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(WATER MANAGEMENT TECHNICAL AND ECONOMIC INFORMATION)
VTEI/2022/5

THEME

Water regime in changing climatic conditions

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13th October – International Day for Disaster Risk Reduction

"The world faces cascading crises that are causing profound suffering today, and carry the seeds of dangerous inequality, instability, and climate chaos tomorrow." António Guterres, UN Secretary-General, July 2022, United Nations Office for Disaster Risk Reduction, New York.

International Day for Natural Disaster Reduction was declared an international day by the UN General Assembly at its plenary session on 22nd December 1989. The goal of the activities associated with this day is to involve every government and every citizen in building communities and nations that are more resilient to disasters. Commemorating this day should lead to thinking about how people can influence the occurrence and course of natural disasters with their behaviour, especially climate change and global warming, and ideally reduce them. Today, we have the possibility to predict disasters with great accuracy, be it earthquakes, floods, hurricanes and others, but the possibilities of preventing these disasters are in many cases very limited.

Given the urgency of the issue, the UN General Assembly adopted a resolution in 2002 to commemorate the day annually as a means of spreading a global culture of natural disaster risk reduction, including prevention, mitigation, and preparedness. Seven years later, in 2009, the UN General Assembly decided to celebrate the day on 13th October every year and also changed its name to International Day for Disaster Reduction.

In 2015, at the Third UN World Conference on Disaster Risk Reduction in Sendai, Japan, the international community was reminded that natural disasters have the greatest impact at the local level, but with the potential to cause economic and social losses that go far beyond that local level. Sudden and unexpected natural disasters in some cases result in the displacement of millions of people, with a negative impact on investments in sustainable development. At the conference in Japan, the Sendai Framework for Disaster Risk Reduction (2015–2030) was adopted. Among other things, this document is linked to other agreements related to Agenda 2030, including the Paris Agreement on Climate Change.

The Sendai Framework promotes substantial reduction of disaster risk and loss of life, livelihood, and health as well as economic, physical, social, cultural, and environmental assets of individuals, businesses, communities, and countries. Simultaneously, it recognizes that the state has the primary role in reducing the risk of disasters, but other stakeholders should also take responsibility, including, for example, local governments and the private sector.

"Climate change is undoubtedly the biggest threat facing the planet and humanity. 90% of major disasters in the last 20 years are linked to climate change. Their impacts make sustainable development unattainable." Mami Mizutori, Special Representative of the UN Secretary-General for Disaster Risk Reduction and Head of the UN Office for Disaster Risk Reduction (UNDDR), July 2022, United Nations Office for Disaster Risk Reduction – New York.

Commemorating International Day for Disaster Risk Reduction thus becomes one of the opportunities to be fully aware of this danger and, as a result, to decide to use all our forces and means to avert it.

VTEI Editorial

In September 2015, at the General Assembly of the United Nations, the global community adopted common sustainable development goals to be achieved by 2030.

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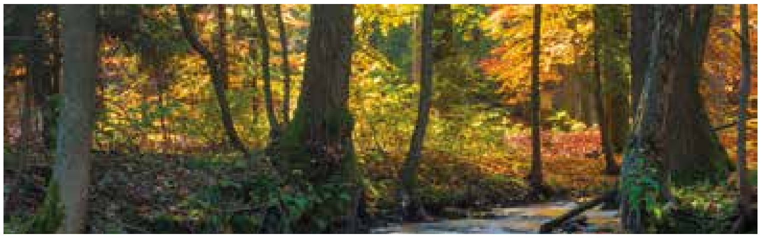

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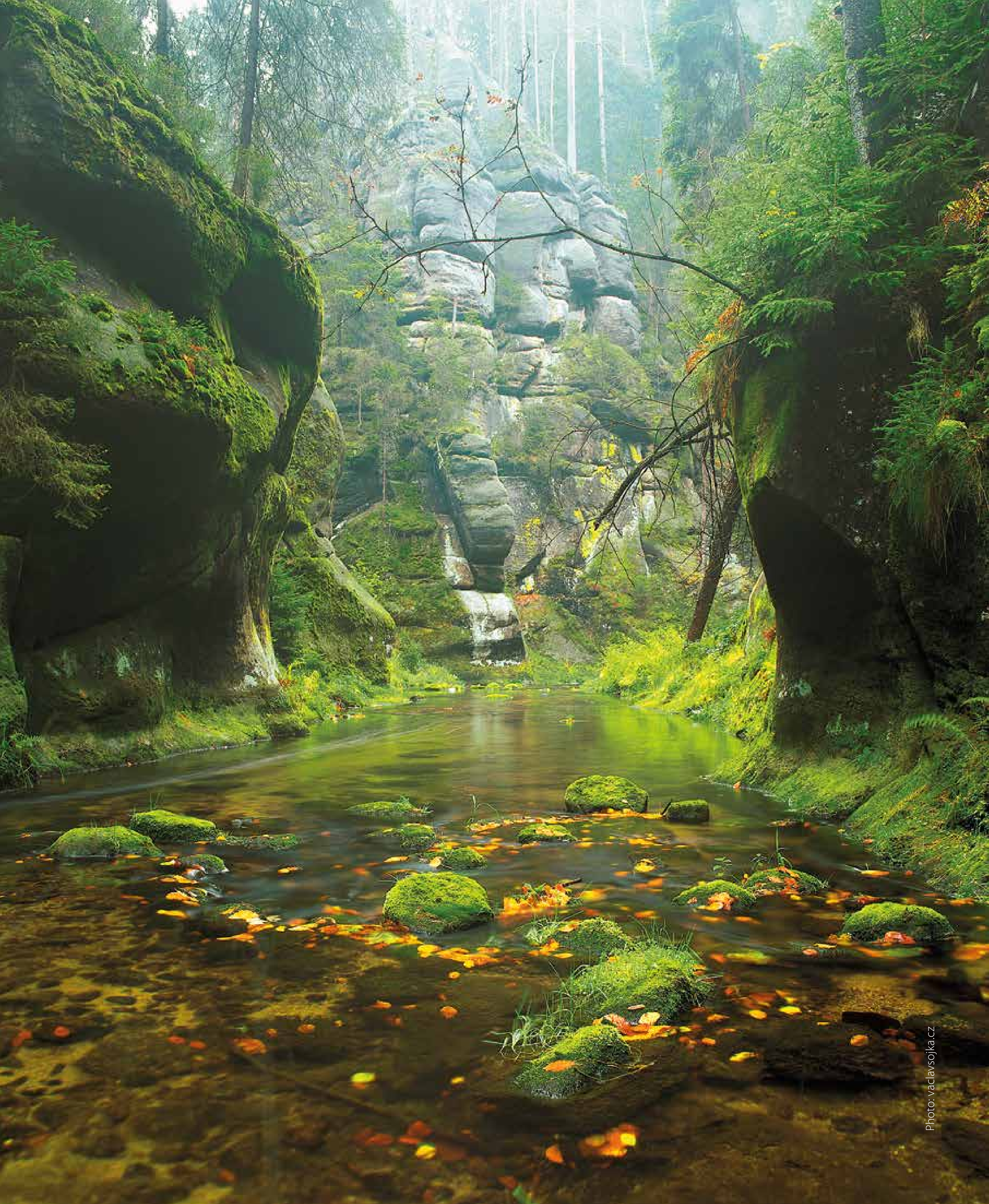
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Dear readers,

In the past few days we commemorated a quarter century since the floods in Moravia and Silesia and the 20th anniversary of the floods in Bohemia, including Prague. Many dead, thousands of destroyed houses, and enormous damage made us aware of how uncertain the world we live in is, and how much we need to stick together not only as a family or a team, but also as a whole nation and humanity. A tornado in Moravia, energy crisis, and a war not far from our borders send a direct signal for us to focus on the essence of our being rather than entertainment, comfort, and the trappings of modern life. In the same way, the hundred-year flood in Moravia and the thousand-year flood in Prague (and perhaps also the flood in 2013), the recent six-year drought, a number of fires due to drought (including the latest one in Bohemian Switzerland National Park), and torrential rainfall – they all indicate that our environment is indeed changing. 20 years ago, climate change was not emphasized so much, people rather spoke about unusual meteorological situations; however, in today's terminology, these events would already be considered evidence of climate change.

Perhaps it is worth realizing that we are not alone. I looked at press releases from the last few days to find events that can indirectly affect us as well, and I will present a few of them:

"Before this year's Communist Party Congress, China hoped for stronger economic growth, but stagnation is coming instead. The country has not seen a longer heat wave since 1961. Temperatures reached over 40 degrees Celsius and one of its consequences is the drying up of rivers and water reservoirs, which are an important source of energy for China; the level of the Yangtze River has dropped to its lowest level since 1865. In addition, due to the parched soil, there is a risk of flooding."

"In Kenya, water taps are more of a household accessory. Water rarely flows from them. Kenya is one of the countries with the greatest water shortage. Its inhabitants therefore have to look for it from natural sources, such as streams. However, no one guarantees that it will be drinking water. According to UNICEF, nearly 10 million Kenyans drink contaminated water."

"Floods in Pakistan caused by monsoon rains have already claimed at least 1,136 lives and caused 10 billion USD (246 billion CZK) in damage in the country, according to preliminary government estimates. Torrential rains, which came in June, washed away roads, bridges, a million houses, and crops from the fields. The floods affected over 33 million people, i.e., more than 15 per cent of Pakistan's population."

"California is experiencing a chronic 'mega-drought' where dry summers are becoming more frequent and wet summers are becoming rarer. The current drought, which began around 2000, is the second worst in 1,200 years. The drought has shrunk California's Lake Shasta, which is California's largest reservoir. It is a key source of water for agriculture in the Central Valley. The level of the reservoir dropped by 33 metres in one year and its water supply decreased by about 40%. The largest reservoir in the USA, Lake Mead, which supplies drinking water to 20 million inhabitants of the cities of Las Vegas and Los Angeles, is in a similar situation; its level has been falling since 2000, but more rapidly in recent years. This year, the water level is the lowest since it was filled in 1935."

Those are distant countries, but if you look around Europe, Germany is experiencing its sunniest summer in 70 years – the sun is set to shine for 817 hours this year – and the lack of water on the Rhine is making it difficult to transport oil and coal. France has had its hottest summer on record, 2.3 °C above the 1991–2020 norm.

