part of the Cheb basin and Slavkovský les protected area of natural water accumulation. Along the eastern edge of the site runs the boundary of the PLA Slavkovský les. The southern edge of the site adjoins an area with a high radon index, there are also old mines for the exploration of radioactive raw materials. In the vicinity of the site and also on the banks of the Jesenice water reservoir, slope instabilities appear, the area falls into the territory of the medium class of landslide susceptibility.

Summary

Šitbořský stream currently mainly has a discharge effect on shallow groundwater cycle. The dam will cause a local rise in the groundwater level below the reservoir and in the immediate vicinity. Consequently, in places where there is a collector with a free water level and an unsaturated zone above the groundwater level, the groundwater supply will increase locally. After the situation stabilizes, it can be assumed that surface water will infiltrate into the permeable layers of gravel-sand of the river terraces, or sand layers of Neogene sediments. In the vicinity of the dam, surface water infiltration and groundwater discharge will occur below the dam.

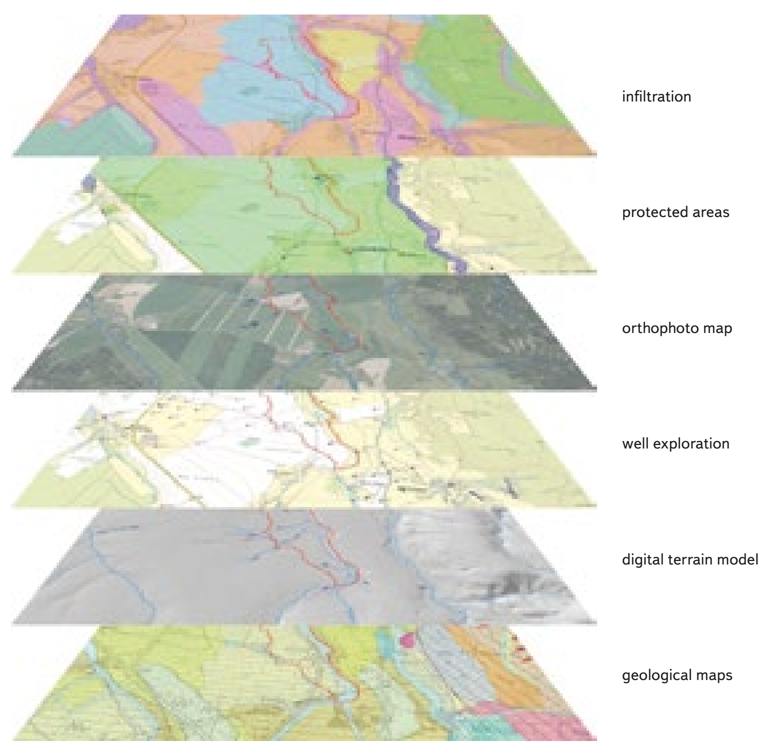


Fig. 5. An example of a possible summary of data on map for a location LAPV Tuřany (Data source: HEIS, Czech Geological Survey, The Ministry of the Environment and The Ministry of Agriculture of the Czech Republic, Cenia, etc.)

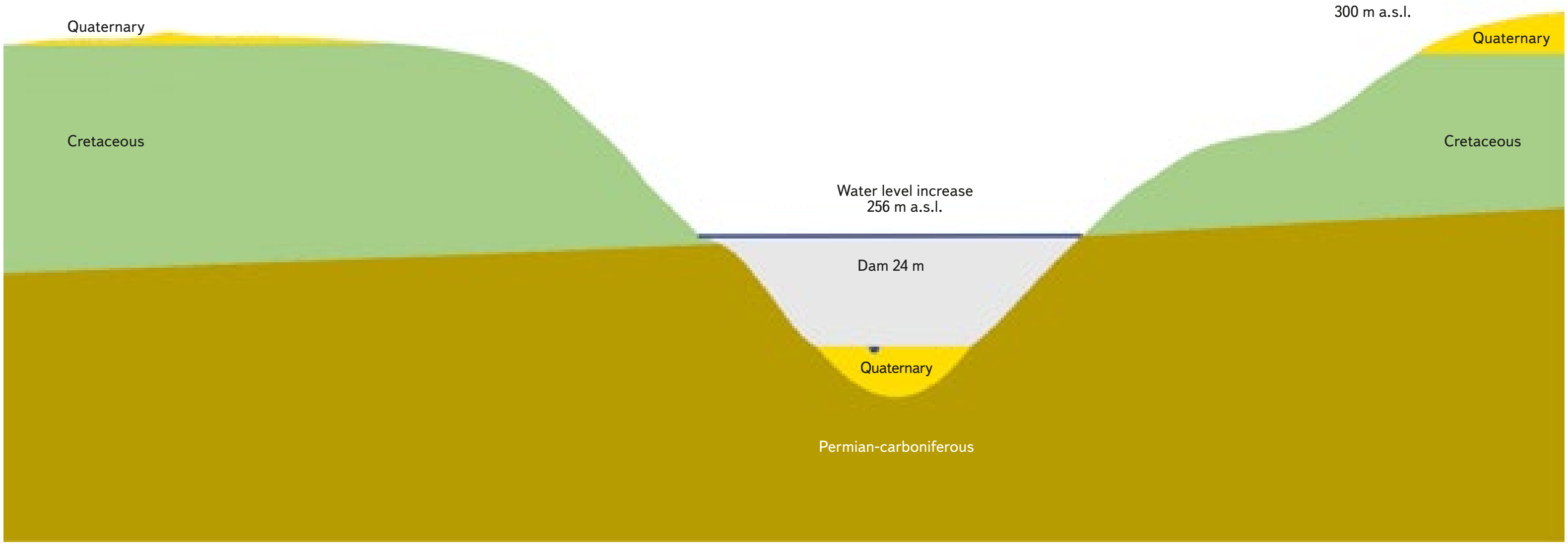


Fig. 6. Schematic geological exaggerated section of locality LAPV Tuchoraz, Šembera stream

An example of LAPV on Permian-carboniferous and Cretaceous sediments – Tuchoraz on the Šembera stream

The classification of individual LAPVs into groundwater zones sometimes does not fully correspond to the real hydrogeological environment. An example can be LAPV Tuchoraz on the Šembera stream in the Central Bohemian region. The Tuchoraz site belongs to the Cretaceous region 4350. In reality, however, the subsoil of the reservoir bottom will consist mainly of Permian deposits, covered at the surface by Quaternary sediments. Only the marginal higher side parts of the bottom when the reservoir is fully filled will be formed by the sediments of the Czech Cretaceous Basin (*Fig. 6*).

In the Šembera valley, in the potential area of the LAPV backwater, there are three important collection areas for supplying municipalities with potable water, and this is a more general issue. More significant groundwater collections are usually located in the valleys of watercourses, as there are often significantly more favourable conditions for these collections. Usually, there is the highest thickness of highly permeable fluvial Quaternary sediments. The valleys of watercourses tend to be tectonically predisposed, and their bottoms therefore tend to have stronger permeability due to the tectonic disruption of bedrock. There is a more or less constant groundwater level shallow below the terrain. Last but not least, in this environment, there is the possibility of improving the collection of groundwater by bank infiltration from the watercourse.

Groundwater collection facilities at the reservoir site will disappear. Due to the fact that the filling of the hydraulic structure with water will mostly flood the entire valley floodplain and the area where fluvial sediments occur, it will be possible to build potential collection facilities outside the zone of surface water spillage; i.e., either below the hydraulic structure dam or higher up along the watercourse. Building the reservoir close to municipalities dependent on groundwater resources from a shallow aquifer in backwater area may cause the need for accompanying investments in water management infrastructure, or even a total reconstruction of the supply network.

DISCUSSION

The construction of water reservoirs will lead to local changes in the regime of both surface water and groundwater. Groundwater circulation will be affected especially in the shallow horizon, which mainly includes Quaternary sediments deposited along watercourses. The spatial limitation of the influence of surface water accumulation on groundwater will depend on the character of the rock environment, especially on its permeability.

A significant part of the LAPV is located in an environment where the most suitable site for the location of a used groundwater source is the environment of fluvial sediments along watercourses. Building a dam and filling the reservoir will lead to the disappearance of any used groundwater resources (wells, etc.) in the extent of the flooded area; on the other hand, the conditions for the use of groundwater resources will improve in the vicinity of the reservoir.

By increasing the level of the erosion base, a more extensive fissure system can be connected in the hydrogeological massif, thereby improving the conditions for the use of individual groundwater resources in these areas.

The direct effect of surface water accumulation on groundwater quality will not be significant. The risk of groundwater contamination will remain essentially the same; however, a thorough survey of flooded areas must be carried out to prevent flushing out old landfills, mine waste dumps, etc.

We assume that if the surface water accumulation is implemented, the positive effect on the water management use of groundwater resources will prevail due to the onset of the water level and the increase in groundwater storage.

The discharge of municipal wastewater in particular has a significant effect on the quality of surface water and, subsequently, on the quality of groundwater. The effect of wastewater discharge on groundwater in individual cases will decrease, for example, due to the retention of surface water and other self-cleaning processes in the reservoir (e.g., reduction of faecal bacteria), as well as due to the stabilization of the outflow and the maintenance of a minimum flow below the reservoir during the year, and thus maintaining the dilution ratio.

CONCLUSION

Reservoirs constructed in LAPV areas will stabilize and equalize runoff and create groundwater storage. Their importance will grow with the predicted manifestations of climate change in the future.

However, it is necessary to assess the expected positive effect of LAPV reservoirs in detail for each site. On some LAPVs, the negative effects may prevail – for example, in places where groundwater resources for supplying municipalities

Fig. 7. Groundwater pumping facility in Šembera alluvial plain (LAPV Tuchoraz)

Fig. 8. Piped water flow/melioration in Šitbořský stream valley and the bottom of the future reservoir (LAPV Tuřany)

are located in the valley floodplains of watercourses, and the accumulation of surface water could lead to the disappearance of these resources.

Acknowledgements

The article was created on the basis of research carried out as part of the project "Water systems and water management in the Czech Republic in conditions of climate change (Water Centre)" – SS02030027).

References

[1] MoA and MoE: *Generel území chráněných pro akumulaci povrchových vod a základní zásady využití těchto území*. Prague, August 2020.

[2] VIZINA, A., VYSKOČ, P., KOŽÍN, R., NOVÁKOVÁ, R. Potenciál chráněných území pro akumulaci povrchových vod pro zmírnění dopadu klimatické změny na zásobování pitnou vodou. *Vodohospodářské technicko-ekonomické informace*. 2023, 65(1), pp. 32–41. ISSN 0322-8916.

[3] KOŽÍN, R., HANEL, M., KAŠPÁREK, L., PELÁKOVÁ, M., VIZINA, A., TREML, P. Možnosti zmírnění dopadů změny klimatu využitím území chráněných pro akumulaci povrchových vod. *Vodohospodářské technicko-ekonomické informace*. 2015, 57(4–5), pp. 11–16. ISSN 0322-8916.

[4] KRÁSNÝ, J. et al. *Podzemní vody České republiky. Regionální hydrogeologie prostých a minerálních vod*. Prague: Czech geological survey, 2012. 1 144 pp.

[5] KANDRÍK, R., VIDO, J., CHRIAŠTEĽ, R. Vliv výstavby jezu v lokalitě Abovce (Slovensko) na hladinu podzemních vod – případová studie v povodí Slané. *Vodohospodářské technicko-ekonomické informace*. 2023, 65(1), pp. 24–30. ISSN 0322-8916.

[6] FOJTÍK, T., JAŠÍKOVÁ, L., KURFIŘTOVÁ, J., MAKOVCOVÁ, M., MAŤAŠOVSKÁ, V., MAYER, P., NOVÁKOVÁ, H., ZAVŘELOVÁ, J., ZBOŘIL, A. GIS and Cartography at TGM WRI, *Vodohospodářské technicko-ekonomické informace*. 2022, 64(1), pp. 47–52. ISSN 0322-8916.

[7] HRKAL, Z. et al. *Zpracování metodiky pro posuzování problematiky umělé infiltrace v ČR DU4. Návrh pilotních lokalit*. Prague: MS TGM WRI, 2010.

[8] MORAVEC, M., VALDHANS, J. *Studie: Zdobnice, Pěčín, výstavba přehradní nádrže – předprojektová příprava – 1. etapa*. Prague: Společnost SHDP + VRV Sweco Hydroprojekt a. s., 11/2017.

Authors

Mgr. Jiří Prinz
✉ jiri.prinz@vuv.cz

Mgr. Pavel Eckhardt
✉ pavel.eckhardt@vuv.cz
ORCID: 0000-0002-4218-5344

Ing. Roman Kožín
✉ roman.kozin@vuv.cz
ORCID: 0000-0002-5773-6567

T. G. Masaryk Water Research Institute, Prague

This article was translated on basis of Czech peer-reviewed original by Environmental Translation Ltd.

DOI: 10.46555/VTEI.2023.07.003


Photo: J. Unucka

Study of stream morphological changes and its application in the design of environmentally acceptable channels

PETR SKLENÁŘ

Keywords: open channel flow — 3D scour — bed and bank erosion — fluvial processes — energy dissipation — design of channel renaturation

ABSTRACT

Climatic change is manifested in a number of places by significantly spatially localized torrential rainfall with a short duration, but with great intensity. One of the expected consequences of this type of precipitation is the occurrence of flash floods, characterized by a sharp rise from the value of the normal flow to the value of the peak flow and a rapid decrease again. The consequence of this type of short episodic floods is the initiation of morphological transformations in the beds of smaller and medium upland streams, often with devastating effects for the section of the watercourse channel. The article summarizes research on the formation and development of a scour hole in the section at the transition from a lined riverbed with fixed bed and banks to the riverbed with loose channel boundry which can be transformed morphologically in an uncontrolled manner. In this research, the main attention was paid to the formulation of a parametric model of the scour hole morphological development at the transition between a lined and an unlined channel. The results of this model can be used both to understand the hydraulic-morphological processes that occur at the site of a sudden river bed change, and for the practical design of restoration modifications to the river bed at the transition from a fully lined to an unlined river bed without any protective measures, approaching the original pristine conditions.

INTRODUCTION

Riverbed restoration is one of the adaptation measures in the field of reducing the impact of drought on the water regime in the landscape. These adaptation measures are among the main topics of the research activity of the project SS02030027 *„Water systems and water management in the Czech Republic in conditions of climate change (Water Centre)"*. This is mainly the area of draft measures leading to the reduction of flood risks with a focus on aspects of the influence of climate change on floods. This also includes research into the impact of climate change on ecosystems and the reduction of the consequences of anthropogenic influence on aquatic and water-related environments and the creation of conditions for improving protection of ecosystems. Nowadays, watercourse channel restoration is perceived on a narrower hydromorphological scale as a set of measures that enable the formation of a channel in the presence of a wide spectrum of channel-forming, primarily fluvial, processes. These processes also include the creation of hydraulic current structures in watercourse channels – for example, current contraction and expansion, the formation of wakes with the presence of vortices with a vertical axis, and the formation of a hole with a horizontal axis as part of a hydraulic jump. Furthermore, erosion, transport and sedimentation processes arise, which are linked to the previous hydraulic phenomena. They depend on the geomechanical properties of the material in which the channel is transformed and on the stability of the banks, which with their malleability significantly contribute to the variable geometry of the channel. When designing restoration modifications, it is advisable to base it on knowledge and observations of successional processes involved in the channel transformation. Significant morphological changes can be observed in field conditions during flash floods and after them, where morphological changes have a significantly accelerated course. Furthermore, morphological changes can be observed during targeted physical research in laboratory conditions, in which the process can be monitored and evaluated in more detail, but should, if possible, be verified for conditions that are as close as possible to real river channels. In this paper, the author focuses on the creation and development of a 3D scour, often called a „pear" due to its characteristic shape, which is created at the transition between a lined and open channel. This also corresponds to the restoration of watercourses in the past, marked by continuous amelioration, during which lining was removed in entire sections of a channel.

Investigation of a scour hole in the transition zone of an open channel

The issue of stabilization of an open channel in its expansion has already been dealt with by a number of authors, e.g. [3, 7]. Research at WRI Bratislava [3], which in its character was probably closest to this 3D scour hole study, was the first to adopt the working designation „pear" for this morphological object on a watercourse (*Fig. 1 right*). Although the research was carried out on a model of a „pear" type in several shape alternatives (including taking into account the influence of sediment transport from the upper parts of a watercourse), hydrotechnical methodology was not given, just general recommendations for the construction of these objects.

The author's own research project, dealing with morphological changes in small, relatively steep upland streams under high flows, was carried out in two stages:

1. Field investigation with monitoring the river channels' reaction to natural or artificially induced morphological changes. The aim of this stage was to perform a qualitative description of the changes.
2. Laboratory model experiments, which were focused on the design of a quantitative model of morphological transformations with the ability to predict the morphological response of the river channel when using environmentally friendly and cost-effective restoration measures.

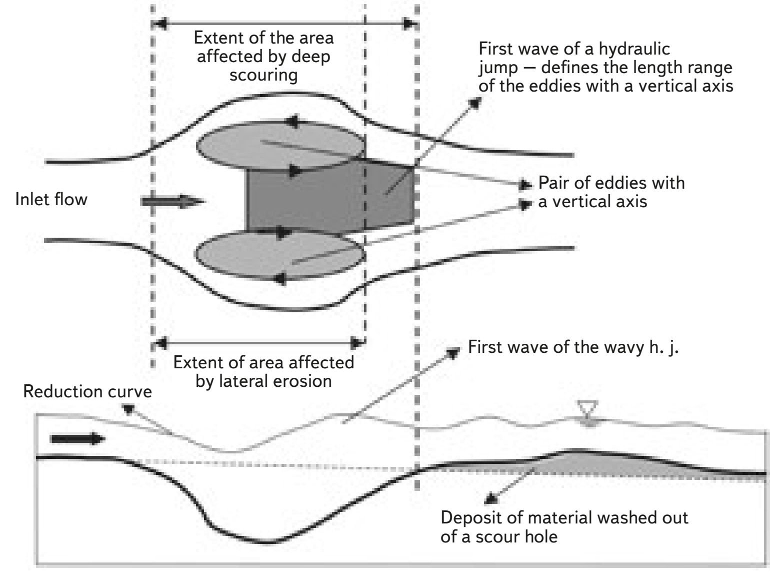


Fig. 1. Development of the „pear shaped" scour resulting from degradation of a drop structure on flash flood (left); feature of flow in transitional zone of the spatial 3D scour (right)

In a part of the project with the aim of enabling the quantification of morphological changes, systematic research was carried out in laboratory conditions on two different types of channel model in the transition zone. For a more complex description of the model behaviour, a „complete 3D" model of the river channel in the transition zone of its opening was chosen (*Fig. 2 left*). In order to speed up the process of documentation of the immediate development of the scour hole depression of the river channel, a model of a symmetrically simplified „half" river channel was designed (*Fig. 2 right*). The axis of channel symmetry was the glass wall of the hydraulic channel, in which the channel was created in the entrance lined part and the transition open part. This second model made it possible to capture the course of the water level and river bed very quickly in the longitudinal direction almost immediately. To speed up geometric alignment of the water level and river bed, optical accessibility through the glass side wall of the channel was used. It was also possible to measure the velocity fields in the transition zone of the river channel significantly faster than with the complete 3D model of the river channel. It is obvious that the assumption of symmetry was also a simplifying assumption from the point of view of the real development of the river channel in the opening, which had to be verified in the next phase of the project with a complete 3D river channel model. In principle, there should be no objective reasons for significantly asymmetric scour hole development, unless special conditions are created. Further details of the research are described in the literature [5, 6] and are not presented here for brevity.

Fig. 2. Full space model of the channel in the transition zone of scour hole development (left); symmetric half-space model of the channel with axis at the flume glass wall (right) – all under laboratory conditions

Scour hole development in a complete channel model

Based on the observation of the successive development of the 3D scour hole in non-cohesive materials, partial findings can be summarized as this (see diagram in *Fig. 1 right*):

- At the transition from channel section with a fixed boundary to section with a loose boundary, the whole process begins with the formation of a small erosive hole in the bed, as also happens with wide channels. When a sill is spontaneously formed in the bed at the transition between the channels, a flow with the character of a hydraulic jump arises. At first, it is a flow with an undular or weak hydraulic jump.
- As the depth of the bed depression increases, this flow in the longitudinal level does not significantly change its character. As soon as the bed depression reaches the foot of the slopes, their stability is disturbed and small parts or even whole blocks of material start to slide into the depression. The slopes of the changing channel near their foot no longer smoothly follow the slopes of the lined channel. Here, the current breaks away from the wall and the first lateral vortices are formed at the foot of both slopes.
- Lateral vortices begin to gradually grow and become stronger. They get the majority of their circulation energy from the main stream near the channel axis. The side holes expand from both sides, compressing the central stream and leading to its lateral contraction. This multiplies its tangential shear effect at the bed, and from this moment the deepening of the scour hole proceeds very quickly.
- The more the scour hole extends to the sides, the more developed the circulation structure of the side holes is. The sand material, carried from the bed by strong current of the hydraulic jump near the longitudinal axis of the channel, is partly carried away from the scour hole area and partly circulated in the side holes. The movement of individual sand particles in the circulation areas takes place from the centre of the stream to the sides towards the slopes; from here along the side slopes it is sucked upstream and back into the main stream in the channel axis.
- Once this circulating sediment process stabilizes, further development of the maximum scour hole depth begins to slow down. The main stream already has a partially exhausted transport capacity with the material that is circulated in the side holes. This material re-enters the main stream whenever the flow in the side holes moves it at the bottom to the channel axis.

Sometimes the width of the side holes becomes too large for the back-current along the slopes to have sufficient force to remove the material from the bed. The scour hole deepens more near the centre; at the edges it deepens less or not at all. In such cases, the bed at the edges of the scour hole depression is very flat, and at the centre of the channel it slopes steeply to the point of maximum depth of the scour hole. Some kind of side platforms are created here with one narrow deep bed hole in the middle of the profile.

Hydraulic basics of scour hole study

Since a hydraulic jump occurs in the place of a 3D scour hole, the characteristics of which can be obtained by applying momentum theorem, it is quite natural to consider that the model of a 3D scour hole will also be based on this principle. Momentum theorem allows an exact solution when designing the dimensions of constant-width apron in weir, but for the case of a „pear" 3D scour hole the width is variable. It is also necessary to take into account the normal pressure force, which is the reaction of the walls of the „pear" object, although in the case of deformable banks this does not apply either. In plan view, the dimension of the hydraulic jump from the sides is not defined by solid walls, but by the interfaces with the lateral votices (*Fig. 1 right*). Due to the fact that the water has a peripheral velocity at the interface with lateral vortices with vertical axis, which is determined by the intensity of the flow circulation in the vortex, it is necessary to calculate not only the magnitude of the normal force, but also the tangential shear force. In addition, the distribution of pressures in the inlet profile may not always be hydrostatic, and the momentum of the flow in the outlet profile is also affected by the size of the Boussinesq number (the ratio of the actual momentum of the flow to the momentum expressed from the cross-sectional velocity) due to the non-uniform distribution of velocities in the cross section profile. It is clear from the above that a simple application of momentum theorem does not achieve the objective. The author's proposal appears to be more promising; following the example of Hunzinger [4], he makes the dimensionless length of the wake in wide channel section:

$$\lambda_w = \frac{2L_w}{B_2 - B_1} \qquad (1)$$

and the parameter F of the kinetic to potential energy exchange due to flow expansion (*Eq. 2*).

$$\lambda_w = 2.2 - 2.8\ln(1 - F) \qquad (2)$$

The dimensionless parameter F was defined by Ashida [1] by the following relationship:

$$F = \left(\frac{V_2^2}{V_1^2}\right)^{1.1} \left(\frac{h_{p2}}{h_{p1}}\right)^{2.1} \qquad (3a),$$

which is an expression of the energy exchange in the transition zone between the input profile 1, where the original width of the channel is unchanged, and profile 2 where, in contrast, the width of the scour hole to the sides is the largest. The reason why the energy exchange parameter F could be a good indicator of the tendency to create a „pear" 3D scour hole stems from the consideration that the more fluid's energy (kinetic and potential) is converted in the balance cross section into a dissipative form of energy and into a part of the energy applied during the transport of river channel bed and banks material, one can expect greater transformative effects of the current on the channel morphology, and thus a greater spatial extent of the created scour hole. All quantities appearing in relationship (*Eq. 3a*) are shown in *Fig. 3*. In this diagram, the meaning of the given values is as follows:

V_1, V_2 [m.s^{-1}] – cross-sectional velocities in the respective profile
A_1, A_2 [m^2] – flow areas in the relevant balance profile
$c \cdot A_2$ [m^2] – part of the flow area in profile 2, reduced by the recirculation area of the lateral vortices
H_1 [m] – flow depth in balance input profile 1
h_{p1}, h_{p2} [m] – water stage at the entrance to the scour hole and in the scour hole respectively, measured from the lowest level of the bottom of the scour hole
$\Delta H_p = h_{p1} - h_{p2}$ [m] – difference in the water stages in the balance profiles
Y_s [m] – „pear" scour hole depth
L_w [m] – total „pear" scour hole length
B_1, B_2, B_3 [m] – stream widths at the surface at the entrance to the scour hole, in the scour hole, and just behind the scour hole

In *Eq. 3a*, however, a single cross-sectional velocity is considered in the entire profile 1 and 2. Based on the author own research on the distribution of point velocities in the transition zone of scour hole development [5], it is recommended to modify the cross-sectional velocity elements in profiles 1 and 2 with the respective profile kinetic energy coefficients (Coriolis number α_e), including the ratio of the actual kinetic energy height to the energy height expressed from the mean cross-sectional velocity.

$$F = \left(\frac{\alpha_{e2} V_2^2}{\alpha_{e1} V_1^2}\right)^{1.1} \left(\frac{h_{p2}}{h_{p1}}\right)^{2.1} \qquad (3b)$$

In the balance relationship (*Eq. 3b*), special care must be taken to choose the appropriate position of both balance profiles – especially profile 2 (*Fig. 3*).

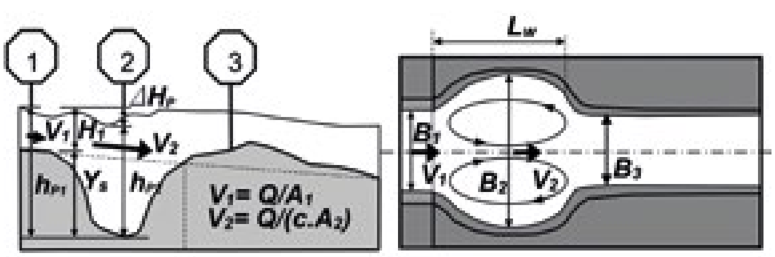


Fig. 3. Typical form of the "pear" shaped scour hole in a long section (left) and a plan view (right) with basic dimensions marked at characteristic profiles of scour hole

Methodology for determining channel changes

The main goal of this paper is to propose, based on previous observations [5, 6], a simple procedure for determining the dimensions of a 3D scour hole, which occurs at the transition from a lined channel section with fixed boundary to a channel with completely loose boundary without any technical support. The procedure should be as simple as possible, making it possible to determine the extent of morphological changes in the river channel without the need to know too many details, which can mostly only be determined in laboratory conditions.

Relationships for determining the basic dimensions of a 3D scour hole

The measurement procedure on the „full" 3D model was very slow and tedious. It was not possible to measure the corresponding time courses of the water level and the bottom in the longitudinal profile and in both balance cross profiles. For systematic measurement, it was therefore necessary to limit access to a half channel. All evaluated experimental data in the graphs in *Fig. 4* come from these measurements.

It is not very practical for a river engineer to use a formula in the form of *Eq. 3b*, for example due to a lack of knowledge about the distribution of local velocities in profile 1 and especially 2 (*Fig. 3*), where the lateral vortices arise. Some alternate, more straightforward relationships need to be used. The relationship between F a $\beta = B_2/B_1$ plotted in *Fig. 4* (*Graph 1*) is presented. It is clear that F is not only a function of the geometric dimensions of the scour hole, but is also related to the properties of the flow before entering the changing channel. Therefore, the following relationship is proposed: $F = F(\beta, Fr_1)$, where Fr_1 is the Froude number of the flow in the inlet section 1 defined by the relationship $Fr_1 = V_1/(gH_{1str})^{0.5}$, where H_{1str} is the mean flow depth $H_{1str} = A_1/B_1$, A_1 is the flow area in the balance profile 1 and B_1 is the width of the surface flow in the same section. An exponential relationship (*Eq. 4*) was derived, which naturally fulfils the logical condition $F = 1$ for the channel widening ratio $\beta = B_2/B_1 = 1$.

$$F = 0.084 exp\left(\frac{2.48}{\beta^{0.85} Fr_1}\right) \qquad (R^2 = 0.867 \text{ – see } \textit{Fig. 4 – Graph 1}) \qquad (4)$$

The relationship obtained by interpolating experimentally determined points reaches the coefficient of determination $R^2 = 0.867$.