The output of the Rhône and Garonne nuclear power plants has been temporarily reduced because there is not enough cold river water to cool them. The French tax authorities even used artificial intelligence to search for the owners of thousands of undeclared private swimming pools, who have had to pay a total of about 10 million EUR in taxes for them. Italy has been experiencing its worst drought since 2003. A massive heat wave in the country has destroyed agricultural production – a third of it is said to be at risk this year. In Switzerland, three power stations have been shut down due to cooling and the army was deployed to prevent herds of cows from dying of thirst. Many reservoirs in Norway have historically low water levels and, as a result, the government has decided to limit the export of electricity to other countries until the reservoirs are replenished. At the beginning of August, the Netherlands declared a nationwide water shortage. In Poland, the authorities have already introduced restrictions on river transport due to very low water levels. In Britain, they are preparing citizens for water shortages and teaching them to be less sensitive about what water they drink, even if it is mixed with treated wastewater; such water is said to be *"completely safe and healthy, even if some people don't like it."*

Of course, we could continue the list of disasters and threats, sometimes perhaps a little exaggerated, for a long time. However, the point was to show that we must not wait for problems with drought and water to arise, but we must deal with them proactively and ahead of time. Water management constructions or measures related to the environment will only show up in 10 or 20 years, and even if we sometimes do not choose the ideal path, it is better than nothing.

I hope that this monothematic VTEI issue, focused on hydrology, hydraulics and hydrogeology, will contribute at least a little to the realization that, despite all our problems, our situation in the Czech Republic is not too bad, and that it is primarily up to us how pragmatically we assess and solve challenges such as water retention in the countryside, care for drinking water sources, protection against floods, agricultural and energy self-sufficiency, and other activities dependent on water. We have the conditions, educated water managers and researchers, and even the financial resources for it. We just have to find the courage to enforce the changes.

Ing. Tomáš Urban
Director of TGM WRI, p. r. i.

Estimation of natural groundwater resources in hydrogeological zones in the Czech Republic under changing climatic conditions 1981–2019

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Keywords: hydrogeological zone — groundwater resource — groundwater outflow

ABSTRACT

In the Czech Republic, hydrogeological zones were defined as early as 1965 as a part of the regional hydrogeological survey. A hydrogeological zone (HGZ) is defined as a unit with similar hydrogeological conditions, defined tectonically and geologically, in whose territory a certain type of aquifer and groundwater circulation prevails. The boundaries of HGZs have been modified over time and their numerical hydrogeological characteristics have been determined by various methods; one of the basic characteristics is the amount of natural groundwater resources. Natural resources are the dynamic component of groundwater and are expressed in $m^3.s^{-1}$. They are determined by the recharge of water to the aquifer system (precipitation, groundwater overflows from other aquifers, natural infiltration of surface water, etc.). If the HGZ is hydrogeologically closed, the long-term average of its recharge from precipitation and the long-term average of baseflow can be used as an estimate of the natural groundwater resource. In the "*Groundwater Rebalance Project*", estimates of natural groundwater resources in 152 hydrogeological zones in the Czech Republic were processed and are presented in the report [1]. The natural resources were determined by several different methods using data from 1971–2010 and 2000–2010.

Due to the intensive increase in average annual air temperatures in the Czech Republic after 1980, and with special consideration of the dry period 2014–2019, we used data from the period 1981–2019 for the current estimation of natural groundwater resources in the hydrogeological zones. The applied method of calculation was based on determination of total runoff from the hydrogeological zone and its conversion to baseflow using the baseflow index (BFI), the regional elaboration of which is included in the study [2]. Two calculation alternatives were used to determine total runoff: by the balance difference between precipitation and estimated evapotranspiration and by the regression relationship between precipitation and runoff. Both types of relationships were derived from the results of flow monitoring at Czech Hydrometeorological Institute (CHMI) water gauging stations and from monitoring of rain gauge and climate stations. For each HGZ, a relationship derived from data of the basins in which the zone lies and which it is adjacent to was used, taking into account the orographic similarity of the zone and the basin. Long-term averages of precipitation and temperature were calculated for the HGZ. According to these relationships, long-term total runoff averages were determined by interpolation or extrapolation.

The results of the calculations showed that the method based on regression of runoff on precipitation gives estimates on average 5 to 6% greater than the method using evaporation estimates. Both calculation alternatives, when compared to previous results from the "*Groundwater Rebalance Project*", show a decrease in average baseflow, and a corresponding decrease in average groundwater recharge, of approximately 7 to 12% during the 1981–2019 period compared to the 1971–2010 period. The decrease can be attributed to an increase in average air temperature of approximately 0.4 °C between the compared periods, with nearly unchanged average precipitation. The observed changes in natural groundwater resources over the two periods show regional differences due to the hydrogeological characteristics not included. As the results were not obtained by the same methods, their use for intercomparison is limited. The results for the HGZ show changes in the interval ± 20% for 61% and 72% of the cases, respectively, depending on the method used.

INTRODUCTION

Determining the usable amount of groundwater for sampling is one of the basic tasks of hydrogeological research. The main part of this work is the assessment of the size of groundwater resources within the defined balance hydrogeological unit. For these purposes, hydrogeological zones (HGZ) were defined as basic balance units used to determine the size of groundwater resources. The Czech Republic is divided into 152 HGZ.

The size of groundwater resources is determined spatially (in the optimal case, it refers to a hydrogeological structure with a closed groundwater cycle, which contains both infiltration and drainage areas) and temporally (both in terms of a time interval, e.g. a hydrological year, and in terms of temporal variability formation of groundwater resources due to temporal fluctuations of hydrological parameters).

Three types of groundwater resources are distinguished: natural, induced, and artificial. Natural resources are formed under natural, mostly unaffected conditions in a certain hydrogeological unit in a defined period of time. Under anthropogenically changed conditions, induced resources (e.g., bank infiltration near abstraction facilities) and artificial resources (e.g., artificial seepage of water into underground structures) may arise.

This article refers to natural groundwater resources in individual HGZ which are formed in the area of these zones. Hydrological balance approaches were used, which are based on the fact that infiltrated precipitation is the main source of groundwater formation. Natural groundwater resources as a dynamic component of their reserves are determined by the process of hydrological balancing as spatio-temporally defined baseflow. It is necessary to see the limits of the hydrological methods used, which in principle cannot include overflows between collectors, as well as induced groundwater resources, which manifest themselves, for example, in Quaternary zones (the influence of bank infiltration, or ongoing drainage from subsoil units, etc.).

The size of natural groundwater resources can be estimated using a combination of different methods, which can be divided into three basic groups: first, according to the amount of infiltration; second, according to the underground flow through the corresponding collector; and third, according to the amount of water that is drained from this system.

The dry period of 2014–2019 had a significant impact on the size of groundwater resources, as evidenced by the lowering of groundwater levels within groundwater monitoring in the CHMI nationwide network. In the *"Groundwater Rebalance Project"* (2011–2016), estimates of natural groundwater resources were made in all 152 HGZs based on input hydrological data for the period 1971–2010, with comparative use of partial data for the period 2000–2010. The determination therefore did not include the following dry season. At present, it has already been possible to proceed with a new balance estimate based on data from the period 1981–2019 and try to compare the results with the previous outputs of the *"Groundwater Rebalance Project"*.

However, a direct comparison of the achieved results for both periods is hindered by the different methodological approaches that were chosen to determine natural resources in individual HGZs in the *"Groundwater Rebalance Project"*. This was related to the different level and amount of available data that had to be reckoned with in different zones. As follows from the report [3], a more detailed approach was chosen in 55 defined zones, where measured data was also used. Derived regression relationships between precipitation and runoff and between precipitation and baseflow, or a balance approach using a balance equation including determination of evaporation, were chosen to determine natural resources. The final list of natural resources were the result of an individual assessment of the results achieved using different methods according to the specific situation of each zone.

In another 30 HGZs, detailed hydrological balance models were processed and their outputs used to determine the baseflow. In another seven HGZs, it was not possible to determine natural groundwater resources, mainly due to the massive anthropogenic impact of the areas, mostly through the extraction of raw materials. That left 60 zones where the base runoff was estimated using the chosen hydrological approaches. In 31 zones created by division of the original zones, the method of analogues and the distribution of precipitation within the zones was used to determine baseflow, and for the remaining 29 zones, original values from 2006 were used, converted to averages and to the period 1981–2010. The procedures used are described in detail in the report [1].

As shown below, the new results obtained on the basis of the derived balance and regression relationships are thus not completely comparable with the older data in order to mechanically compare the numbers for the two periods. Their comparison can only be done individually within individual zones.

METHODOLOGY

One of the basic methods of determining the groundwater recharge is the use of a hydrological balance model which allows the calculation of the time course of groundwater recharge. Normally, the parameters of the model are calibrated according to data from the catchment area of water gauging stations so that runoff modelled according to precipitation and air temperatures is as close as possible to observed runoff. Except for cases where the HGZ coincides with the catchment area of the water gauging station, the estimate of runoff from the HGZ is based on the results of modelling of the catchments into which the HGZ extends to, and from nearby catchments with a similar hydrogeological character. In this procedure, the parameters and input variables – precipitation and air temperature – evaluated for the HGZ area are transferred to the hydrological balance model. The described procedure is quite complex and laborious, usually requiring the calculation of several solution variants, their assessment, and selection of the resulting estimate.

If the purpose of groundwater recharge estimate is not its time course, but only the long-term annual average, instead of transferring the model solution, information can be used from the balance relationships from the basins in which the HGZ is located, as well as neighbouring basins. The calculation is based on determination of total runoff from the HGZ and its conversion to baseflow using the baseflow index (BFI). To determine total runoff, two calculation alternatives were used: first, according to the balance difference between precipitation and estimated areal evaporation, and second, according to the regression relationship between precipitation and runoff.

DERIVATION OF RELATIONSHIPS FOR ESTIMATING AVERAGE ANNUAL RUNOFF

Calculation of runoff as the difference in precipitation and areal evaporation

The calculation of the long-term averages of groundwater recharge in HGZ uses the basic relationships of hydrological balance, according to which the long-term average of total runoff R [mm.year^{-1}] is the difference between the long-term average of precipitation P [mm. year^{-1}] and the long-term average of areal evaporation E [mm. year^{-1}]. In the balance equation of long-term averages from several decades, if we ignore change in water supplies, the following applies:

$$R = P - E \qquad (1)$$

This equation (1) can be applied to the hydrological catchments of water gauging stations on the assumption that the catchment is not only morphologically, but also hydrogeologically closed, i.e. there are no inflows or outflows of water between neighbouring catchments. Areal evaporation can then be estimated as the difference between observed precipitation and runoff calculated from the monitored flows. If the difference P – R deviates from the regional level, an increase indicates runoff outside the closing profile, and a decrease indicates inflow of groundwater from the neighbouring catchment or collector.

The variable that is considered to be the upper limit of areal evaporation is the potential evapotranspiration (PET). To calculate it, we used the following equation:

$$PET = 37.9 \cdot T + 289.4 \qquad (2)$$

where PET is average annual potential evapotranspiration [mm.year^{-1}]
T average annual air temperature [°C]

Equation (2) when applying the areal evaporation calculation method according to Oudin [4], was recommended for the Czech Republic by Beran et al. in their study [5].