Furthermore, the relationship between the dimensionless flood length λ_w was obtained from the experimental data (*Fig. 4 – Graph 2*) in analogy with Hunziger relationship (*Eq. 2*). The relationship takes into account the dependence of the geometric dimensions, participating in the expression of the dimensionless quantity λ_w, on the energy conversion parameter between profiles 1 and 2, and also takes into account the conditions (Fr_1) at the inlet flow to the transition zone of the channel, where the scour hole develops.

$$\lambda_w = 1.47 - 0.65 \ln (1-F)\, Fr_1 \qquad (R^2 = 0.978 \text{ – see } \textit{Fig. 4 – Graph 2}) \qquad (5)$$

Experience from research into the shape a scour hole, which is created by the effect of a submerged horizontal jet on a deformable bed [2], shows that the shape of a scour hole at individual moments of its development is similar – affine (*Fig. 5*). An obvious similarity between the observed shape of the surface and the bed in the longitudinal profile can also be detected (*Fig. 1 right*). Therefore, it is necessary to look for relationships between the basic geometric parameters of the scour hole (B_2, B_3, L_w, and Y_s) and also between the levels of the water level ($\Delta H_p = h_{p1} - h_{p2}$) and the bed ($Y_s$). Other derived relationships (*Eq. 6, 7, 8*) drawn from experimentally obtained data (*Fig. 4 – Graphs 3, 4, 5*) were again determined using statistical analysis [5, 6].

$$B_2 = 1.58 L_w + 0.14 \qquad (R^2 = 0.992 \text{ – see } \textit{Fig. 4 – Graph 3}) \qquad (6)$$

$$B_3 = 0.58 B_2 + 0.10 \qquad (R^2 = 0.978 \text{ – see } \textit{Fig. 4 – Graph 4}) \qquad (7)$$

$$\Delta H_p = 0.51 Y_s \qquad (R^2 = 0.923 \text{ – see } \textit{Fig. 4 – Graph 5}) \qquad (8)$$

The last statistically derived relationship from the experimentally obtained data on the "half" model of the open channel can be seen in *Fig. 4 – Graph 6*.

$$\frac{Y_s}{B_2} = \left(\frac{d_{50}\, tg\varphi}{B_1} \cdot \frac{L_w}{B_1}\right)^{0.57} \qquad (R^2 = 0.955 \text{ – see } \textit{Fig. 4 – Graph 6}) \qquad (9)$$

The author is aware of the fact that *Eq. 9* can also have a different form than the one presented here, with the representation of a number of other combinations of dimensionless quantities. According to [6], from the whole range of verified relationships between dimensionless quantities, the form presented above was selected based on the best achieved criterion value of the optimization process (R^2) when including the minimum number of parameters intended for optimization (only the power exponent), which had a positive effect on the small error in their value. This equation mutually binds all three main parameters of scour hole geometry L_w, B_2, Y_s with the quantity B_1 at the entrance to the scour hole depending on the geomechanical properties of the soil (tg φ [-], d_{50} [m]).

In addition to the definition equation of the energy conversion parameter (*Eq. 3a*) and the proposed empirical equations (*Eq. 4–9*), in accordance with *Fig. 3*, the basic coupling equations for water stages (potential heights in balance profiles 1 and 2) can also be derived.

$$h_{p1} = Y_s + H_1 \qquad (10)$$

$$h_{p2} = Y_s + H_1 - \Delta H_p \qquad (11)$$

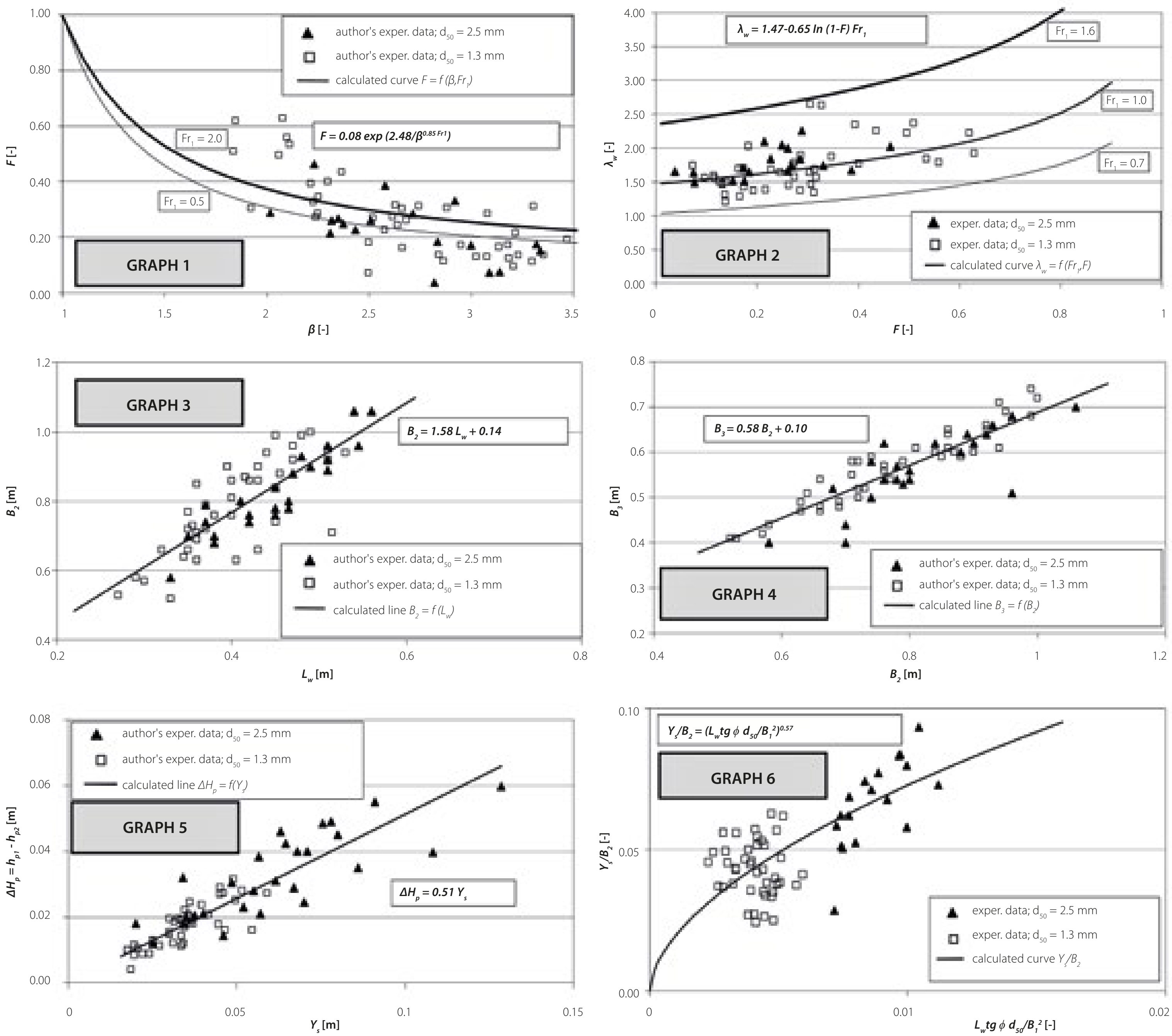


Fig. 4. Relationships derived to design a preformed scour hole at a channel transition; *Graphs 1–6* are referred in the flow chart of design procedure of the scour hole (*Fig. 6*)

The last coupling equation serves to express the dimensionless length of the wake λw, where L_w is the length of the wake corresponding approximately to the length of the scour hole.

$$\lambda_w = \frac{2L_w}{B_2 - B_1} \qquad (12)$$

All the necessary quantitative relationships were derived for the design of the dimensions of the morphological object. All relationships are dimensionally homogeneous; they are presented in the form of dependence of the geometric dimensions of the scour hole (*Eq. 6, 7, 8, 10, 11*) or dependence of dimensionless parameters (*Eq. 3a, 4, 5, 9, 12*). Input data for these formulas are the main geometrical and hydraulic characteristics of the inlet flow (B_1, H_1, V_1, Fr_1) in the section of the river channel before the opening of the stream and the geomechanical properties of the non-cohesive material in the open part (angle of repose of the soil under water φ and representative soil grain size d_{50}). It should be noted that, in the case of applying experimentally derived equations, it is necessary to assume the validity of these relations for a certain range of dimensionless parameters used. Dimensionless relations (*Eq. 4, 5, 9*) were derived in the range of the Fr_1 parameter (0.75; 1.9) – i.e., rather in conditions characteristic of upland to mountain streams. The channel expansion ratio $\beta = B_2/B_1$ in the scour hole in the experiments corresponded to the range (1.8; 3.5); i.e., flow conditions with well to very well developed lateral vortices, which significantly participate in the formation of a 3D scour hole with the characteristic "pear" shape. Dimensionless scour hole parameters were in this range: B_2/H_{1str} (15; 50), L_w/H_{1str} (7; 23), and Y_s/H_{1str} (0.6; 2.7). The energy conversion parameter F was in the range (0.04; 0.8). The experiments were conducted only on two types of granular non-cohesive bed, formed by significantly uniform-grained sharp-edged silica sands FP 1–1.6 and FP 1.6–4 mm with grain d_{50} = 1.3 mm and 2.5 mm, and with inhomogeneity numbers $U = d_{60}/d_{10}$ 1.5 and 1.7, respectively. The specific weight of the sand was 2,516 kg/m^3 and the volume weight 1,560 and 1,600 kg/m^3 for both cases. The angle of repose under water was 33.8° for finer-grained sand and 35.9° for coarser sand.

Changes of all relevant geometric dimensions, which are associated with the formation and development of a scour hole, are dependent on the parameter, which is time – we can therefore speak of a "parametric scour hole" [2]. In the case of designing a "pear" scour hole as a stabilized scour hole, it is necessary to start from one known dimension of the scour hole. In practice, a frequent restriction for the design of a "pear" scour hole is the limited width of the adjacent bank, where it is not necessary to solve complicated relationships with the owners of the surrounding land. Therefore, this limited dimension will be chosen, corresponding to the quantity B_2; however, it is possible to choose any of the other dimensions (Y_s, L_w). With this option, the time factor is indirectly introduced into the calculation. The designer of a "pear" shaped scour hole does not need to know how much time t it would take to create a scour hole of the calculated dimensions. What is essential is the fact that the dimension of the chosen scour hole (variable at time t) is a limit beyond which it is no longer possible to go, and that the shape of the scour hole corresponds to one of the affine intermediate states (*Fig. 5*), corresponding to the current extent of a pair of vertical water holes. The "pear" scour hole must then be stabilized in the dimensions determined by the calculation, for example with embedded lined ribs in the bed and on the slopes at the beginning and end of the scour hole. However, specific technical measures for the stabilization of scour holes must be based on common local practice on the given watercourse, respecting in particular the character of the soils in the alluvial deposits and the available material base.

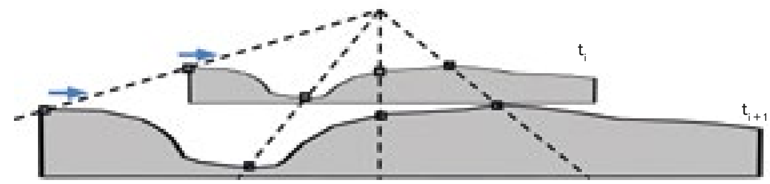


Fig. 5. Parametric scour hole development – the scour hole shape for any time instant *t* is affine to the shape at another time instant *t + 1*

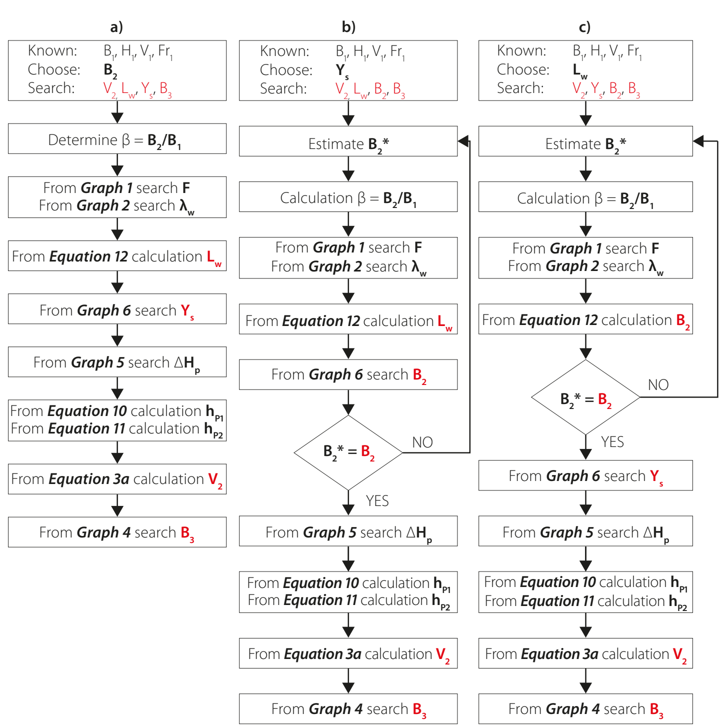


Fig. 6. Flow chart of design procedure of the 3D scour hole where one dimension is chosen: a) B_2 is given; b) Y_s is given; c) L_w is given. The referenced graphs are shown in *Fig. 4;* the numbers of the referenced formulas correspond to the text

3D scour hole design methodology

The procedure for determining the basic dimensions of the scour hole in the transition zone of the open river channel is based on *Fig. 6*. For the inlet shape-fixed profile 1 of the lined river channel, the following flow characteristics are known: depth H_1, velocity V_1, value of the Froude number Fr_1, and width of the flow B_1 corresponding to the initial width of the channel in the transition area of the open channel. The design of the scour hole as a spatial morphological element consists in determining its basic geometric dimensions B_2, L_w, Y_s, B_3, and determining the reduced cross-sectional velocity V_2 in the extended profile 2 (*Fig. 3*). The procedure for determining the basic dimensions of the scour hole differs for alternatives a), b) or c) in *Fig. 6*, depending on whether the initial known or specified dimension of the scour hole is its maximum width B_2, depth Y_s, or length L_w. In all calculation alternatives, the channel widening ratio $\beta = B_2/B_1$ must first be determined; if B_2 is not known or specified, it must be estimated. Furthermore, it is necessary to determine the energy conversion parameter F depending on β and the value of Fr_1 according to *Graph 1* or from the relationship (*Eq. 4*) and according to *Graph 2* or the dimensionless length of the flood λ_w from the relationship (*Eq. 5*), which connects the basic plan dimensions of the scour hole depression L_w, B_1 and B_2 through the relationship (*Eq. 12*). If B_2 was not known at the beginning of the calculation and it was necessary to choose it, its correct choice can be verified by the relationship (*Eq. 12*), or also *Graph 6*, or the relationship (*Eq. 9*), which connects the geomechanical properties of the non-cohesive material in the channel opening and all the basic geometric dimensions of the scour hole depression. If a sufficient agreement of the estimate B_2 with its value determined by the calculation is achieved, it is possible to proceed further by determining the width of the bed at the end of the scour hole depression B_3 according to *Graph 4*, or using the relationship (*Eq. 7*). If it is necessary to determine the cross-sectional velocity V_2 in profile 2 (e.g., to assess the critical non-scrubbing velocity of bed particles), the level reduction is first determined in the scour hole ΔH_p according to *Graph 5*, or by relationship (*Eq. 8*) and subsequently the coupling relationships (*Eq. 10*) and (*Eq. 11*) are used to determine the position heights h_{p1} and h_{p2}. After that, the definition relationship (*Eq. 3a*) can be used to determine the cross-sectional velocity V_2 in profile 2 in the scour hole.