According to this equation, potential evapotranspiration increases linearly with increasing air temperature. Since the relationship between air temperature and precipitation is mostly linear, a decrease in potential evapotranspiration with increasing precipitation is usually linear. This can be seen in *Fig. 1*, which shows the courses of the balance variables depending on precipitation. The course of areal evaporation plotted against precipitation is non-linear and shows that, in the interval of precipitation less than about 600 mm (where precipitation is less than potential evapotranspiration), evaporation increases with precipitation and is limited by precipitation. Above the specified limit for increasing precipitation, evaporation decreases; the influence of the decrease in potential evapotranspiration corresponding to the decrease in air temperature prevails. The change described is continuous and is manifested by the curvature of the relationship between precipitation and runoff.


Photo: 123rf.com

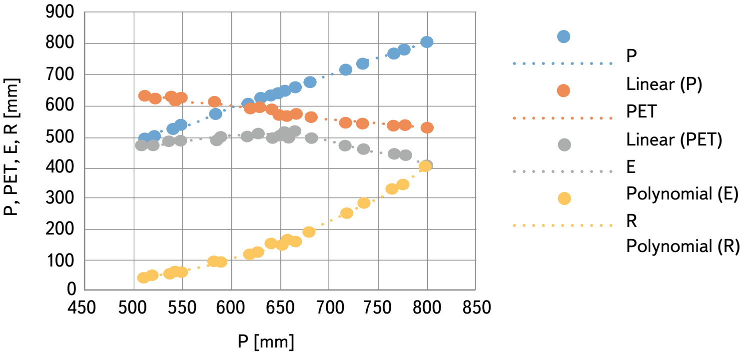

Fig. 1. Long-term annual averages of balance variables plotted against average annual precipitation; an example derived from observed data from water gauging stations in the Svratka basin above the Svitava tributary

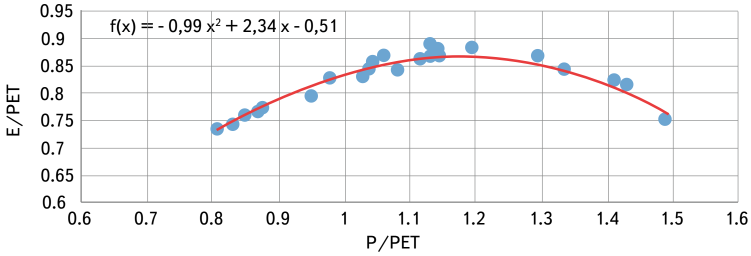

Fig. 2. Example of the relationship between E/PET ratio and P/PET ratio, observed data from water gauging stations in the Svratka basin above the Svitava tributary

The courses shown in *Fig. 1* serve as an example. The data come from a set of catchments of water gauging stations from the Svratka basin above the Svitava tributary. The results from other basins have a similar course; the area of change in areal evaporation trend is mostly in the interval of average annual precipitation of 600 to 700 mm.

A procedure was developed for regional analyses in which relative variables are used from the point of view of the influence of air temperature, or potential evapotranspiration. Evaporation is characterized by the E/PET ratio, so we estimate it as a percentage of potential evapotranspiration. The variability of the E/PET ratio, depending on precipitation, corresponds to the above-described cumulative effect of precipitation and temperature on the amount of areal evaporation. The E/PET ratio increases with increasing precipitation up to the area where there is sufficient temperature for evaporation, and then it decreases for the fact that falling air temperature limits evaporation. The P/PET ratio can be used as an independent variable; see [6]. An example of such processing is shown in *Fig. 2*. We used this type of correlation analysis to estimate average evaporation and, based on this, calculated an estimate of average annual runoff by subtracting it from precipitation. For the analytical expression of the correlation relationship between P/PET and E/PET, we used a second degree polynomial in most catchment areas.

Regression relationship of runoff and precipitation

To express the relationship between long-term average annual precipitation P [mm] and average long-term runoff R [mm], a non-linear dependence – a second degree polynomial, see *Fig. 1* – proved suitable.

$$R = a \cdot P^2 + b \cdot P + c \qquad (3)$$

The parameters a, b, c of relationship (3) describe the shape of the function R = f(P) corresponding to the fact that areal evaporation reaches its maximum in the area where the combination of precipitation and temperature is optimal for it. The non-linear courses of runoff dependence on precipitation are clearly visible when analysing data with a large range of precipitation. When analysing local data with a smaller precipitation range, linear function also provides usable results.

Data selection procedure for deriving a relationship for estimating average annual runoff for individual hydrogeological zones

With a few exceptions, both procedures described above were used for all HGZs.

We derived parameters of the relationships from the flow monitoring results in CHMI water gauging stations and according to monitoring of rain gauging stations and climate stations in the basins and their surroundings. Monthly series were processed; average monthly flows were supplemented with water use and reservoir operation. From the monthly series, long-term annual averages of runoff, precipitation, and temperatures were calculated in the catchment area of the water gauging stations. Data from 1981–2019 were used, providing that there is an evaluated flow monitoring for at least 18 years in a row. During processing, isolated cases were excluded in which the relationship of precipitation and air temperature or the relationship of precipitation and runoff quite obviously deviated from the range of data in neighbouring basins. After this reduction, the used set contained data for the basins of 395 water gauging stations.

The selection of stations for deriving relationships was also influenced by what data and how reliable it was for the area around a specific HGZ and its surroundings. For several HGZs, we could not find data to use the relationship between the E/PET ratio and P/PET ratio, so the result is only runoff estimates based on the precipitation-runoff relationship.

For individual hydrogeological zones, the selection of water gauging station basins from which both types of relationships described above were derived was directed, on the one hand, by an effort to capture regional differences in the hydrological and hydrogeological regime, and on the other hand, by the need for at least a minimum number of cases that allow to estimate the correlation relationship.

Special attention had to be paid to the few cases with very small precipitation in the HGZ, less than the minimum precipitation in the catchment data set used to derive the relationship. The derived analytical relationship was then used for extrapolation, and other types of relationship than the standard polynomial of the second degree had to be considered.

During the calculations, estimates of total runoff determined by both described procedures were continuously compared. In some cases, significantly deviating results were identified and the probable cause of the deviation was sought. Relationships between precipitation and air temperatures were also used here, according to which estimation of precipitation for several small basins showed to be inaccurate. On rare occasions, data from deviating results were excluded from deriving the relationships.

For the deduction of long-term averages of groundwater recharge in a hydrogeological zone, we assume that the balance relationship, derived on observed basins in the area where the HGZ is located, describes the balance in the zone with an acceptable degree of agreement.

We obtained an estimate of the total average annual runoff from the HGZ by substituting average annual precipitation and average annual air temperatures, calculated from observations of rain gauge and climate stations in the HGZ, into the relationships compiled for the area in which the HGZ lies.

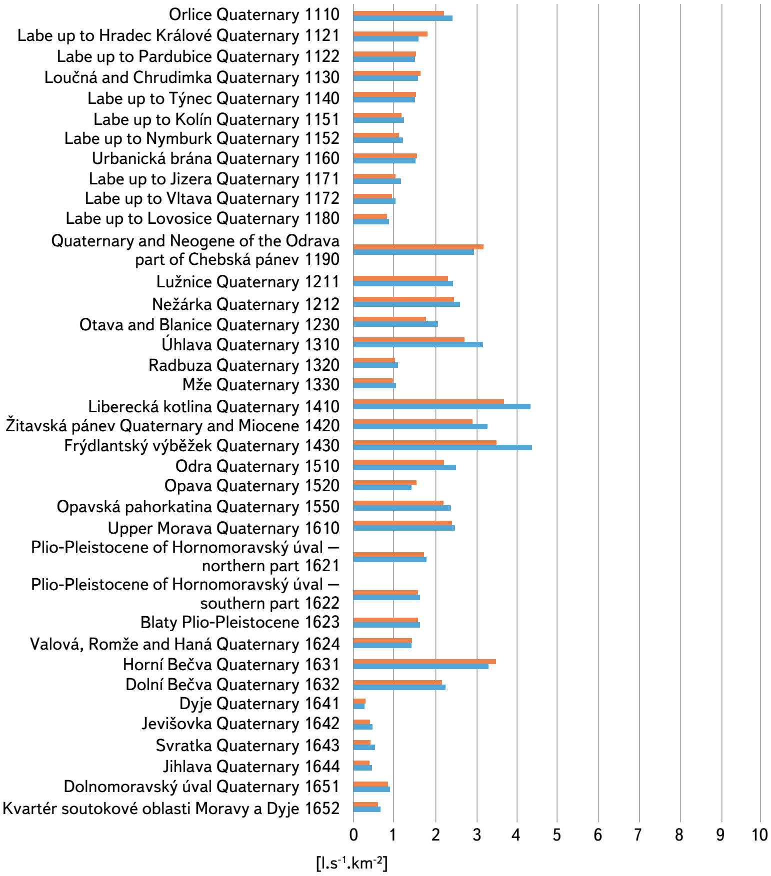

Fig. 3. Specific groundwater outflows from hydrogeological zones – Quaternary formations; estimates based on precipitation-runoff relationship are shown in blue, and estimates based on runoff as the difference between precipitation and evaporation are shown in red

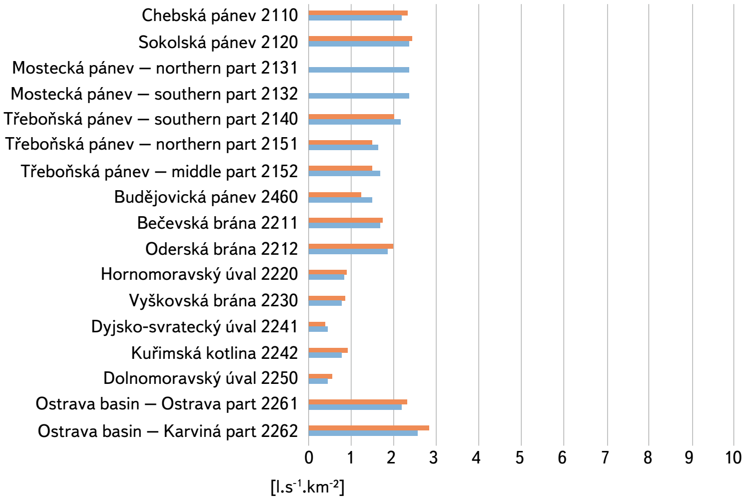

Fig. 4. Specific groundwater outflows from hydrogeological zones – Tertiary and Cretaceous basin formations; estimates based on the precipitation-runoff relationship are shown in blue, and estimates based on runoff as the difference between precipitation and evaporation are shown in red