RESULTS AND DISCUSSION

The set of empirical equations *4–9* together with the height relationships equations *10, 11* and the definition relationships (*Eq. 3a*) and (*Eq. 12*) form a system for the full model of the 3D "pear" scour hole. The interconnected application of individual relationships in scour hole calculation, forming a comprehensive procedure, is understood as a "pear" type scour hole design methodology. However, each of the empirical equations was only statistically specified

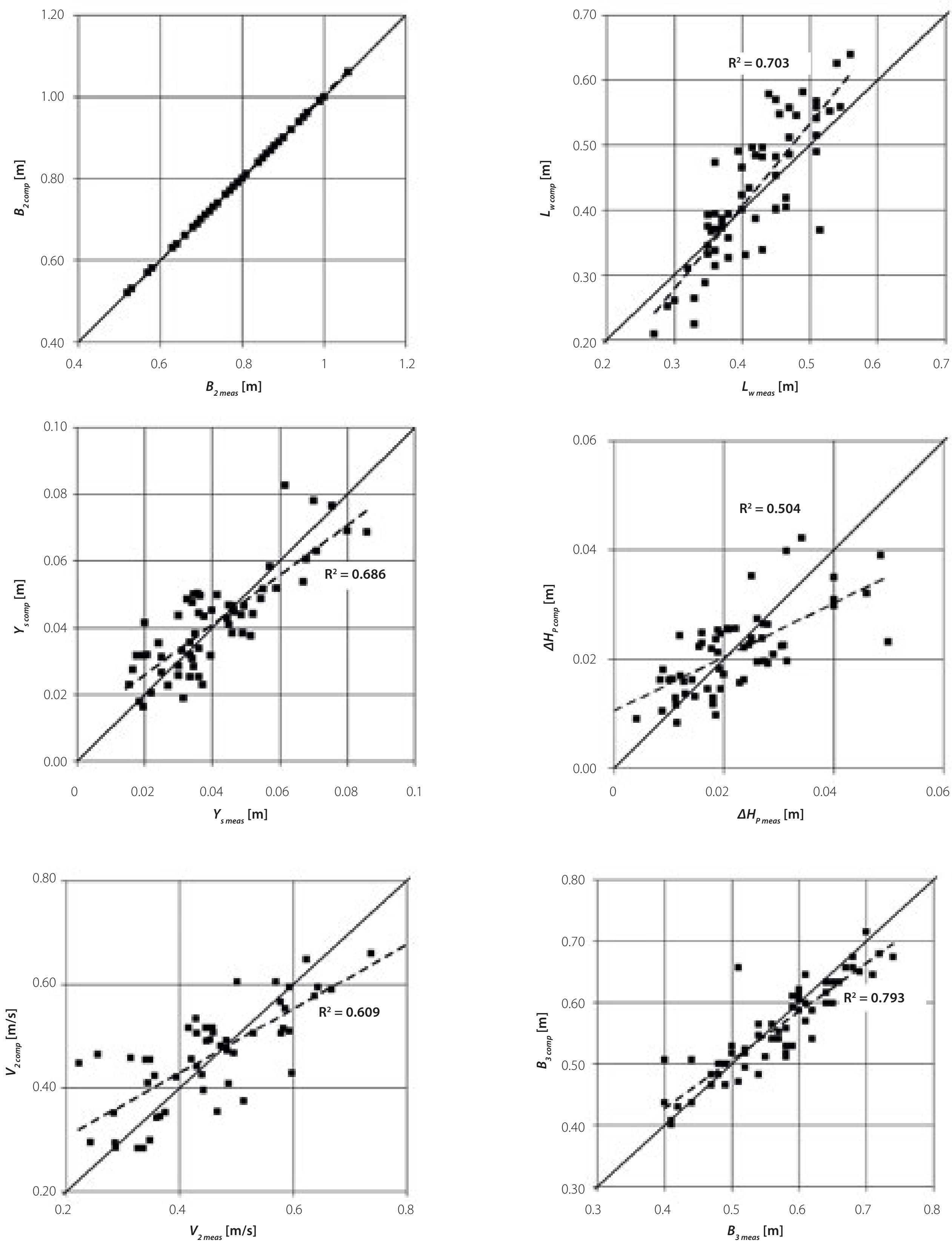


Fig. 7. Assessment of the scour hole computation methodology suitability by testing the agreement between calculated (*comp*) and measured (*meas*) geometric and hydraulic characteristics when selecting the width B_2

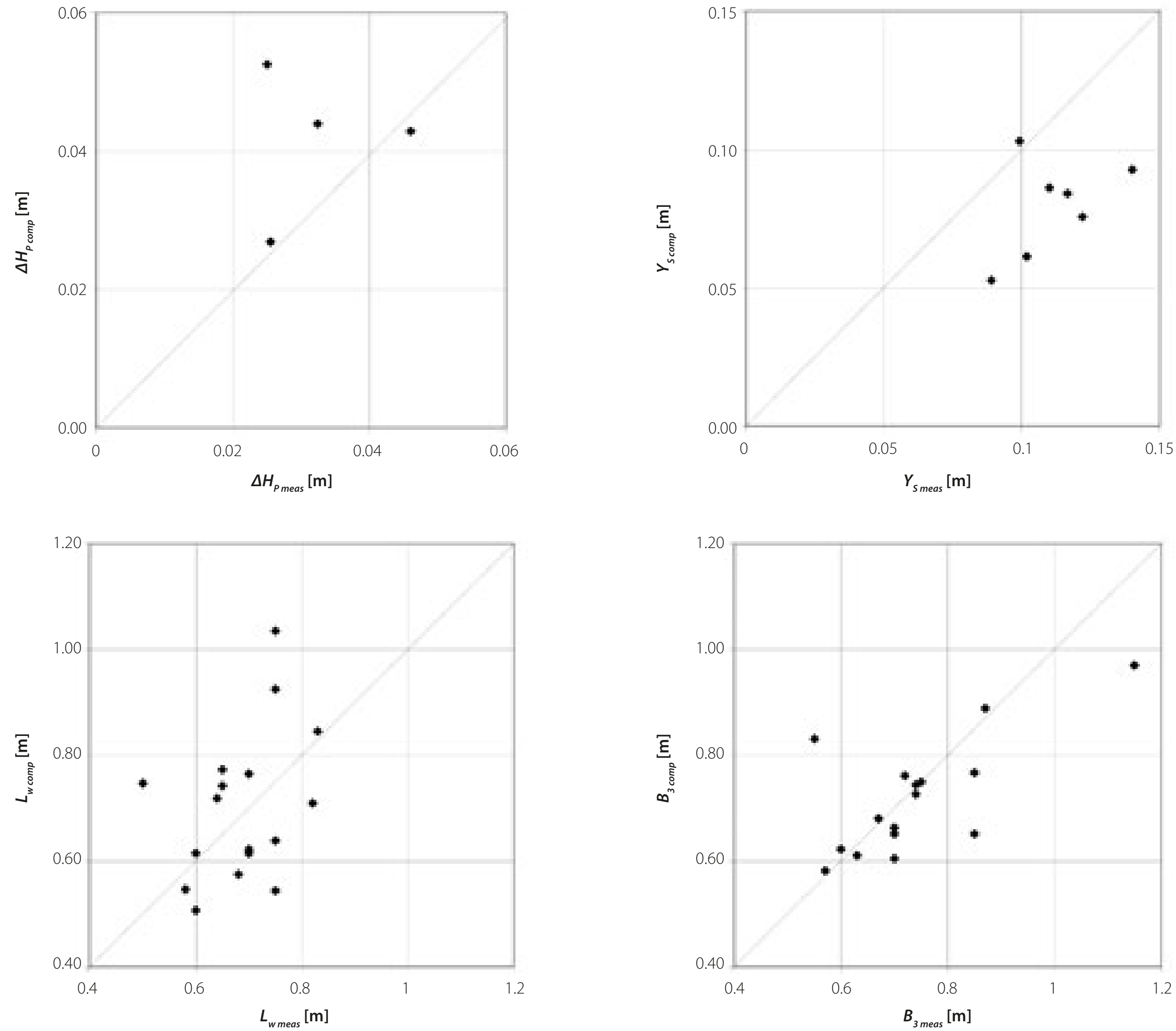


Fig. 8. Visual assessment of the "pear" scour hole computation methodology (when B_2 is given) by scatter plot between computed data and measured data in the "full" 3D model

individually. It is therefore necessary to check what degree of agreement with the measured data can be achieved when applying the entire system of proposed relationships – the design methodology. This is not a verification on an independent data set. It is only a matter of checking how "close" the whole scour hole calculation methodology is compared to the measured data, from which each of the used empirical relationships was individually derived. When designing a "pear" scour hole, one of the dimensions of the scour hole must always be selected, which introduces a time factor into the design of a parametric scour hole. Depending on which of the dimensions is chosen, the methodological procedure must be slightly modified – the same relationships are used, but in a different order. Flow diagrams of the procedure in the case that the dimensions a) B_2, b) Y_s, or c) L_w are chosen, are shown in *Fig. 6*.

The procedure for assessing "closeness" was as follows. It was based on known data on the flow on the inlet profile to the scour hole (cross-sectional velocity V_1, depth H_1, and stream width B_1 and the value Fr_1 determined from them) and geomechanical properties of the soil (d_{50}, ϕ) – these data will also be known in practice. Individual procedures were applied depending on which of the dimensions B_2, Y_s, or L_w was chosen as the starting point for the calculation. The result was the calculated quantities B_2, L_w, Y_s, ΔH_P, V_2, B_3 (marked with the index *comp = computed*). These were compared with the quantities measured in the half-channel model (indicated by the index *meas = measured*) using a scatter plot. *Fig. 7* shows the results of the scatter plot for the calculation with the selected dimension B_2. The first graph of the set shows a complete match, since the targeted data was also used as the starting dimension in the calculation. The scatter plots performed for the other selected default scour hole dimensions Y_s a L_w (not shown) allow us to conclude that the calculation methodology of the scour hole is the "closest" if the scour hole width B_2 is used as the default selected dimension for the calculation.

In addition to assessing the "closeness" of the proposed computation methodology, its verification was also performed with a group of independent data obtained on a "full" 3D model. From the set of 23 experiments on the 3D model, it was possible to evaluate only some assessed quantities with a frequency of values in the set in the range of 4–17. This comparison between the computation methodology derived on the "half" model and the data found on the "full" 3D model is useful (*Fig. 8*). It can be determined here how significantly the simplifying assumption of flow symmetry in the scour hole is reflected in the correctness of the calculation methodology derived under simplified assumptions.

There is little data for comparison. Those that were available show that the simplifying assumption of symmetry does have some impact on the accuracy of the proposed "pear" scour hole calculation methodology when applied to the full 3D scour hole. However, it can be assumed that the influence of the correctness of the calculation methodology due to the assumption of flow symmetry does not exceed the influence of other factors, including measurement errors. For example, the vertical velocities determined in the "half" model were measured in a simplified way, and the glass wall in the stream axis apparently slightly influenced the shape of the surface and bed in its vicinity. In contrast, with the "full" model, there was a less accurate and time-consuming measurement of the bed and the level with a tip scale. When considering all the mentioned influences included in the framework of errors and distortions in the chosen procedure of experimental work, it can be assumed that the presented calculation methodology has a real base and could be beneficial in the field of design of morphological objects during watercourse restoration.

CONCLUSION

The above-mentioned procedure for designing a 3D scour hole depression in flow opening can be used in the design of small, environmentally acceptable watercourse channels or in the process of restoration of insensitively channelized small upland watercourse channels. The construction of pre-created morphological objects in the form of transition from fixed to lose perimeter of channel boundary, which support the creation of spatial flow and the dissipation of excess kinetic energy, can be a useful and cost-effective measure in the prevention of destructive erosion by flood flow in the river channel, and at the same time can lead to an increase in morphological and therefore habitat diversity within the watercourse channel.

However, the adoption of these measures as part of the process of river channel restoration must always be properly assessed by the relevant water authority from the point of view of the change in the condition and use of the actual watercourse channel and the area around the watercourse; for example, a fixed ameliorated drainage channel changes to an open shallow meadow stream and the surrounding drained agricultural area will be transformed into occasionally inundated meadows.

Acknowledgements

The article was created as part of the implementation of the project supported by the Technology Agency of the Czech Republic SS02030027 "Water systems and water management in the Czech Republic in conditions of climate change (Water Centre)".

References

[1] ASHIDA, K. On River Bed Variations and Stable Channels in Alluvial Streams. *Bulletin of the Disaster Prevention Research Institute*. 1964, 14, pp. 23–45.

[2] BREUSERS, H. N. C. Scour below Low Head Structures. In: BREUSERS, H. N. C., RAUDKIVI, A. J. *Scouring. IAHR Hydraulic Structures Design Manual* 2. Rotterdam/Brook-field: Balkema, 1991, pp. 123–142. ISBN 978-9061919834.

[3] HRAZDÍLEK, I. *Etapa č. 02. Výskum transformácie prizmatických korýt ako súčasť ich revitalizácie a výskum vzájomného ovplyvňovania prúdenia v inundácii a v koryte*. Bratislava: VÚVH, 1999. 138 p.

[4] HUNZINGER, L. *Flussaufweitungen – Morphologie, Geschiebehaushalt und Grundsätze zur Bemessung*. Zürich: VAW, 1998. 206 s. Mitteilung der Versuchsanstalt für Wasserbau, Hydrologie und Glaziologie der ETH, 159.

[5] SKLENÁŘ, P., WRIGHT, C. Scour Formation and Dissipation of Kinetic Flow Energy in a Channel with Loose Boundary and Small Width/Depth Ratio. In: *Proceedings of the International Conference on Fluvial Hydraulics – River Flow*. Vol. 2. A. A. Balkema Publisher, 2002, pp. 1 117–1 125. ISBN 978-9058095169.