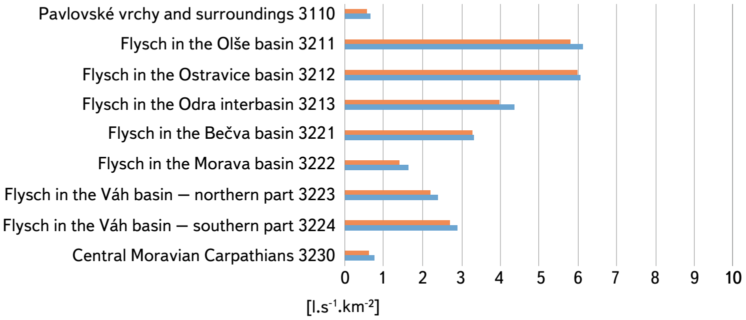

Fig. 5. Specific groundwater outflows from hydrogeological zones – Flysch sediments; estimates based on precipitation-runoff relationship are shown in blue, estimates based the runoff as the difference between precipitation and evaporation are shown in red

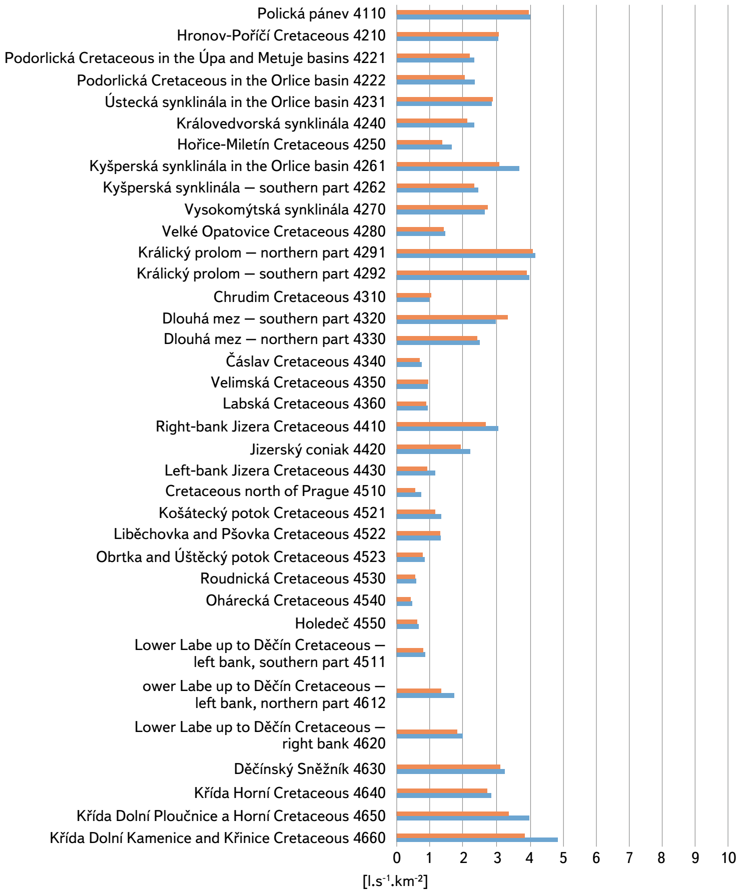

Fig. 6. Specific groundwater outflows from hydrogeological zones – Upper Cretaceous sediments; estimates based on precipitation-runoff relationship are shown in blue, and estimates based on runoff as the difference between precipitation and evaporation are shown in red

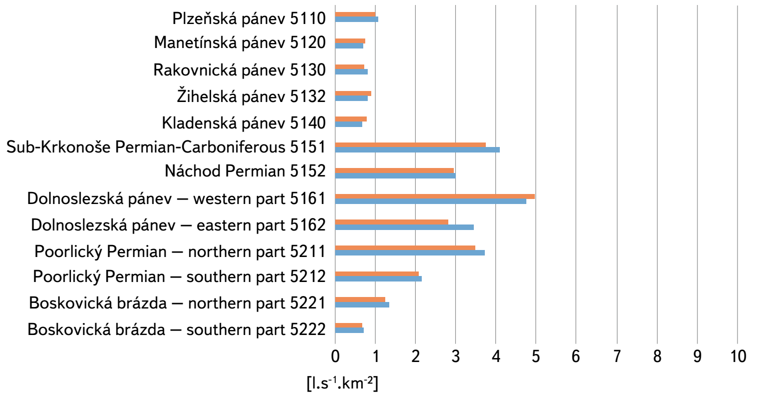

Fig. 7. Specific groundwater outflows from hydrogeological zones – Permocarbon limnic basins and trenches; estimates based on precipitation-runoff relationship are shown in blue, and estimates based on runoff as the difference between precipitation and evaporation are shown in red

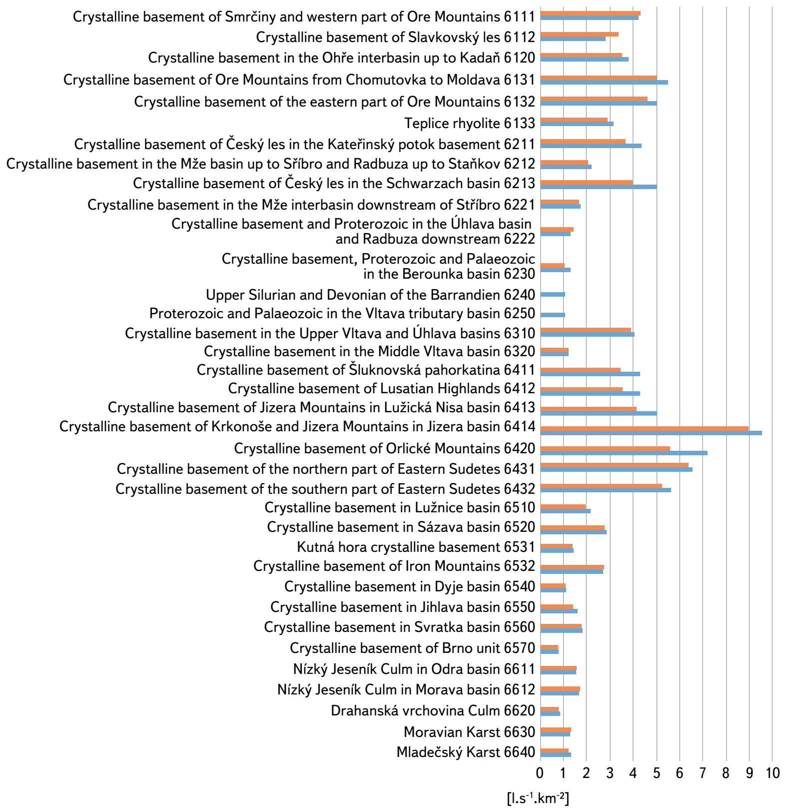

Fig. 8. Specific groundwater outflows from hydrogeological zones in a hydrogeological massif; estimates based on precipitation-runoff relationship are shown in blue, and estimates based on runoff as the difference between precipitation and evaporation are shown in red

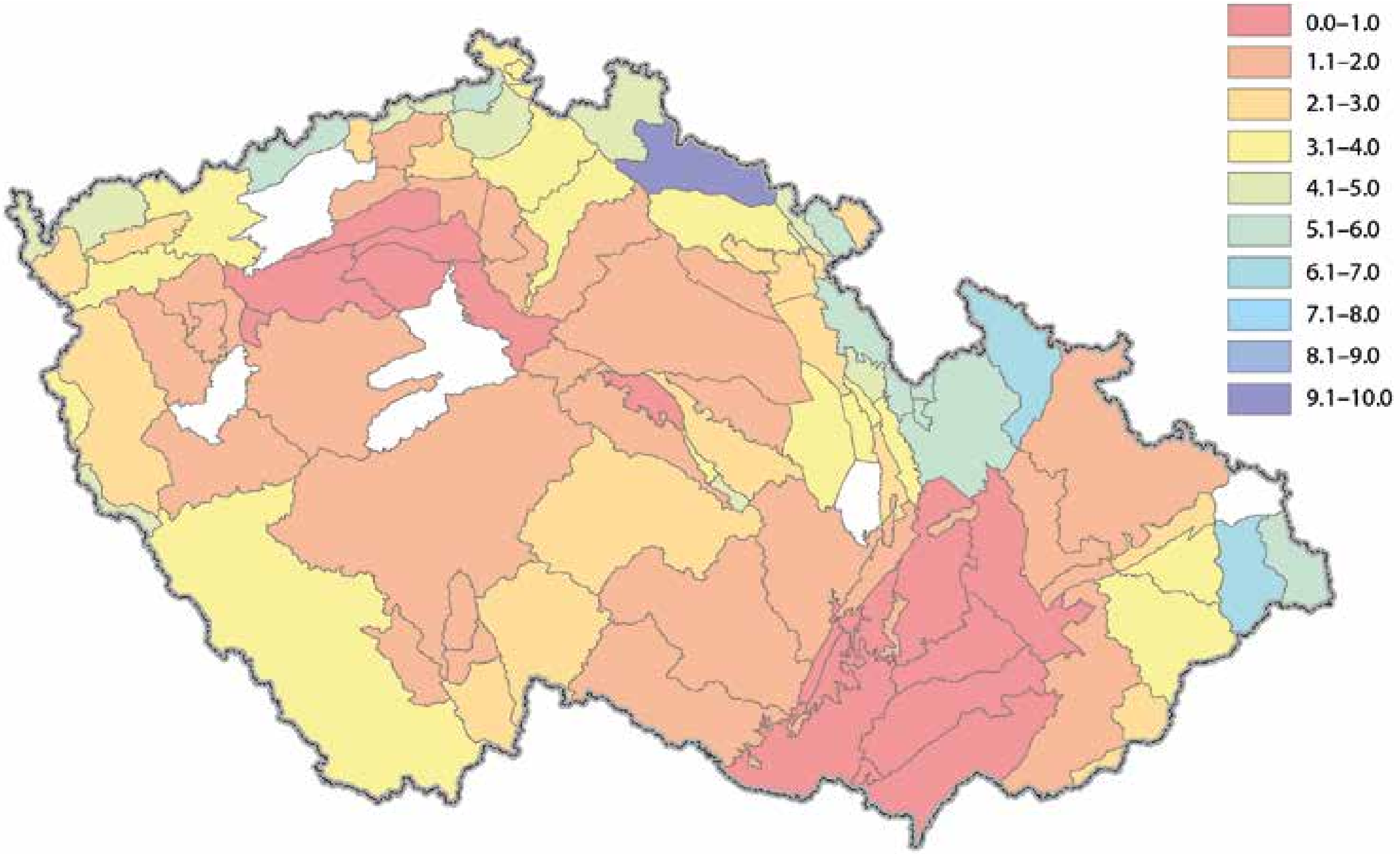

Fig. 9. Estimates of specific base flow of groundwater determined from runoff estimates (difference between precipitation and evaporation) in $l.s^{-1}.km^{-2}$; no results for uncolored zones from previous overall assessment