[6] SKLENÁŘ, P. *Hydraulické a morfologické účinky proudění v korytech malých vodních toků s revitalizačními úpravami. Dissertation Thesis.* Prague: Faculty of Civil Engineering CTU, 2004.

[7] ZARN, B. Stabilising a Riverbed by Local Widening – A Case Study of the River Emme, Switzerland. In: *Sediment Transport Mechanisms in Coastal Environments and Rivers. Proceedings of the EUROMECH 310 Conference, Le Havre, France, 13–17 September 1993.* World Scientific Publication, 1994, pp. 388–396. ISBN 978-9810218546.

Author

Ing. Petr Sklenář, Ph.D.[1, 2]
✉ petr.sklenar@vuv.cz
ORCID: 0000-0003-4591-3148

[1]T. G. Masaryk Water Research Institute, Prague
[2]CTU – Faculty of Civil Engineering, Prague

This article was translated on basis of Czech peer-reviewed original by Environmental Translation Ltd.

DOI: 10.46555/VTEI.2023.07.002

Foto: 123rf.com

Will summer flows in watercourses be a half lower by 2060?

The increase in potential evapotranspiration due to warming is quite often used as an indicator of ongoing and predicted changes in the hydrological balance. However, without assessing its effect in basins with different precipitation regimes, it is not correct to consider a change in potential evapotranspiration as an increase in actual evapotranspiration or a decrease in runoff.

For a better understanding, let us repeat the definitions of the basic components of the hydrological balance which we will use in the following considerations and calculations.

— PRECIPITATION in the form of rain, snow, hail, dew, hoarfrost, frost, etc. is the only input of the hydrological balance.
— EVAPOTRANSPIRATION includes evaporation (evaporation from water surface, soil, and wet plant surface) and plant transpiration.
    - POTENTIAL EVAPOTRANSPIRATION is the theoretical upper limit of evaporation from a surface under given natural and meteorological conditions. It expresses the ability of the air environment to remove water from the surface – it corresponds approximately to evaporation from a free water surface or evapotranspiration from grassland with optimal humidity. It depends mainly on the air temperature.
    - ACTUAL EVAPOTRANSPIRATION depends on air temperature, or potential evapotranspiration, and is limited by the amount of water available for evaporation and transpiration.
— SURFACE RUNOFF occurs in two situations – if the intensity of precipitation exceeds the rate of infiltration, or if the upper soil profile is completely saturated with water. It reaches the nearest watercourse quickly, within minutes to hours.
— HYPODERMIC (SUB-SURFACE) RUNOFF takes place through preferential paths in the upper layer of soil and subsoil without contact with the groundwater level. It enters the watercourse within a few days after rain or snowmelt.
— BASEFLOW (UNDERGROUND RUNOFF) is water flowing from groundwater storage in the form of springs or hidden under the surface into watercourses and reservoirs. It manifests itself in a watercourse within weeks to months after rain or snowmelt.
— WATER STORAGE is found in groundwater collectors, soil, wetlands, water reservoirs, and snow and ice, usually for a temporary period. If we deal with averages from a sufficiently long multi-year period, the influence of water storage can be omitted; however, it is significant when assessing the balance of individual years or shorter periods.

The hydrological balance of the basin, which can be expressed by the following equation, includes actual, not potential, evapotranspiration:

PRECIPITATION = EVAPOTRANSPIRATION + SURFACE RUNOFF + SUB-SURFACE RUNOFF + UNDERGROUND RUNOFF ± CHANGE IN WATER STORAGE (*Fig. 1*)

The hydrological balance of a basin can be described as a competition between two output components – evaporation from the basin surface and water runoff from the basin for a share of the input component, which is atmospheric precipitation. Here, ‚runoff' means the total runoff, created in time-varying proportions by the component of surface runoff, sub-surface runoff, and groundwater runoff/baseflow, concentrated in the flow through a closing profile of a watercourse.

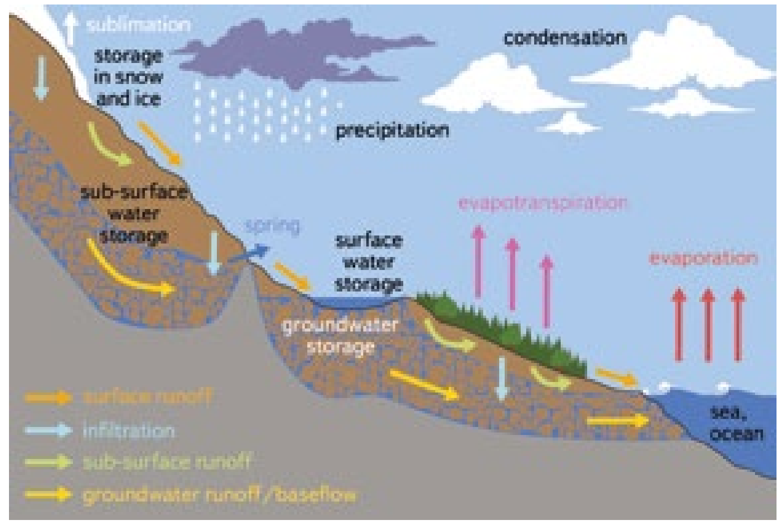


Fig. 1. The hydrological cycle [2]

The long-term average annual precipitation in the Czech Republic is 680 mm, actual evapotranspiration is 490 mm, total runoff 190 mm; i.e., only 28 % of precipitation, while 72 % of precipitation evapotranspirates. In our climatic conditions (with the exception of surface runoff from torrential rain, which on a long-term average makes up about 2 % to 6 % of precipitation) the decisive part of the balance is influenced by actual evapotranspiration, which depends on potential evapotranspiration, but is limited by the amount of precipitation and the available amount of water in the soil surface layer, which is the result of the balance of the previous period.

Potential evapotranspiration

There are several calculation methods for determining potential evapotranspiration. In the field of hydrological modelling, a relatively simple procedure according to article [1] has proven itself, in which its course is determined by air temperature. Potential evapotranspiration is given in the same units as precipitation, i.e., the amount of water that has fallen or evaporated per year or month. Due to its dependence on air temperature, potential evapotranspiration has a typical course during a year, shown in *Fig. 2*. It shows the long-term average monthly amounts of potential evapotranspiration during the hydrological year in the Labe basin in Děčín. As an example of its variability in individual years, values are shown for the extremely cold year 1941 and the very warm year 2015. The biggest difference between the values from 2015 and 1941 is in August – it is 26.5 mm and corresponds to 30.8 % of the value in 1941. Greater differences in potential evapotranspiration are shown in *Fig. 3*, which shows its course in the Rakovnický stream basin in central Bohemia in the extremely warm year 2018 and the course in the Chomutovka mountain basin below Třetí Mlýn in the relatively cold year 1987. The biggest difference in the courses is in July: 36.9 mm, i.e., 38.5 % of the value in Rakovník.

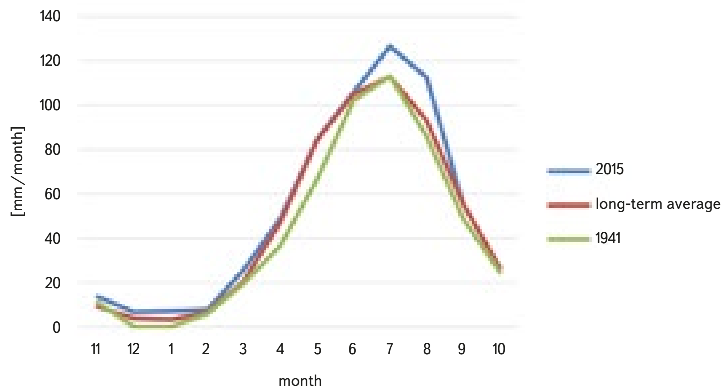


Fig. 2. Course of potential evapotranspiration in the Labe basin below Děčín in the warm year 2015, in the extremely cold year 1941, and in the long-term average

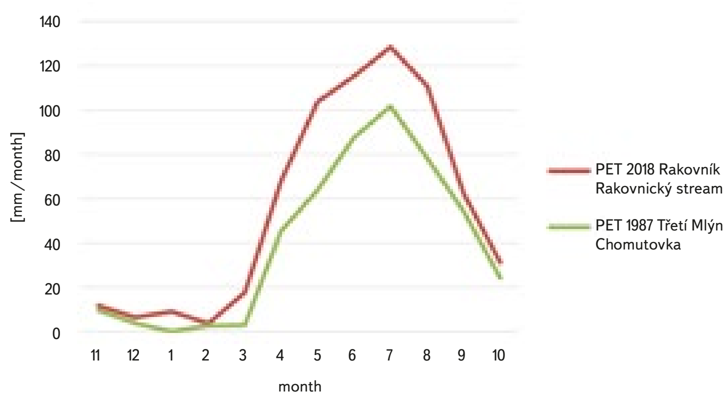


Fig. 3. Course of potential evapotranspiration (PET) in the warm year 2018 in the Rakovnický stream basin and in the cold year 1987 in Chomutovka basin

Actual evapotranspiration

Examining regression relationships for estimating annual evapotranspiration levels showed that for most basins, the relationship between evapotranspiration and precipitation is significantly tighter than the relationship between evapotranspiration and potential evapotranspiration. In the regional estimation of long-term averages of actual evapotranspiration (i.e., also long-term runoff averages), relations using precipitation and temperature as explanatory variables are usually applied. The relationship between potential evapotranspiration and precipitation over time is a decisive factor for the amount of actual evapotranspiration, the replenishment of water in the soil, and the formation of runoff. To describe the hydrological balance, we choose a monthly step, in which the balance storage components compensate for the more detailed fluctuations of the balance quantities. During the balance process, two different situations occur:

- When the distribution of precipitation in a month is omitted, the assumption can be used that if precipitation in a given month exceeds potential evapotranspiration, part of it is consumed for actual evapotranspiration equal to potential evapotranspiration, and the remaining part infiltrates into the soil. If the soil is fully saturated, some precipitation will percolate through the soil, generating sub-surface runoff and replenishing groundwater storage.
- If precipitation in a given month is less than potential evapotranspiration and the soil is saturated, all of it is used for actual evaporation. If the soil is not completely saturated, some precipitation will increase the water storage in the soil, some will contribute to evaporation, but actual evaporation is less than potential evapotranspiration.

Considering the consequences of ongoing warming, it should not be forgotten that an increase in air temperature, or an increase in potential evapotranspiration, is manifested by an increase in actual evapotranspiration only when water from precipitation and from the soil storage is available for evaporation and transpiration. Such conditions will more probably occur in basins at higher altitudes where precipitation is greater. As a result of lower temperatures, there is less potential evapotranspiration in basins at higher altitudes, so the described condition is more easily met.

Examples of courses of balance quantities in relation to potential evapotranspiration

Monthly values of precipitation, potential evapotranspiration, evapotranspiration, and runoff in the cold year 1986 and the warm year 2015 are shown in *Figs. 4* and *5* from the Chomutovka mountain basin (43.6 km^2), and in *Figs. 6* and *7* from the Rakovnický stream basin (302 km^2). *Tabs. 1* and *2* contain the annual hydrological characteristics of listed years. Annual evapotranspiration values correspond to monthly modelled courses shown and differ from the differences (precipitation minus runoff) by empting or filling water storage in the basin (the largest decrease of 46.7 mm in 2015 in the Rakovnický stream basin). *Tab. 3* shows an analogous data set for the Labe basin in Děčín, presented without the corresponding figures.

Tab. 1. Characteristics of the hydrological years 1986 and 2015 – Chomutovka basin below Třetí Mlýn

Characteristics	**1986**	**2015**	**Change between 2015 and 1986**
Air temperature [°C]	5.45	7.46	2.01
Precipitation [mm/year]	916	861	-55
Runoff [mm/year]	482	370	-112
Runoff (% of precipitation)	53	43	-10
Potential evapotranspiration [mm/year]	505	554	49
Evapotranspiration [mm/year]	466	521	55
Evapotranspiration (% of potential evapotranspiration)	92	94	-2

In the Chomutovka basin in the cold 1986, potential evapotranspiration exceeded precipitation in only two months, so evapotranspiration was only 8 % less; even in the warm 2015, it was only 6 % less. The increase in evapotranspiration in 2015 compared to 1986 is similar to the increase in potential evapotranspiration. The decrease in runoff is greater, it is contributed by the decrease in precipitation and evapotranspiration.

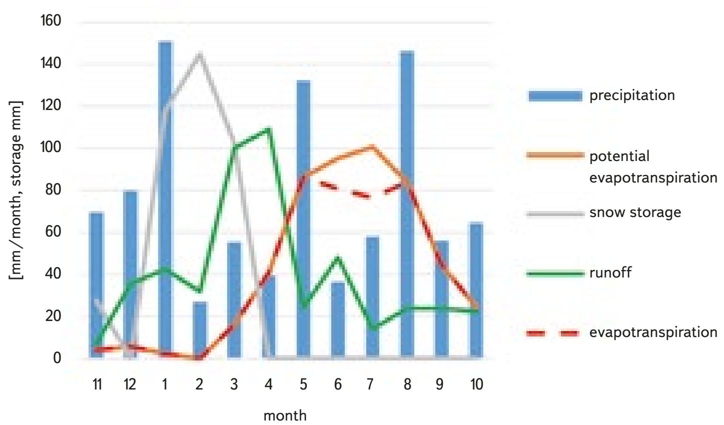


Fig. 4. Course of balance hydrological quantities in 1986 – Chomutovka basin

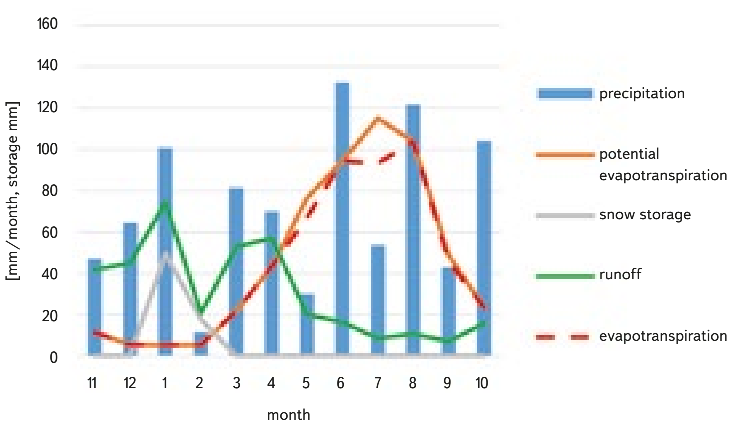


Fig. 5. Course of balance hydrological quantities in 2015 – Chomutovka basin

Tab. 2. Characteristics of the hydrological years 1986 and 2015 – Rakovnický stream basin below Rakovník

Characteristics	**1986**	**2015**	**Change between 2015 and 1986**
Air temperature [° C]	7.36	9.66	2.3
Precipitation [mm/year]	571	423	-148
Runoff [mm/year]	67.9	50.7	-17.2
Runoff (% of precipitation)	11.8	12	0,2
Potential evapotranspiration [mm/year]	575	637	62
Evapotranspiration [mm/year]	477	419	-58
Evapotranspiration (% of potential evapotranspiration)	83	66	-17

In the Rakovnický stream basin, even in the cold 1986 (especially in June and July), potential evapotranspiration significantly exceeded precipitation; evapotranspiration was 17 % less. In the warm and dry 2015, it was 34 % less. The increase in potential evapotranspiration in 2015 compared to 1986 did not materialize; as a result of the decrease in precipitation by 148 mm, actual evapotranspiration decreased. The decrease in runoff is small compared to the increase in potential evapotranspiration, even in view of the decrease in precipitation. Evidently, the runoff, approaching the drying up of the stream, was formed by the outflow of the rest of the dynamic groundwater storage and was supplemented by precipitation only until January. It can be seen in *Fig. 7* that, even if in 2015 the precipitation from May to July had been significantly greater, it would not have resulted in a significant increase in runoff: it would have been consumed by evapotranspiration.