Tab. 1. Comparison of calculated characteristics for the whole set of processed zones

	R = f(P)	**R = P - E**	**Difference**	**[%]**
Sum of groundwater outflow Qz [$m^3 \cdot s^{-1}$]	193	182	-1.1	-5.5
Average total runoff R [mm]	181.4	169.8	-11.6	-6.4
Average baseflow Rz [mm]	76.8	72.2	-4.6	-6.0

CONVERSION OF AVERAGE ANNUAL RUNOFF FOR INDIVIDUAL HYDROGEOLOGICAL ZONES TO AVERAGE ANNUAL GROUNDWATER OUTFLOW

From the estimation of runoff R for each hydrogeological zone according to the equation

$$R_z = R \cdot BFI \qquad (4)$$

the long-term average of the baseflow Rz was calculated, which in a long-term average, neglecting changes in water reserves, corresponds to the average groundwater recharge from precipitation. It does not include possible water overflows between HGZs. The values of the BFI (baseflow index, i.e. the ratio between baseflow and total runoff) were taken from an article [2]. For several HGZs, they were derived from an observed series of average daily flows at a water gauging station whose catchment lies in the relevant HGZ, or has similar hydrogeological characteristics. The determination procedure is described in the cited article.

CALCULATION RESULTS

To show the results, average annual runoff from the HGZ were recalculated to average specific groundwater outflows from the HGZ [$l.s^{-1}.km^{-2}$]. These values are recorded in *Fig. 3–8*, broken down by type of hydrogeological structures. For the calculation based on estimation of runoff as the difference of precipitation and evaporation, they are shown in the map in *Fig. 9*. Due to overlaps, the areas of the Quaternary HGZ are not plotted on it.

COMPARISON OF RESULTS ACCORDING TO ESTIMATION PROCEDURES

Tab. 1 compares the characteristics calculated from the entire set of processed HGZs. It is clear that the procedure based on regression estimate of runoff according to precipitation amount provides estimates on average 5 to 6% larger than the method using evaporation estimate. Deviations in individual HGZ are

Tab. 2. Overall differences between data from the "Groundwater Rebalance Project" and data from the regression relationship R = f(P)

	Rebalance	R = f(P)	Difference	[%]
Sum of groundwater outflow Qz [$m^3 . s^{-1}$]	207	193	-1.4	-6.8
Average total runoff R [mm]	189.4	181.4	-8.0	-4.2

Tab. 3. Overall differences between data from "Groundwater Rebalance Project" and data from the R = P - E balance relationship

	Rebalance	R = P - E	Difference	[%]
Sum of groundwater outflow Qz [$m^3 . s^{-1}$]	207	182	-2.5	-11.9
Average total runoff R [mm]	189.4	169.8	-19.6	-10.3

Tab. 4. Differences in long-term averages of precipitation and temperature between the two assessed periods 1971–2010 and 1981–2019

	1971–2010	1981–2019	Difference	[%]
Average precipitation at HGZ [$mm . year^{-1}$]	685.6	674.5	-11.0	-1.6
Average temperature at HGZ [°C]	8.0	8.4	0.4	

in the range of 19.8 to 22.8%. The difference in the results of used procedures probably corresponds to the fact that the parameters of the relationships are estimated in alternative procedures according to the agreement of different variables. In addition, average air temperature is used in the procedure based on estimation of areal evaporation, which can also influence the resulting values.

COMPARISON OF RESULTS WITH ESTIMATES FROM THE "GROUNDWATER REBALANCE PROJECT"

As part of the *"Groundwater Rebalance Project"*, estimates of natural groundwater resources in 152 hydrogeological zones in the Czech Republic were prepared, which are presented in the report [1]. Natural resources were determined by several different procedures using data from the period 1971–2010 and 2000–2010.

The comparison of the summary results of the performed calculations with the corresponding values from the previous processing in *Tab. 2–4* shows that although in the newly used period 1981–2019 atmospheric precipitation in the HGZ was less than 1.6% on average, groundwater outflow decreased by an average of 6.8% according to the calculations of precipitation-runoff relationships, and by 11.9% according to relationships based on areal evaporation estimate. Decreases in average total runoff R of 8–19.6 mm agree reasonably well with the result of an article [7], in which the relationship between a warming of 1 °C and a decrease in the runoff in the range of 15–45 mm is presented. This corresponds to a range of 6–18 mm for a warming of 0.4 °C. Warming of 0.4 °C occurred in the Labe up to Děčín and the Dyje up to Dolní Věstonice basins; it was smaller in the Upper Morava basin and in the Odra basin.

The map in *Fig. 10* shows the areas in which application of the estimate of natural groundwater resources by the procedure based on calculation of average runoff from the basin according to the difference in precipitation and evaporation leads to values greater, or smaller than the corresponding data from the previous processing mentioned above.

Both calculation alternatives, when compared with previous results from the *"Groundwater Rebalance Project"*, show, according to long-term averages, a decrease in average baseflow, and thus also in average groundwater recharge in 1981–2019 compared to 1971–2010 in the range of about 7–12%, which can be attributed to an increase in average temperature by about 0.4 °C (with almost unchanged average precipitation). In area vies, areas with decrease predominate. When using the results, it should be taken into account that the compared values were not obtained using the same methodological procedure and estimates for individual HGZ are also burdened by uncertainty when determining input variables.

CONCLUSION

The described procedure estimates natural resources of HGZ corresponding to recharge of the runoff regime from precipitation; it does not include recharge from watercourses in Quaternary zones or possible overflows of groundwater between zones and collectors. The estimate is based on determination of total runoff from the HGR and its conversion to basic outflow using the BFI. To determine total runoff, two calculation alternatives were used: first, according to the regression relationship between precipitation and runoff; and second, according to the balance difference between precipitation and estimated areal evaporation. A procedure based on regression estimation of runoff according to precipitation provides estimates that are on average 5–6% larger than a procedure using evaporation estimation.

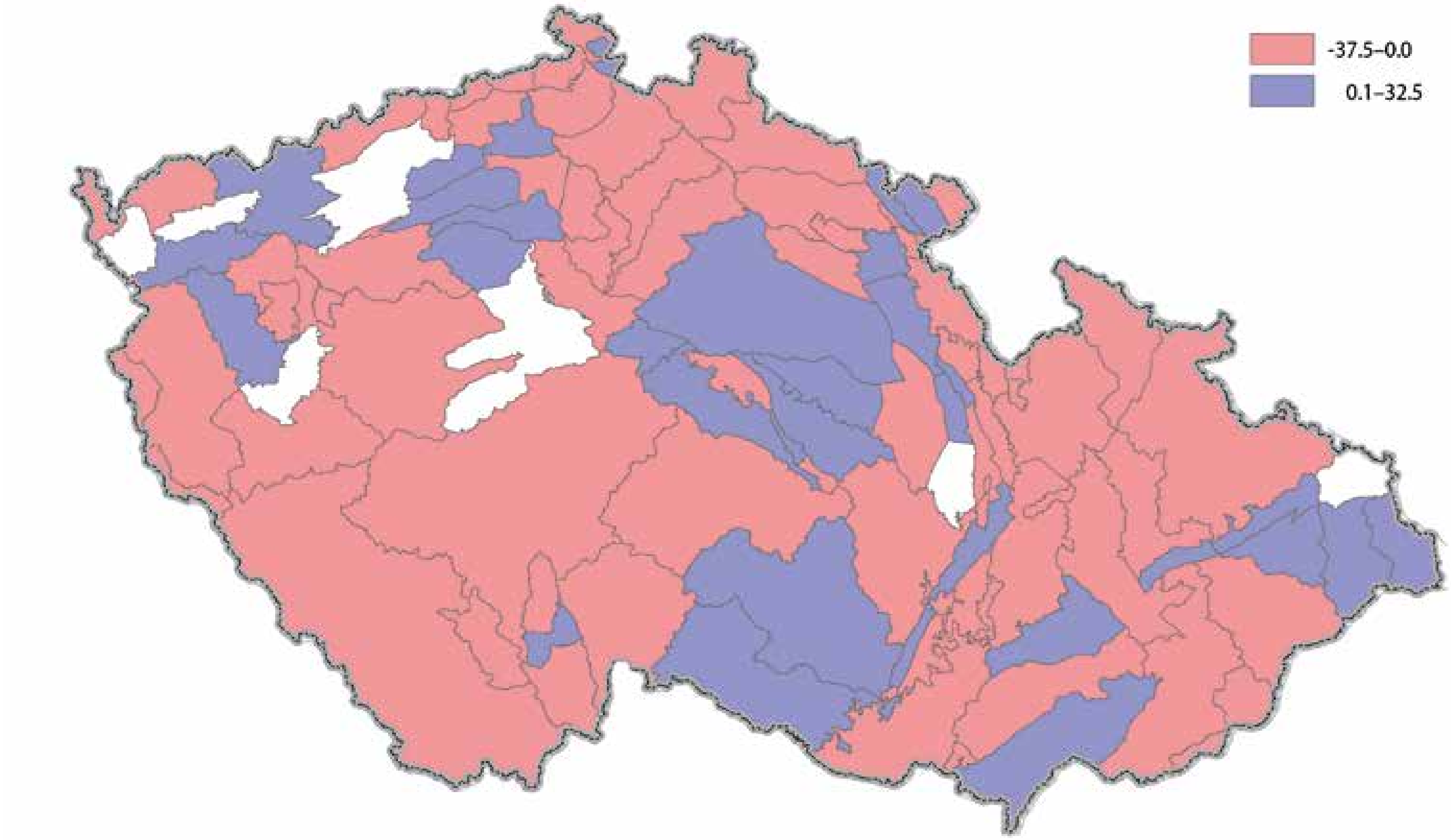

Fig. 10. Differences in the estimate of specific groundwater baseflow determined from the estimate of runoff as a difference in precipitation and evaporation from the results of the previous overall assessment, expressed as a percentage; no results for uncoloured zones from the previous overall assessment

When compared with previous results from the *"Groundwater Rebalance Project"*, according to long-term averages, both calculation alternatives show a decrease in average baseflow, and thus also in the groundwater recharge in 1981–2019 compared to 1971–2010 in the range of about 7–12%, which can be attributed to an increase in average temperature by about 0.4 °C (with almost unchanged average precipitation). Changes in natural groundwater resources show regional differences. Given that the results used for comparison were not obtained using the same methods, the changes for individual HGZs range within ± 20%, namely for 61% and 72% of the cases, respectively.