Tab. 3. Characteristics of the hydrological years 1986 and 2015 – Labe basin below Děčín

Characteristics	**1986**	**2015**	**Change between 2015 and 1986**
Air temperature [° C]	7.04	9.19	2.15
Precipitation [mm/year]	733	496	-237
Runoff [mm/year]	205	118	-87
Runoff (% of precipitation)	28	23.7	-4.2
Potential evapotranspiration [mm/year]	562	622	60
Evapotranspiration [mm/year]	509	416	-93
Evapotranspiration (% of potential evapotranspiration)	90.4	66.9	-23.5

In the Labe basin, even in the cold 1986, evapotranspiration was 9.4 % less than potential evapotranspiration, and in 2015 33.1 % less, so the limitation of evapotranspiration by the amount of precipitation is manifested here. A decrease in precipitation and an increase in potential evapotranspiration contribute to the decrease in runoff.

The given examples of the course of the hydrological balance in basins with different precipitation regimes show that data on the increase in potential evapotranspiration can, without assessing the effect of precipitation, even if it does not change, characterize the effect of warming only in basins with relatively high precipitation. In most of the Czech Republic, the long-term average of potential evapotranspiration is greater than the long-term average of precipitation, especially in the summer half-year (*Fig. 8*). In this predominant part of the country, the change in actual evapotranspiration, or runoff, cannot be equated with the change in potential evapotranspiration without further analysis of the hydrological balance.

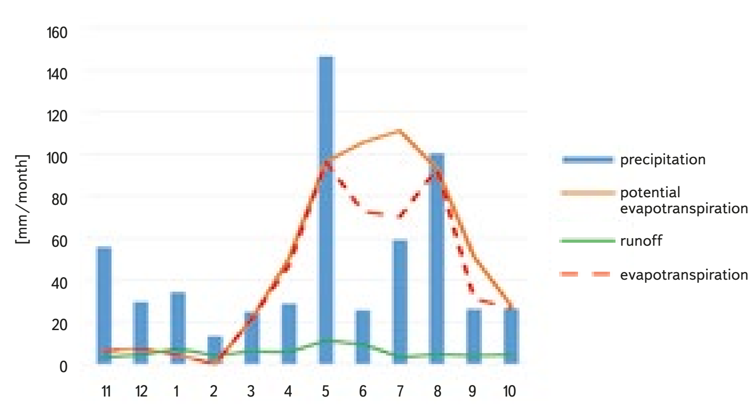


Fig. 6. Course of balance hydrological quantities in 1986 – Rakovnický stream basin

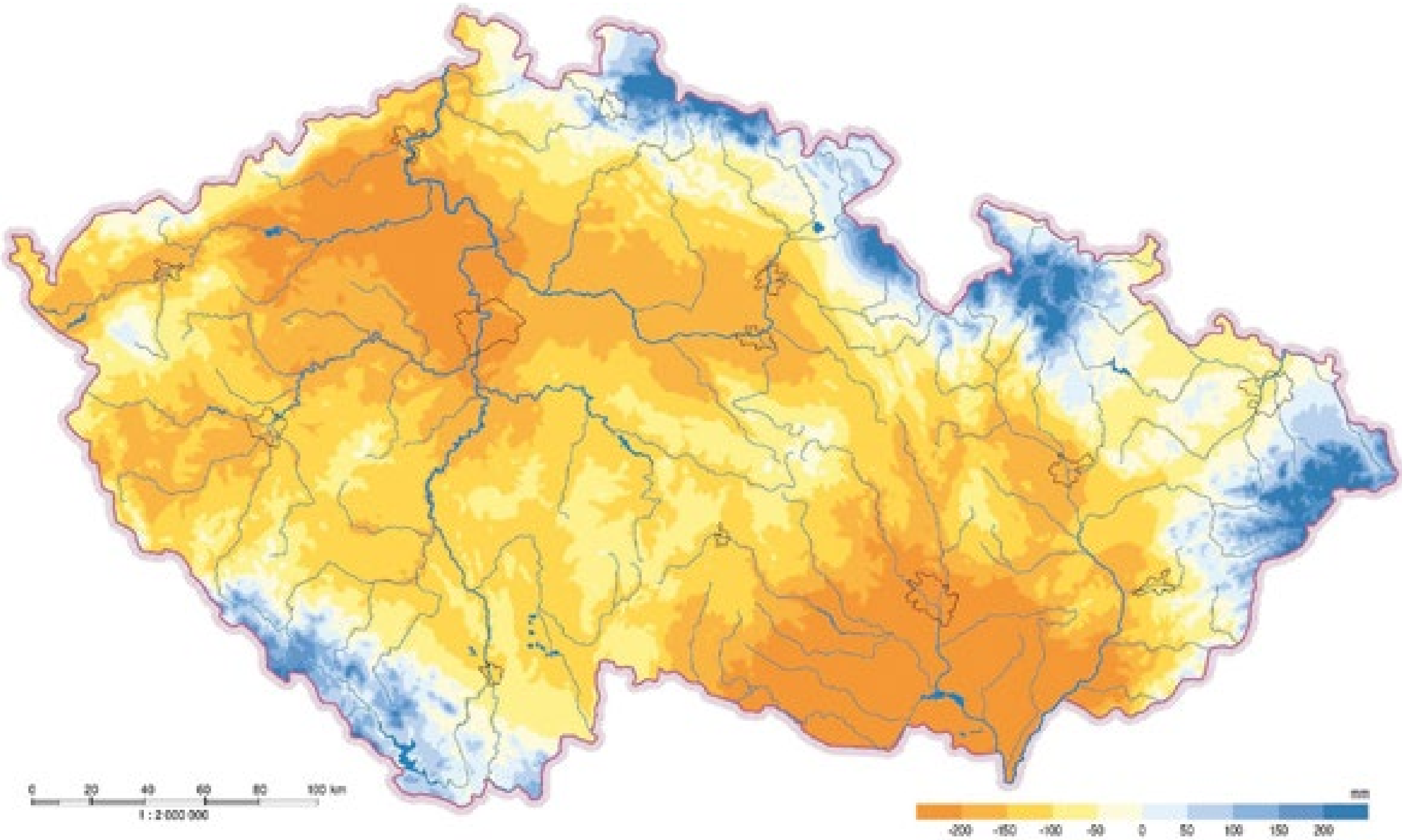


Fig. 8. The difference between total precipitation and potential evapotranspiration in the summer half-year (May to October) in the Czech Republic according to [3]

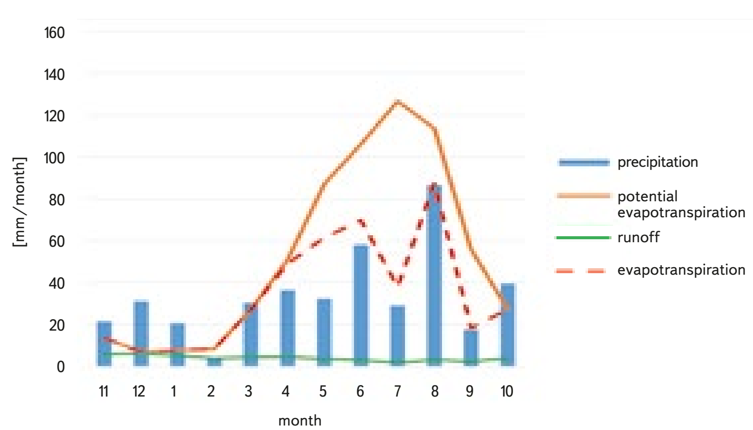


Fig. 7. Course of balance hydrological quantities in 2015 – Rakovnický stream basin

Consequences of differences in the hydrological balance in the summer and winter half-year for the decrease in flows due to warming

Throughout the Czech Republic, there are significantly different relationships between precipitation and potential evapotranspiration in the cold part of the year. In the winter half-year, precipitation exceeds potential evapotranspiration, so that at positive air temperatures, the soil profile becomes saturated during the winter, and at negative temperatures, snow storage is created. Groundwater storage is supplemented in both types of winter regime. It is more favourable for the further temporal development of runoff when most of the water percolate through the soil later. However, with rapid snowmelt, groundwater storage may be depleted by surface and intensive sub-surface runoff.

To assess the differences in the hydrological balance in the winter half-year (November to April) and in the summer half-year (May to October), we used data from the Labe basin in Děčín. *Tab. 4* shows the long-term average values of balance characteristic.

Tab. 4. Long-term averages of precipitation and runoff for the Labe basin in Děčín for the winter and summer half-years, quantities except ratios are in units [mm/half-year]

Half-year	Precipitation P	Runoff R	R/P	Potential evapotranspiration PET	P-PET	PET/P
winter	259	102	0.39	91	168	0.35
summer	410	72	0.18	478	- 68	1.17

In the winter half-year, precipitation accounts for 63 % of summer precipitation, but potential evapotranspiration is only 19 % of the summer value. Precipitation outweighs potential evapotranspiration. The winter runoff is 1.42 times greater than the summer runoff.

From the point of view of the predicted further warming, it is important that not only the magnitude of potential evapotranspiration, but also the gradient of its increase due to the increase in air temperature is significantly smaller in the winter months than in the months of the growing season (*Figs. 9* and *10*). The gradients shown on them were derived using the method of calculating potential evapotranspiration according to [1]. Not only from the results of hydrological observations, but also from the theoretical justification, it is clear that summer runoff will decrease significantly more than winter runoff with continued warming.

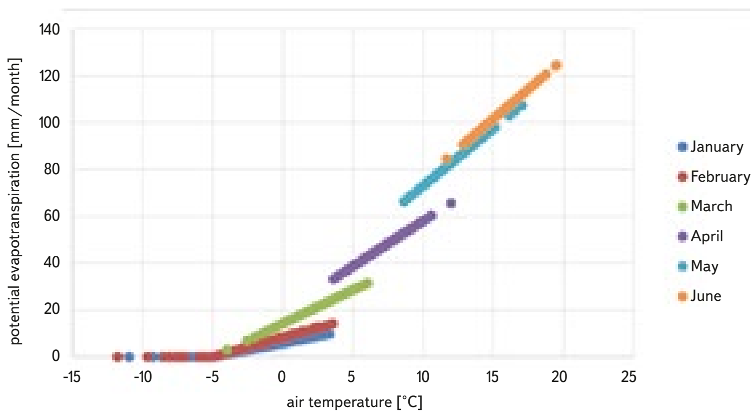


Fig. 9. Relationship between temperature and potential evapotranspiration in individual months of the first half-year

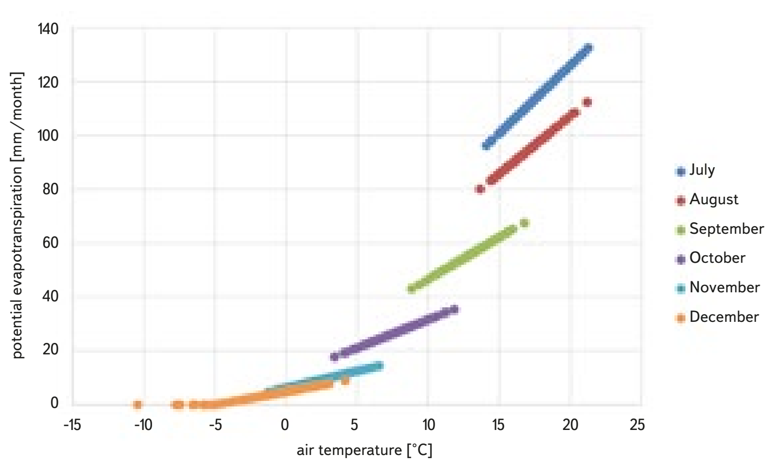


Fig. 10. Relationship between temperature and potential evapotranspiration in individual months of the second half-year

To estimate the consequences of warming, we assessed how the balance quantities changed in the Labe basin in 1991–2019 compared to the corresponding values from the period 1961–1980. 1980 is close to the beginning of an intensive rise in temperatures during the long-term fluctuation of air temperatures. *Tab. 5.* shows the averages of balance quantities from both periods and their differences (data from 1991 to 2019 minus data from 1961 to 1980). Precipitation increased very slightly in both half-years. In the winter half-year, a very small increase in precipitation outweighed the effect of increased potential evapotranspiration, and even with a warming of 1.1 °C, runoff increased slightly.

A rise in potential evapotranspiration by 33 mm in the summer half-year with an increase in temperature of 1.2 °C resulted in a decrease in runoff by 18.5 mm, i.e., by 22.3 %. When we estimate the effect corresponding to an increase in precipitation of 11 mm according to a runoff coefficient of $0.18 \times 11 = 2.0$ mm, we get an estimate of the runoff decrease due to warming of $18.5 + 2.0 = 20.5$ mm/year at a temperature increase of 1.2 °C. When reducing to a change in temperature by 1 °C, we estimate the gradient of the decrease in the average runoff in the summer half-year is 17 mm when warming by 1 °C.

It is clear from the above results that the risk of a decrease in flows due to warming is significantly greater in the summer half-year, when, in addition, temperatures rise more than in the annual average. With continued warming, runoff in the summer half-year will decrease to an ever greater extent, the hydrological drought will be prolonged and deepened, and it will be necessary to use more water transferred from the winter half-year in the summer half-year for water abstractions and the preservation of ecological flows. This cannot be ensured other than by using storage reservoirs. It is therefore necessary to assess to what extent it will be sufficient to ensure this function of the existing reservoirs at the expected intensity of warming. Due to the long time required to build reservoirs (from the plan to the actual construction), this task must be addressed well in advance.