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Impact of Teplice restoration on river basin runoff – preliminary results

ADAM BERAN

Keywords: catchment hydrology – restoration – evaporation – monitoring

ABSTRACT

As part of the project for the Ministry of the Environment of the Czech Republic dealing with the monitoring of the impact of semi-natural measures on improving the hydrological regime of small river basins, the Teplice river basin in the White Carpathians has been monitored. The monitoring has been taking place since 2018, the measures were implemented in 2020. Data are available for the time period before the measures were implemented and for the year 2021, on which it is possible to see the impact of the implemented restoration. The data show the fluctuation of the daily runoff from the river basin and its overall reduction, which is probably caused by increased evaporation from the newly formed water bodies and increased water infiltration into the underground zone, which, however, is not supported by monitoring. Based on the evaluation of the obtained data, a visible reduction of the surface runoff from the basin was found, which may nevertheless also be caused by the low rainfall totals in 2021.

INTRODUCTION

Unsparing interventions in water regime significantly affect runoff from a basin. This mainly concerns the method of agricultural management and land drainage, canalization of watercourses, inappropriately designed anti-flood measures and, last but not least, the method of land use (impervious surfaces, buildings with roof drainage, etc.). In addition to anthropogenic influences, nature currently has to come to terms with the impact of climate change, which manifests itself mainly in the rise in air temperature with the consequence of increased evapotranspiration of water, and subsequently the limitation of runoff and recharge to soil and groundwater. These manifestations increase the risk of longer dry periods [1, 2].

To avoid the negative consequences of anthropogenic influences and the impact of climate change on the overall water status, it is necessary to strengthen water retention in the landscape; therefore various forms of increasing water retention in the landscape are an integral part of adaptation measures designed to limit the negative impact of climate change. Comprehensive implementation should also include such measures regarding the use of land that would directly prevent the accelerated runoff of water from the landscape. One of the means to retain water in the landscape are semi-natural measures, which can, by increasing the infiltration of water in the floodplain on a local scale, slow down the runoff from the catchment and thus strengthen the groundwater resources. Another benefit can be an increase in air humidity in the immediate vicinity of newly constructed water bodies, which has a positive effect on the neighbouring ecosystem.

The article summarizes the results of hydrological monitoring in the Teplice river basin in the White Carpathians. The monitoring has been ongoing since 2018, semi-natural measures were implemented in 2020. Changes in the behaviour of the hydrological regime before and after the implementation of the restoration are documented on the data obtained by measuring the runoff from the basin.

METHODS AND DATA

Project *"Drought – monitoring of semi-natural measures"*

As part of the project *"Drought – monitoring of semi-natural measures"* for the Ministry of the Environment, a comprehensive monitoring of watercourses and land in their catchment areas was carried out in the Czech Republic in order to evaluate the impact of the implementation of restoration measures to protect against the impact of drought. For the purposes of evaluating their influence, it is necessary that the subject areas and sites be comprehensively monitored even before the implementation of the individual measures begins due to the impact on the initial state of the natural system, while monitoring should continue for several years after the implementation of the proposed measures.

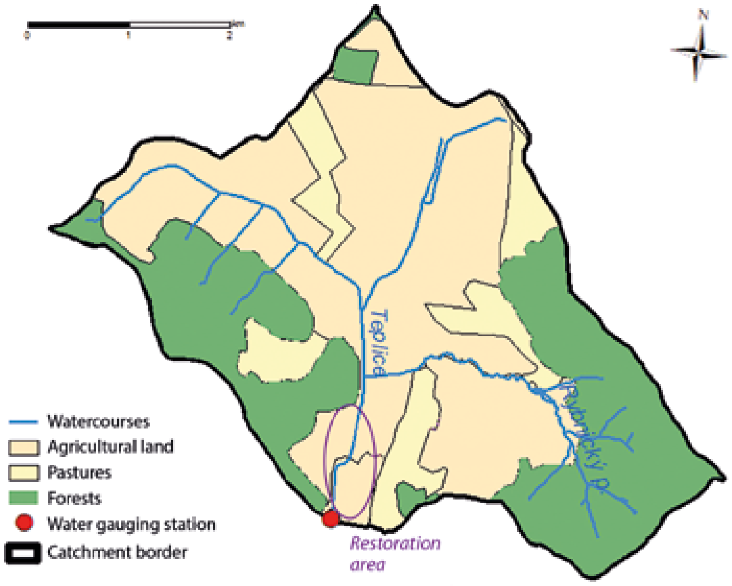

Fig. 1. Teplice catchment

Monitoring of watercourses and catchment areas took place in sites where semi-natural measures were planned to be implemented within a time horizon of one to three years, i.e. in 2017–2019. These were monitoring techniques guaranteeing the determination of hydrological and hydroecological properties of watercourses, including water quality and soil properties of the affected sites [3].

Teplice catchment

The area of interest of the Teplice catchment *(Fig. 1)* is located in the White Carpathians PLA in the South Moravian region, in the eastern part of the Hodonín district. The closing profile with the water gauging station is located in Slovakia, 100 m from the state border with the Czech Republic. The altitude of the basin ranges from 340 to 631 m above sea level. Teplice springs south of the village of Kuželov near the Czech-Slovak state border. The two more significant left-hand tributaries in the basin are Javornický potok and Rybnický potok. Teplice, as Teplica, flows further through the territory of Slovakia and flows into the Myjava river near the village of Senica. It then flows into the Morava River south of Břeclav at the triple border of the Czech Republic, Slovakia and Austria.

The area of the Teplice basin to the closing profile of the water gauging station is 17.57 km^2. There are forests (6.05 km^2), agricultural land (9.39 km^2) and pastures (2.13 km^2) in the catchment area.

In the monitored period 2018–2021, the average runoff from the basin was 16 l/s..

Teplice restoration

The implementation of the restoration took place in 2019–2020. The project was co-financed by the European Union – the European Fund for Regional Development within the Operational Programme Environment, and the managing body of the Ministry of the Environment.

The part of the Teplice watercourse south of the village of Kuželov was modified and straightened in the past to prevent agricultural land from becoming wet. The runoff from the basin was thus accelerated. The restoration of the channel aimed to carry out eco-stabilization interventions that will

Fig 2. In the left is the area of interest before the implementatin of the measure (2018), in the right after the completed revitalization (www.mapy.cz)

contribute to the retention of water in the landscape and to the improvement of the overall hydrological situation of the area. The project was supposed to lead to the restoration of natural processes and to the strengthening of biodiversity in the White Carpathians PLA.

Fig. 2 shows a comparison of the morphology of the watercourse on orthophoto maps from 2018 with the Teplice channel still straight, and from 2021, where the completed reopening of the Teplice channel in the landscape is supplemented by newly established water bodies. The photo in *Fig. 3* comes from the time of implementation, while *Fig. 4* documents the state after the completion of the restoration works..

Hydrological monitoring and data

The restoration of Teplice in the area of interest near Kuželov took place in 2020. The hydrological monitoring of TGM WRI took place before the implementation of the measures in 2018 and 2019, then during the implementation in 2020, and continues after its completion. The year 2021 was the first year suitable for evaluating the effect of the measures on the hydrological regime.

The runoff from the basin is continuously monitored by a water gauging station, equipped with a sensor with a pressure sensor and a built-in microprocessor compensating for the temperature dependence of the sensor and its possible non-linearity, which records the height of the water level in the measuring profile. The conversion of water level to flow rate takes place on the basis of the specific flow rate curve determined by hydro metering. The data on precipitation and air temperatures used to monitor hydrometeorological conditions in the basin are taken from the Czech Hydrometeorological Institute database, namely from the adjacent climatic stations Velká nad Veličkou (B1VELV01_SRA; 289 m above sea level; 6.5 km from the closing profile) and Strážnice (B1STRZ01_T; 176 m above sea level; 15 km from the closing profile).

Estimation of evaporation from the water surface

The estimation of evaporation from the water surface of new water bodies created during the restoration was based on the simplest empirical relationship, requiring only measured values of air temperature [4]. This relationship, expressed by the formula below, was derived based on the dependence of observed evaporation and air temperature at the Hlasivo station in 1957–2018. Formulas using global solar radiation, water temperature, or a combination thereof, give more accurate results, however, we did not have these measured quantities available and the purpose was to provide an approximate estimate for which the given relationship suits us.

$$VVH = 0.0824 \times T_{vzd}^{\,1.289}$$

where VVH is evaporation from the water surface
T_{vzd} mean air temperature [°C]

Furthermore, a Slovak formula (frequently used in the past) was used to calculate the evaporation from the water surface, in which the evaporation is also dependent on the air temperature [5]:

$$VVH = 10^{(0.0452*Tvzd\,-\,0.204)}$$

The formulas calculate the daily value of evaporation in millimetres; in the case of calculation using the average monthly temperature, the result must be multiplied by the number of days in the given month.

RESULTS AND DISCUSSION

Fig. 5 shows a graph with the daily course of flows and precipitation totals from 1st January 2018 to 31st December 2021. Hydrological characteristics for the monitored period are shown in Tab. 1. The long-term mean precipitation total in 1961–1990 was 750 mm [6]. In 2018 and 2019, there was below-average precipitation of 612.8 mm and 661.9, respectively. 2020 was above average with 838.8 mm, while in 2021 the precipitation total was only 547.2 mm. The mean air temperature for the reference period 1961–1990 was 7.5 °C. In the monitored period, it was 11.24 °C (2018), 10.98 °C (2019), 10.52 °C (2020), and 9.68 °C (2021), with an average flow in the closing profile of 16, 4 l/s, and then 13.4 l/s in 2018, 115.4 l/s in 2019, and 19.3 in 2020. After the restoration, in 2021, the average annual flow in the closing profile reached a value of only 13.9 l/s.

A detailed look at the daily course of the water flow through the closing profile (*Fig. 6* and *7*) shows a significant fluctuation during the day, which began to appear after the completion of the restoration. The highest flows occur

Fig. 3. Implementation of measures, 2020

Fig. 4. Completed revitalization, 2021

in the afternoon between 12:00 and 18:00 and the lowest in the morning between 2:00 and 8:00. These intraday differences amount to a maximum of 30 to 40 l/s.

The reopening of the watercourse took place on a 1.5 km long section of the previously straight channel, the length of which was extended to 2.6 km. The result of the restoration was pools with a surface area of approximately 25,000 m^2. At an average air temperature of 21 °C in the summer months, about 140 m^3 of water evaporates from this area per day, which when converted corresponds to a flow rate of 1.6 l/s. However, this water loss is twice as high due to plant transpiration. It can therefore be said that the loss of water through evaporation from water bodies amounts to approximately 3 l/s on warm days. Due to the increase in the groundwater level in the restored section, it can be assumed that the entire area of the restored section (i.e., not only the water surface), and the extended channel of the watercourse can be included in the evaporation area. Based on the monitoring, an increase in evaporation from the water surface in the restored section can be clearly confirmed. The impact on the groundwater recharge was not monitored, so it cannot be substantiated.

CONCLUSION

Hydrological monitoring of the Teplice basin showed differences between the runoff characteristics from the basin before and after the implementation of semi-natural measures. The measurement of the water flow in the water gauging station in the first year after the restoration showed in particular the daily fluctuation of the runoff from the basin due to the increased evaporation from the created water bodies and the reopened channel.

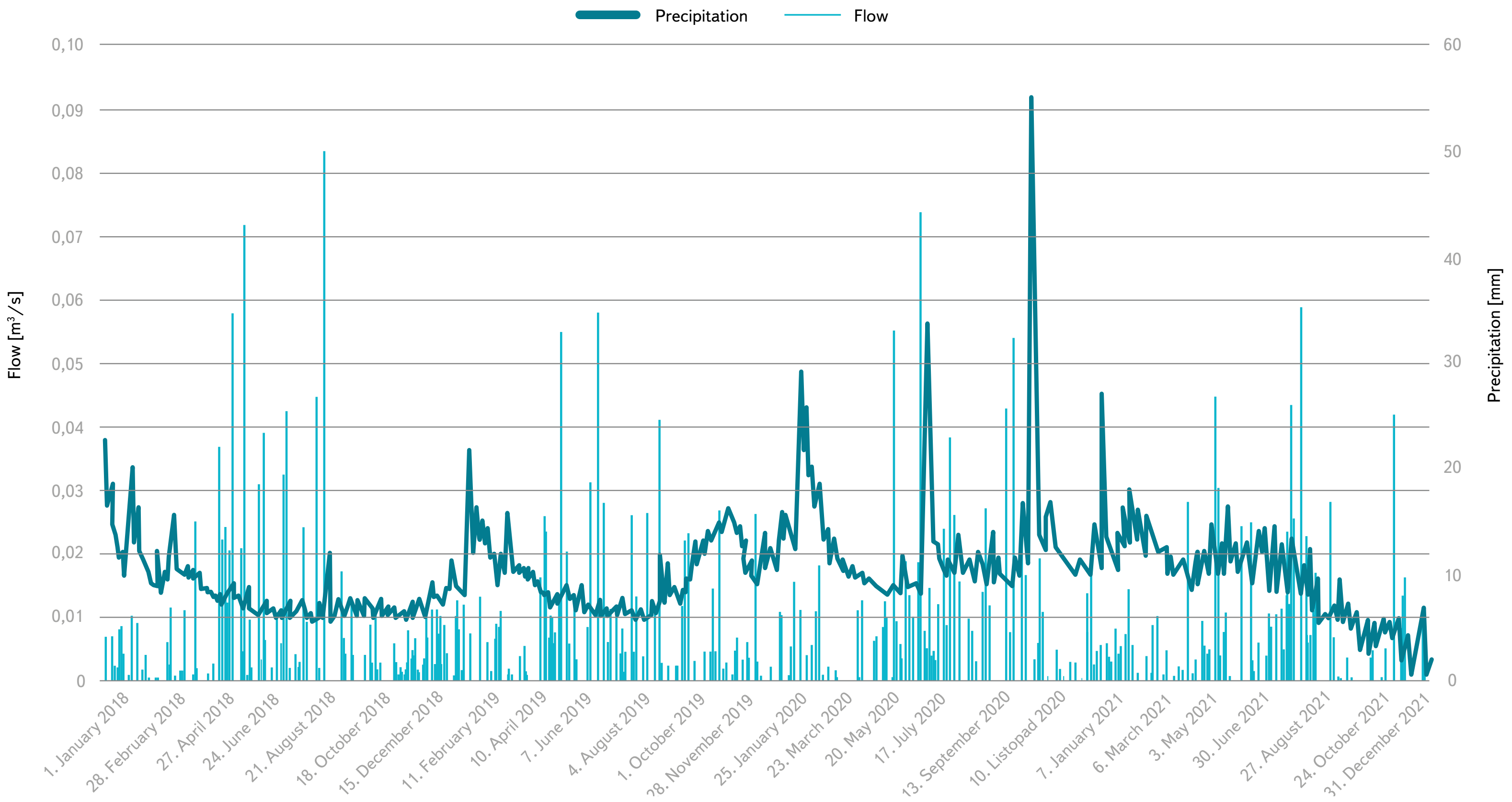

Fig. 5. Runoff and precipitation from 1 January 2018 to 31 December 2021

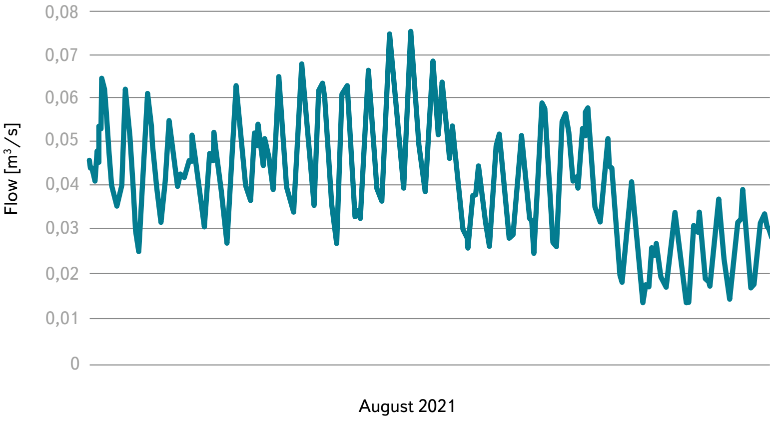

Fig. 6. Flow fluctuations after imlementation of revitalization (sample data August 2021)

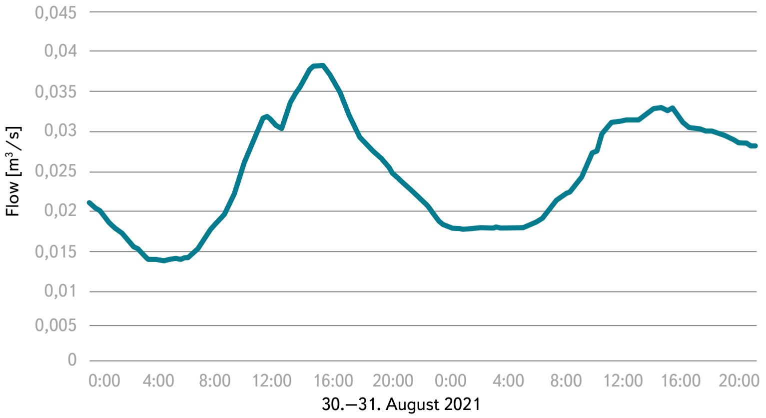

Fig. 7. Daily course of runoff (sample data – 30 August and 31 August 2021)

Tab. 1. Hydrological characteristics in daily steps (sum of precipitation, mean air temperature, mean runoff)

		Precipitation	Temperature	Flow	Runoff coefficient		Precipitation	Temperature	Flow	Runoff coefficient
Year	**Month**	**[mm]**	**[°C]**	**[m^3/s]**			**[mm]**	**[°C]**	**[m^3/s]**	
2018	1	32.4	2.84	0.0220	0.10	**2020**	18.1	0.22	0.0199	0.17
	2	17.9	-1.86	0.0178	0.14		45.8	5.86	0.0314	0.10
	3	20.6	2.61	0.0168	0.12		28.2	5.49	0.0180	0.10
	4	16.8	14.76	0.0148	0.13		15.9	10.02	0.0153	0.14
	5	110	17.44	0.0128	0.02		89	12.74	0.0146	0.03
	6	112.9	19.27	0.0116	0.02		151.8	18.02	0.0192	0.02
	7	60.4	21.04	0.0109	0.03		104.4	19.17	0.0176	0.03
	8	59.8	22.45	0.0102	0.03		54.3	20.17	0.0160	0.05
	9	99.4	16.17	0.0109	0.02		59.2	15.32	0.0163	0.04
	10	29.6	12.30	0.0106	0.05		200.9	10.52	0.0258	0.02
	11	9.5	6.13	0.0107	0.17		21.1	5.14	0.0191	0.13
	12	43.5	1.75	0.0119	0.04		50.1	3.55	0.0187	0.06
	Total/ average	**612.8**	**11.24**	**0.0134**	**0.039**	**Total/ average**	**838.8**	**10.52**	**0.0193**	**0.041**
2019	1	61.6	-1.02	0.0140	0.03	**2021**	33	0.91	0.0207	0.10
	2	31.6	1.90	0.0213	0.10		23.7	-0.34	0.0209	0.13
	3	28.7	6.55	0.0174	0.09		14	3.63	0.0175	0.19
	4	31.2	10.78	0.0148	0.07		44.3	8.13	0.0166	0.06
	5	134.1	12.10	0.0128	0.01		82.2	13.10	0.0185	0.03
	6	39	22.14	0.0116	0.04		34.2	20.32	0.0189	0.08
	7	73.5	20.10	0.0109	0.02		33.8	21.67	0.0170	0.08
	8	51.6	21.20	0.0102	0.03		147.5	18.34	0.0133	0.01
	9	60.1	15.05	0.0137	0.03		30.3	14.85	0.0099	0.05
	10	45.9	11.39	0.0188	0.06		4.3	9.72	0.0053	0.19
	11	50.4	8.38	0.0220	0.06		59.4	4.78	0.0057	0.01
	12	54.2	3.20	0.0173	0.05		40.5	0.99	0.0029	0.01
	Total/ average	**661.9**	**10.98**	**0.0154**	**0.042**	**Total/ average**	**547.2**	**9.68**	**0.0139**	**0.046**

Confirmation of the effect of evapotranspiration on the fluctuation of water runoff from the basin in the day/night regime can also be confirmed by the research of Kovář et al. [7], who studied the evapotranspiration of riparian vegetation in the dry season on Starosuchdolský potok in Prague. This phenomenon was also described in [8]. The increased infiltration of water into the underground zone probably has an effect on slowing down the runoff from the basin, however, groundwater level monitoring was not part of the project, so this assumption cannot be confirmed. It is also necessary to mention that in 2021 the precipitation total in the basin was below average at 547.2 mm.

The article analysed data for a relatively short period of time, so these are preliminary results. The monitoring of the site will therefore continue in the future, so that the research results so far can be confirmed on the basis of data obtained through long-term monitoring.