Assuming a temperature rise of 1 °C over 30 years and a uniform decrease in runoff with the indicated gradient of 17 mm/1 °C, the average long-term summer runoff from the Labe basin in Děčín in 2060 would be around 30 mm. For comparison, the minimum average summer runoff so far observed in a single year (2018) was 22 mm in 169 years.

Tab. 5. Characteristics of the hydrological balance of the Labe basin in Děčín – winter and summer half-years

Half-year	**Winter**				**Summer**			
Period	1961–1980	1991–2019	difference	difference [%]	1961–1980	1991–2019	difference	difference [%]
Temperature [°C]	1.1	2.2	1.1		13.2	14.4	1.2	
Precipitation [mm/half-year]	251.7	260	8.3	3.3	406.3	417.3	11	2.7
Runoff [mm/half-year]	112.3	114.6	2.3	2.0	82.9	64.4	-18.5	-22.3
Potential evapotranspiration [mm/half-year]	89.4	102.3	12.9	14.4	462.2	495.5	33.3	7.2

References

[1] OUDIN, L., LÆTITIA, M., HOCINE, B., PIERRE, R. Estimating Potential Evapotranspiration without Continuous Daily Data: Possible Errors and Impact on Water Balance Simulations. *Hydrological Sciences Journal*. 2010, 55(2), pp. 209. Available at: doi: 10.1080/02626660903546118

[2] PELÁKOVÁ, M. et al. *Město a voda*. Prague: TGM Water Research Institute, 2020. 45 p. ISBN 978-80-87402-82-5.

[3] TOLASZ, R. *Atlas podnebí Česka*. Prague: Czech Hydrometeorological Institute, 2007. ISBN 978-80-86690-26-1.

Authors

Ing. Ladislav Kašpárek, CSc.
✉ ladislav.kasparek@vuv.cz

Ing. Martina Peláková
✉ martina.pelakova@vuv.cz

T. G. Masaryk Water Research Institute, Prague

This article was translated on basis of Czech peer-reviewed original by Environmental Translation Ltd.

Photo: J. Uhlíčka

Photo: J. Unucka

Authors

Ing. Adam Beran, Ph.D.

TGM WRI, p. r. i., Prague
✉ adam.beran@vuv.cz
www.vuv.cz

Ing. Adam Beran, Ph.D., is a hydrologist specializing in climate change impacts on the hydrologic regime and adaptation options. He has been working at TGM WRI since 2010; in 2019 he completed the doctoral study programme in Environmental Modelling at the Faculty of Environmental Sciences of the Czech University of Life Sciences in Prague. He is the principal investigator of projects on the topics of changes in the hydrological balance due to climate change, adaptation measures, drought, evaporation, and related issues.

Ing. Ladislav Kašpárek, CSc.

TGM WRI, p. r. i., Prague
✉ ladislav.kasparek@vuv.cz
www.vuv.cz

Ing. Ladislav Kašpárek started to work in the field of hydrology in 1968 at the Czech Hydrometeorological Institute. He focused mainly on the development of methods for evaluating hydrological phenomena (including extreme ones), and on the development of hydrological balance models. Since 1987, he has been working at TGM WRI. In recent years, he has dealt with the assessment of real changes in precipitation and flows due to ongoing global warming, projections of hydrological data for water management measures after the end of open-cast coal mining, methods for calculating the size of natural groundwater resources, and the possibility of extrapolating flow series over centuries, for which there are reconstructed estimates of precipitation and air temperatures.

Mgr. Jiří Prinz

TGM WRI, p. r. i., Prague
✉ jiri.prinz@vuv.cz
www.vuv.cz

Mgr. Jiří Prinz has been an employee of the Department of Hydrogeology at TGM WRI since 2023. In 1997, he completed his master's studies at the Faculty of Natural Sciences of Charles University in Prague, majoring in hydrogeology. He deals with a wide range of issues associated with the use and protection of groundwater. Currently, he participates in ongoing projects of the Department of Hydrogeology.

Ing. Petr Sklenář, Ph.D.

TGM WRI, p. r. i., Prague
✉ petr.sklenář@vuv.cz
www.vuv.cz

Ing. Petr Sklenář, Ph.D., has been working at TGM WRI since 2022 and has been the Head of the Hydraulics Department since 2023. In 1992, he completed his studies at the Faculty of Civil Engineering of the Czech Technical University in Prague, majoring in Water Management and Water Construction, and in 2004 he successfully completed a doctoral study programme at the same faculty and in the same field. He has been working at the Faculty of Civil Engineering at CTU since 1993 at the Department of Hydraulics and Hydrology. He deals with the issues of river hydraulics, riverbed morphology, and flood prevention measures.
During his time at CTU, he has participated in several medium- and short-term stays and courses, especially at foreign universities and research facilities in the UK and Portugal (University of Hertfordshire, HR Wallingford, Universidade do Porto, Instituto Superior de Engenharia de Coimbra, Laboratório Nacional de Engenharia Civil), and worked in the expert section of the IAHR fluvial hydraulics. As the principal investigator or a research team member, he has participated in several research projects in related areas both at CTU and TGM WRI.

Ing. Adam Vizina, Ph.D.

TGM WRI, p. r. i., Prague
✉ adam.vizina@vuv.cz
www.vuv.cz

Ing. Adam Vizina, Ph.D. has been working at the Department of Hydrology at TGM WRI since 2007. In 2014, he completed the doctoral study programme in Environmental Modelling at the Faculty of Environmental Sciences of the Czech University of Life Sciences in Prague. He deals with the assessment of the hydrological balance for current and future conditions, the assessment of hydrological extremes, and hydrological modelling. He is the principal investigator of several research and private projects.


Foto: archiv R. Tolasze

Interview with RNDr. Radim Tolasz, Ph.D., climatologist of the Czech Hydrometeorological Institute

Today, one individual cannot quickly mitigate the current impact of climate change that the entire world is facing by changing their behaviour. However, the promotion and spread of education is one of the main keys to making positive changes in a significant part of the population. In an interview for VTEI, the Czech representative in the Intergovernmental Panel on Climate Change (IPCC), climatologist RNDr. Radim Tolasz, Ph.D., from the Czech Hydrometeorological Institute (CHMI), describes further steps to mitigate the effects of climate change or, for example, his own first professional experience after 1980.

Mr. Tolasz, you have been dealing with climatology, meteorology, and hydrology for a long time. Do you remember the moment you said to yourself that this field would be your „lifelong love"?

Probably not, because the beginning of my professional „career" was very wide spread. I studied physical geography and in my diploma thesis I analysed the regime of sedimentation in the Odra basin. After joining the CHMI branch in Ostrava, I concentrated on the so-called water bearing cadastre between 1931 to 1980, and there I finally got to climatology via studying precipitation. I remember very clearly that the runoff conditions on the Čeladenka (which is a small basin in the Moravian-Silesian Beskydy between Smrk and Kněhyně) in the cadastre showed curious results affected by windward precipitation effects. This is probably where I realized how significantly the climate affects other parts of the physical-geographical sphere. And looking back today, I actually experienced paper, pen and calculator climatology in practice, then „wrote" programs in Fortran on punch cards that I took to the computing centre, only to come back two days later to pick up the result of „error on line 154". Those were interesting times compared to today, when modellers prepare megabytes of data for us, on which we start several processes in the R programming language in a few hours. I really don't know when exactly my interest in climatology was born.

Talk of possible climate change began as early as the 1970s. Can you recall your first awareness of this phenomenon?

We discussed it for the first time at grammar school in Havířov in geography lessons, sometime around 1980. However, it was only basic information focused on the greenhouse effect and not very analytical. But it stuck with me, and when we discussed climate change in more detail a few years later as part of a climatology lesson at the Faculty of Science in Brno, I had something to build on. From today's point of view, however, the information was not very accurate and detailed; in almost forty years climatology has taken a huge step forward. Simply put, it was only an estimate of the behaviour of the atmosphere based on the laws of physics. Today, we already know a lot about feedback, about the combination of natural climate variability and anthropogenic influences, and we can model these phenomena, which also gives us probabilistic estimates of the behaviour of the atmosphere in the near future. In its projections and estimates, climatology thus came between meteorology and its weather forecast and geological estimates of the next ice age, both in terms of time and accuracy.

Are the manifestations of climate change that were predicted twenty to thirty years ago occurring at the moment, or did some of them surprise you?

Today we have already confirmed that the climate projections from the 1980s were quite accurate for several decades ahead. The first IPCC report in 1990 estimated a global temperature rise of 1 °C by 2025, and this will certainly be met and exceeded. At the time, little emphasis was placed on the fact that the temperature rise would be higher on land, and even higher, for example, in central Europe, with a continental climate quite distant from the seas and oceans. And we can therefore be surprised that in our country the rise in temperature is almost double compared to global values. Moreover, even today, we are little aware that the problem for humans is not so much in averages as in extremes. Long heat waves with temperatures above 30 °C were unimaginable fifty years ago in the Czech Republic – and now they are an annual reality. At the same time, we have often emphasized that we do not expect a long-term decrease in precipitation, which is still true today; however, we lack water in the landscape more and more often. Why? Because at a higher temperature there is more evaporation. Even this surprises many people, as they do not realize the basic difference between water vapour and clouds in the atmosphere. The water that is missing in our landscape is kept in the form of water vapour at a higher temperature of the atmosphere, and therefore does not increase the precipitation potential. Today's upper estimate of the average temperature in 2050 in the Czech Republic is at the level of 10 °C with an estimated error of ± 0.3 °C, and we have no reason not to believe these model outputs. Let's just put it in context with the average temperature in the Czech Republic for the normal period 1991 to 2020, which is 8.3 °C. In less than thirty years, we could be another 2 °C warmer on average. What will the summer heat be like?

And perhaps I would add that in recent years in Europe, including in our country, the probability of so-called fire weather has increased. It is logical and corresponds to the previous information, and in reality we can observe it directly. The big fire last year in Bohemian Switzerland National Park was not extraordinary in its occurrence, but in its scope and duration, which was influenced by fire weather parameters. Last year's wildfires in Northern Europe are totally extraordinary – they never appeared in these areas before. And this year's summer season in the Mediterranean is also absolutely extraordinary from the point of view of the scope and duration of natural fires, and is most certainly related to the changes taking place in the climate system.

Is it possible that for some reason, for example, due to the weakening of the Gulf Stream, climate change in the Czech Republic or in Europe will stop, or will „reverse" its course and it will start to cool down?

It is possible. Fluctuations in the volume and temperature of the Gulf Stream are normal, but some oceanographers estimate that the Gulf Stream will slow down in the coming centuries. However, the question remains how such a gradual change can alter the entire ocean circulation system. The Gulf Stream is not an isolated element in the ocean; in nature, everything is connected, and that applies to the ocean too. I'd rather not rely on it when dealing with climate change.

Do you think there are places in the world that will be transformed from inhabited to uninhabitable due to climate change?

Some climate models project, for example, for the Arabian Peninsula in the second half of the century, on some summer days, a combination of high temperature above 50 °C and humidity above 70 %, which will be completely unsuitable for humans and the area will be uninhabitable in the outdoor environment. People will have to take refuge in air-conditioned spaces and not go out at all. For some shopping fans, this will probably not be a change, but it is necessary to prepare for such a situation. However, not everyone lives in the developed and rich part of this region.

TGM WRI cooperates with CHMI on your „PERUN" project, which is very ambitious. Can you say which outputs you are most looking forward to?

We are currently analysing the first available climate scenario in the *„PERUN"* project, which we have prepared based on the pessimistic emission scenario SSP5-8.5. We look at dates that we think and hope will not be achieved on average. We are looking at the upper limit of the possible development of the characteristics of our climate until 2100. Few people realize that the year 2100 is not so far away – today's young children will live to see it. That is also why I am glad that these scenario data will be gradually analysed by our future colleagues to find out what could happen in our landscape, in forests, rivers, but also in groundwater. In connection with the second, more probable scenario according to SSP2-4.5, we will give the state administration, politicians, and the public information that I personally consider important – what our climate will be like in ten, twenty, or fifty years. What conditions must our agriculture, power engineering, drinking water supply, construction, tourism, and other areas prepare for. And I am most looking forward to the time when some of the *„PERUN"* project investigators will evaluate in ten or twenty years whether anyone took our forecasts into account at all.

You are a regular participant in foreign conferences, and you have experience of similar foreign projects. How does the Czech Republic compare in this area? And is it possible to interconnect the outputs of these projects?

Not only is it possible, but it is quite common. The *„PERUN"* project is sometimes accused of being a national project, closed within the borders of the Czech Republic. It is not so. Our modellers are part of the global community, climate scenario experts routinely discuss the possibilities of their use and inclusion in other European results, and hydrologists in neighbouring countries are eager to know how much water we send them in our scenarios. Of course, a lot depends on how well we manage to get the results of the *„PERUN"* project into top peer-reviewed journals. It's not about quantity, it's about quality. In this context, it is good to remember that the seventh IPCC assessment cycle is starting, and it is therefore the right time to try to get our results into the new IPCC reports.

Can you name five things each of us can do to mitigate the effects of climate change? Start with the most important, please.

There is not much an individual can do to mitigate the current impact. In hot days they should change their daily routine if possible, in dry seasons they should not waste water, during a gale they should not walk in the forest, and during floods they should not go canoeing. However, each individual has the power to mitigate the effects of climate change in the future. The most important thing is to elect a political representation that will listen to science and promote climate measures. Furthermore, every person in our country could and should reduce their own consumption, which translates into a much-needed lower consumption of raw materials and energy. Thirdly, I consider it important to support and spread education, because only educated people understand the necessity of implementing the measures that climate change puts before us. It's difficult, but fourthly, let's try to ensure that only competent people make decisions– engineers about power engineering, foresters about forests, transport experts about transport, water managers about water, etc., and always with an overall view and, above all, in context. If these four wishes worked, then we don't need the fifth.

Speaking of the influence and capabilities of each of us, on your website three years ago you decided to write the so-called „Climate Ten Commandments of the Individual", where you try to summarize our options for responding to the ongoing climate change. There are two more points to be added to the list. Do you know what they will be?

I don't know, I think the „ten commandments in eight points" mentioned is a good summary of the options that each of us as an individual have to influence future climate change. Little do we realize that the climate system has a lot of inertia, that all our activities accumulate in it for decades and only then begin to manifest themselves. That is why we see a mismatch between the growth of greenhouse gas emissions and the rise in temperature, that is why greenhouse gas concentrations can increase continuously, but the global temperature of the atmosphere fluctuates. We must not forget the influence of the oceans, which are also warming, and of large forest units, for example in tropical rain regions, which, on the other hand, can absorb more or less greenhouse gases depending on their size and quality. These are all reasons why we need to change our behaviour now so that future generations have fewer problems.

Thank you for speaking to us.

Ing. Adam Beran, Ph.D.
Ing. Adam Vizina, Ph.D.

RNDr. Radim Tolasz, Ph.D.

RNDr. Radim Tolasz, Ph.D., born on 19 March 1964 in Frýdek-Místek, has been working at the Czech Hydrometeorological Institute (CHMI) since 1986 as a climatologist, in 2003–2011 he was deputy director. He is a World Meteorological Organization (WMO) expert on climatological databases and climate data exchange. He is also the co-author of the Czech climatological application CLIDATA, which has been used in CHMI since 2000. In cooperation with WMO, this application is used in more than 30 meteorological services around the world (Estonia, Latvia, Lithuania, Montenegro, Serbia, Tanzania, Ethiopia, Georgia, Ghana, Namibia, Nigeria, Dominican Republic, Trinidad, Tobago, and others). Since 2014, he has represented the Czech Republic in the Intergovernmental Panel on Climate Change (IPCC). He is the author and co-author of many scientific articles and publications, and since 2012 he has also been the editor-in-chief of the Czech *Meteorological News (Meteorologické zprávy)* and a member of the editorial board of the Slovak *Meteorological Journal (Meteorologický časopis)*.


Photo: J. Unucka

„Water Centre“

The research project of the Technology Agency of the Czech Republic SS02030027 *„Water systems and water management in the Czech Republic in conditions of climate change“*, whose guarantor is the Ministry of the Environment, tries to answer the question of whether we will continue to have enough quality water. Climate change and the associated drought, as well as human behaviour and demands threaten water, and solutions must be sought for the immediate future.

WATER FOR PEOPLE (WP3 WORK PACKAGE)

The Department of Hydraulics, Hydrology, and Hydrogeology of the TGM WRI is the principal investigator of the work package called „Water for People“. In the research, it collaborates with the Czech Hydrometeorological Institute, the Global Change Research Institute of the Czech Academy of Sciences, the Faculty of Environmental Sciences of the Czech University of Life Sciences in Prague, and the Faculty of Civil Engineering of the Czech Technical University.

The objective is to find suitable measures for the conservation of water resources for drinking water supply in areas where there is already a shortage, or could be in the future. The following main measures are assessed:

Water transfers from places with its excess to places with its shortage

When dealing with this issue, water transfer refers to the technical infrastructure that ensures the supply of water from a place where there is enough of it to a place where there is not (during a hydrological drought), or diverting part of the flood runoff into a watercourse or water reservoir where it does not cause harm.

Artificial infiltration – controlled seepage of surface water into the ground

The aim of the project is methodological, technical, and professional preparation of specific areas for artificial infiltration technologies. The first stage in 2021–2023 assesses the specific potential of controlled allocation methods. This assessment takes place on a platform of hydrological basins including deficit areas and their surroundings with respect to sites for the accumulation of surface water (lokality pro akumulaci povrchových vod, LAPV) and other proposed adaptation measures in other sub-objectives. The result of the first stage will be the delineation of those areas where water conditions can improve due to the application of artificial infiltration methods. The second stage in 2024–2026 will focus on specific technical solutions in several of the most urgent and suitable pilot sites, which will be assessed by experts in order to design specific technologies.

Protection of valuable groundwater resources, e.g. by adjusting management in their protection zones and other protected areas

The objective is to establish modern principles of complex protection of water resources in the era of climatic and anthropogenic changes affecting water regime and water resources, proposals and recommendations for the necessary changes in the content and functions of protected areas according to the Water Act.

Change in handling or increase in storage space at existing water reservoirs or flood release basins and modelling of water quality in water supply reservoirs

The objective is to assess possibilities for prospective changes to the handling regulations of existing water reservoirs with regard to the results of simulations of climate models with an outlook of 2100. One of the relevant tools for proposing changes in the use of multi-purpose water reservoirs and for modifying handling regulations or redistribution between storage and retention space in the reservoir will be outputs from mathematical modelling of water quality development in relation to handling methods in reservoirs. Another part of the objective is a proposal for changes in the use of the protective area of flood release basins, in particular by allocating sufficient space for permanent water storage or storage space so that these reservoirs fulfil multi-purpose functions while their primary purpose is not limited. Such functions can include, for example, the requirement to ensure minimum residual flows and also the ecological or microclimatic effect.

Construction and restoration of small water reservoirs

The objective is a methodological assessment of the suitability of construction of small water reservoirs (SWR) with regard to their function under current and prospective hydrological extremes (drought, floods). As part of the project, SWR retention abilities will be assessed, as well as the possibility of complying with the minimum residual flows. SWR will also be assessed from the point of view of the overall hydrological balance, microclimate improvement, and infiltration potential.

Support for natural water retention in the landscape by introducing technical and semi-natural adaptation measures

The objective is to choose a suitable methodological procedure for designing adaptation measures supporting natural infiltration through water retention in the landscape. Proposals for retention methods should contribute to extending the duration of increased and mean flows, reducing immediate flood conditions, ensuring higher infiltration into groundwater, reducing soil erosion and chemical runoff, improving water quality, improving the security of surface water and groundwater sources, and contributing to the protection of aquatic and water-related ecosystems.

Possibilities of building new water reservoirs for the accumulation of surface water (LAPV)

The sites listed in *Generel LAPV* will be assessed (especially those in deficit areas), as well as adjacent sites that can favourably influence deficit areas. The project will take into account the importance of individual LAPV with regard to the expected abstractions and flow improvements, and the degree of security, resistance and vulnerability of the planned reservoirs will be assessed. Calculations will be made for existing conditions as well as conditions based on climate change scenarios. The potential impact of the reservoir on the quantity and quality of groundwater, on local ecosystems, and also on changes in the socio-economic aspects of sites will be generally assessed.

For deficit areas in terms of water availability in the Czech Republic, such combinations of the above-mentioned measures will be proposed, which will return water to the landscape as efficiently as possible while minimizing negative impacts on the surroundings.

The main results of the entire WP3 package are aimed at the end of 2026. Now, in the course of the project, it is possible to introduce new elements in the sub-goals of the WP3 package. On the subject of artificial infiltration, the most significant ones are the complex application of surface water and rainwater infiltration methods (bank, artificial and surface infiltration) for a variety of purposes. Induced sources are able to contribute to the overall improvement of the water regime of the landscape, including flood flows, maintaining minimum flows in watercourses during drought, or supporting individual and public water supply systems. Last but not least, they can support protected areas related to water (wetlands, springs, etc.).

Regarding the issue of changing the handling or increasing the storage space of existing water reservoirs or flood release basins, the project suggests an innovative approach within the methods of controlled handling and allocating parts of the storage space in water reservoir. Modelling of quality with full reservoir hydrodynamics will also allow better capture of predicted changes due to expected climate change. Furthermore, it is the application of a comprehensive approach to solving the issue of existing or planned SWR in deficit areas, or in the entire Czech Republic, under current and future climate conditions. Functioning under both minimum and flood flows will also be assessed.

Ongoing research to support natural infiltration is expanding knowledge in the topics mentioned below:

Assessment of semi-natural measures in the catchment area and their effectiveness – Amálie site (small surface retention, change of land use, changes in soil properties, drainage measures).

Rainwater management, assessment of risks and the potential of an integrated solution to rainfall-runoff conditions and retention support in agricultural landscape and urban areas – Vrchlice site.

Modelling the choice of appropriate adaptation measures in agricultural areas (forest land) for specific soil and physical characteristics, assessment of impacts on water resources – use of a simulation tool from the project in the Dyje basin.

Modelling runoff in small basins taking into account changes in land use (CN curve method).

Modelling hydrological balance, water balance in the basin with changed conditions due to the introduction of adaptation measures on watercourses and floodplains – use of semi-natural monitoring measures („*Drought*" project).

Project period: 2021–2026

Authors

Ing. Anna Hrabánková
anna.hrabankova@vuv.cz

RNDr. Josef Vojtěch Datel, Ph.D.
josef.datel@vuv.cz

Ing. Adam Beran, Ph.D.
adam.beran@vuv.cz

Ing. Petr Sklenář
petr.sklenar@vuv.cz

Ing. Roman Kožín
roman.kozin@vuv.cz

Ing. Vojtěch Moravec, Ph.D.
vojtech.moravec@vuv.cz

T. G. Masaryk Water Research Institute, Prague

Funded by:

T A
Č R

Guarantor:

Ministerstvo životního prostředí

Investigation team:

VÚV TGM

Český hydrometeorologický ústav

CzechGlobe

ČZU

FAKULTA STAVEBNÍ ČVUT V PRAZE


Photo: J. Unucka

VTEI/2023/5

Since 1959

VODOHOSPODÁŘSKÉ
TECHNICKO-EKONOMICKÉ INFORMACE

WATER MANAGEMENT
TECHNICAL AND ECONOMIC INFORMATION

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 65

VTEI.cz

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

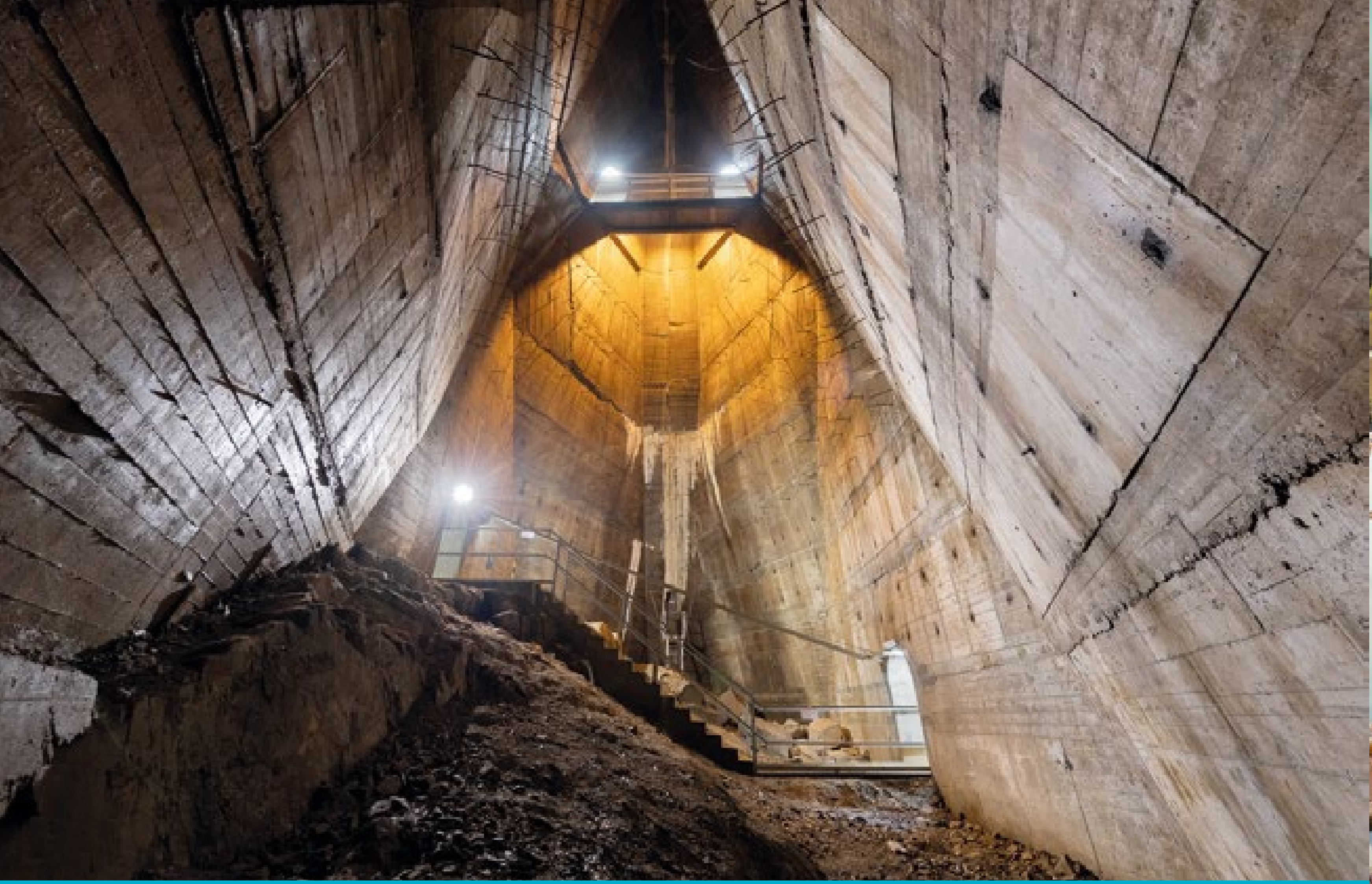
Sources of photographs for this issue:
TGM WRI, 123RF.com, RNDr. Tomáš Hrdinka, Ph.D., doc. RNDr. Jan Unucka, Ph.D., Viktor Mácha

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 December 2023.
Instructions for authors are available at www.vtei.cz

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



FLÁJE WATERWORKS

Fláje waterworks is located on the Flájský stream near Český Jiřetín. The dam was built between 1951 and 1963 as part of the water management system for supplying drinking water to the North Bohemian lignite basin. It is the only concrete gravity buttress dam in the Czech Republic. It consists of 19 Noetzli type pillars and 15 gravity blocks. The design is based on the model of Lucendro buttress dam in Switzerland, built in 1947. The distance between the axes of the individual pillars is 13 m. On the downstream face there is a three-meter gap between the pillars, covered by boards 1 m thick. This leaves huge cavities between the pillars, creating a cavernous effect (*see photo*). The dam is 55.5 m high above the base, with a length at the dam crest of 459 m. The total volume of the reservoir is 23.1 million m^3.
Fláje is a water reservoir with anti-flood function and with the power engineering use of water draw-off by Meziboří peak-load hydropower plant. An interesting fact is that at a distance of less than 8 km downstream in Saxony, there is Rauschenbach dam, another large dam built between 1960 and 1968.
Fláje waterworks significantly shapes the identity of the place and, as the only example of a buttress dam in our country, it has a significant typological value. Since 1987, the dam has been listed. Since 2019, the Povodí Ohře State Enterprise has been offering tours of the inside of the dam for the public.

Text by Ing. Miriam Dzuráková and Ing. Radka Račoch, photo by Viktor Mácha.

VÝZKUMNÝ ÚSTAV
VODOHOSPODÁŘSKÝ
T. G. MASARYKA
veřejná výzkumná instituce

VTEI.cz