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Balance of groundwater resources and demands for human consumption during climate change conditions

HANA PRCHALOVÁ, PETR VYSKOČ, ADAM VIZINA, HANA NOVÁKOVÁ

Keywords: climate change — water resources — groundwater — drinking water supply — water balance

ABSTRACT

This article presents the results of the assessment of the possible impact of climate change on groundwater abstraction for human consumption between 2041 and 2060. Part of the results is the balance of the current amount of groundwater on smaller area units. The methodology is based on the procedures of the water management balance and the assessment of quantitative status of groundwater bodies. First, the balance of current groundwater quantity at the level of working units of water bodies was evaluated, and then the prospective balance including the possible impact of climate change. The current status results were compared; while 12.5% of the area was in poor status for the assessment of the quantitative status of groundwater, 7.3% of the area was at risk for the assessment of working units. This decrease is due to using smaller units for the assessment. Due to climate change, it will probably worsen to 16.1%, that is, by 8.8% compared to the current status. However, it is necessary to keep in mind that the results are burdened with significant inaccuracy. This inaccuracy is mainly due to the method of calculating current groundwater resources, the heterogeneity of groundwater resources in hydrogeological zones, the approximation of groundwater resources into the future, and the high proportion of working units with low abstraction (these units had to be removed from the results because of low reliability).

INTRODUCTION

The impacts of climate change on drinking water supply have been modelled for water reservoirs for some time now. In the long term, the share of groundwater in the supply has been fluctuating between 44–48% of the volume [1], therefore it is necessary to deal with groundwater in more detail. Due to the current drought in the CR, there have already been local problems with groundwater abstraction for households. However, with the increasing impact of climate change, the frequency of occurrence as well as the temporal and spatial extent of extreme hydrological phenomena may be changing. The results of modelling the impact of climate change in the Czech Republic predict a more frequent occurrence of flash floods and long-lasting drought. This fact has been confirmed in many river basins in recent years. The unfavourable situation can also lead to a threat to the reliability of drinking water supply.

The presented balance of groundwater sources and needs for drinking purposes was processed as part of the project VI20192022159 *„Water management and water supply systems and preventive measures to reduce risks in drinking water supply“* of the BV III/1-VS programme of the Ministry of the Interior. The project researcher is T. G. Masaryk Water Research Institute (hereinafter TGM WRI). The project was started in July 2019, with completion planned for December 2022. The project is aimed at evaluating the risks of drinking water supply as a result of climate change and creating technical tools for assessing possible measures to mitigate any adverse impact.

METHODOLOGY AND DATA

The water management balance of groundwater is prepared annually for approximately 99 hydrogeological zones out of a total of 152, which is almost 81% of the area of the Czech Republic [2]. Using a similar procedure, but based on additional data on natural resources, the quantitative status of groundwater bodies is processed every six years [3]. However, hydrogeological zones and groundwater bodies are often quite large; some have an area of up to 5,800 km^2. As a result, in some bodies, part of the body is poor, but this is not reflected in the result of quantitative status (poor or potentially poor) because the entire area is evaluated. Similarly, a whole unit may be evaluated as poor, while in reality problems occur only in part of it. *Fig. 1* shows the result of the evaluation of the quantitative status of the bodies based on data on natural resources and abstraction between 2013 and 2018. Although the former dry period is partly included here, it represents the current quantitative status. There are 34 out of 174 poor and potentially poor groundwater bodies, which make up 12.5% of the total area.

Climate change scenarios in water management

For the creation of climate change scenarios in the context of estimating changes in the hydrological balance, the so-called increment method is used as standard in the Czech Republic, especially for studies in monthly steps. This method consists of transforming the monitored data so that changes in the transformed quantities correspond to changes derived from climate model simulations. For the evaluation, various regional (RCM) and global climate models were tested in the Czech Republic. Eventually, the HadGEM2-ES model was selected for evaluation and recommended in studies [4]. To model hydrological balance, the BILAN model is used, which has been developed for more than 20 years in the TGM WRI Hydrology Department [5]. This model calculates the chronological hydrological balance of a basin or territory in daily or monthly time steps.

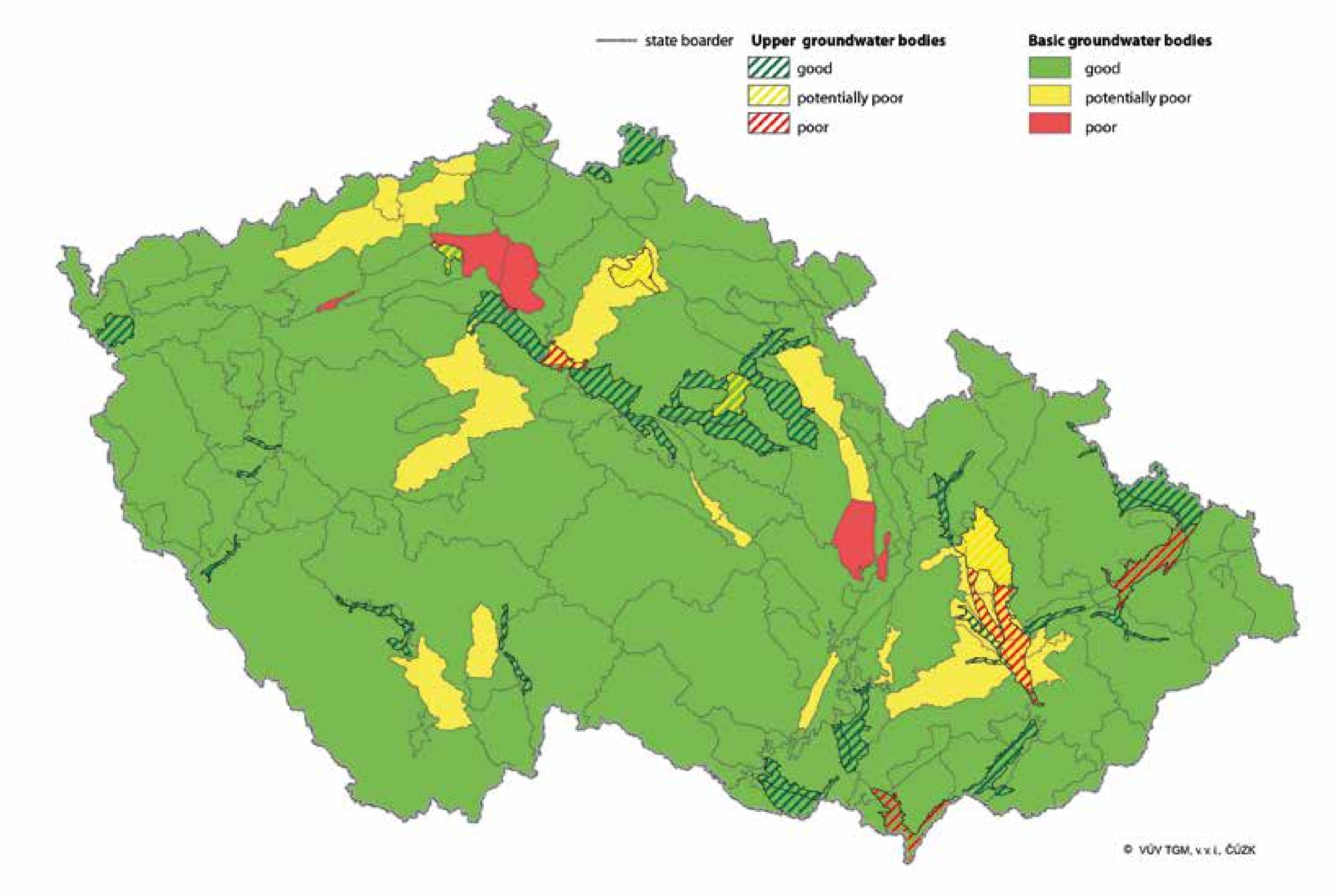
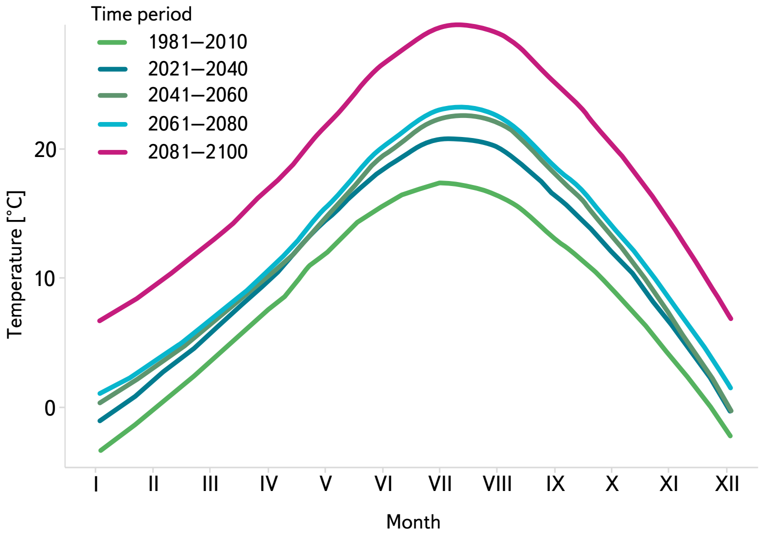


Fig. 1. Quantitative status of groundwater bodies for the third cycle of River Basin Management Plans



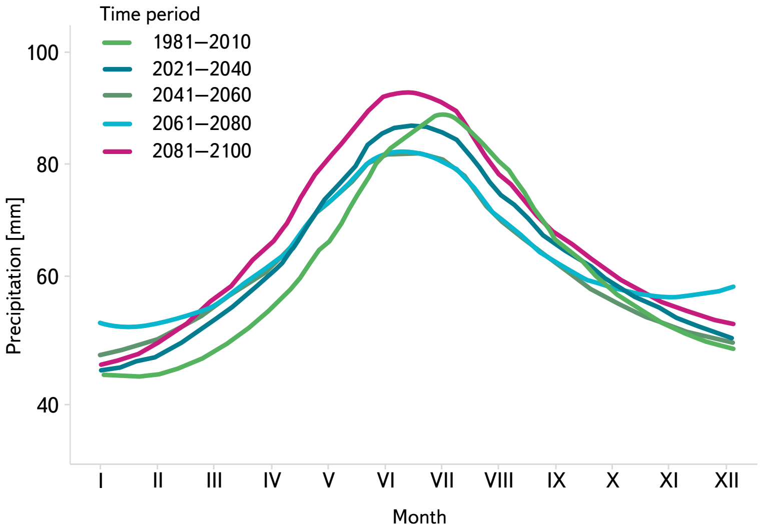


Fig. 2. Air temperatures for the individual time horizons considered

Fig. 3. Precipitation for the individual time horizons considered

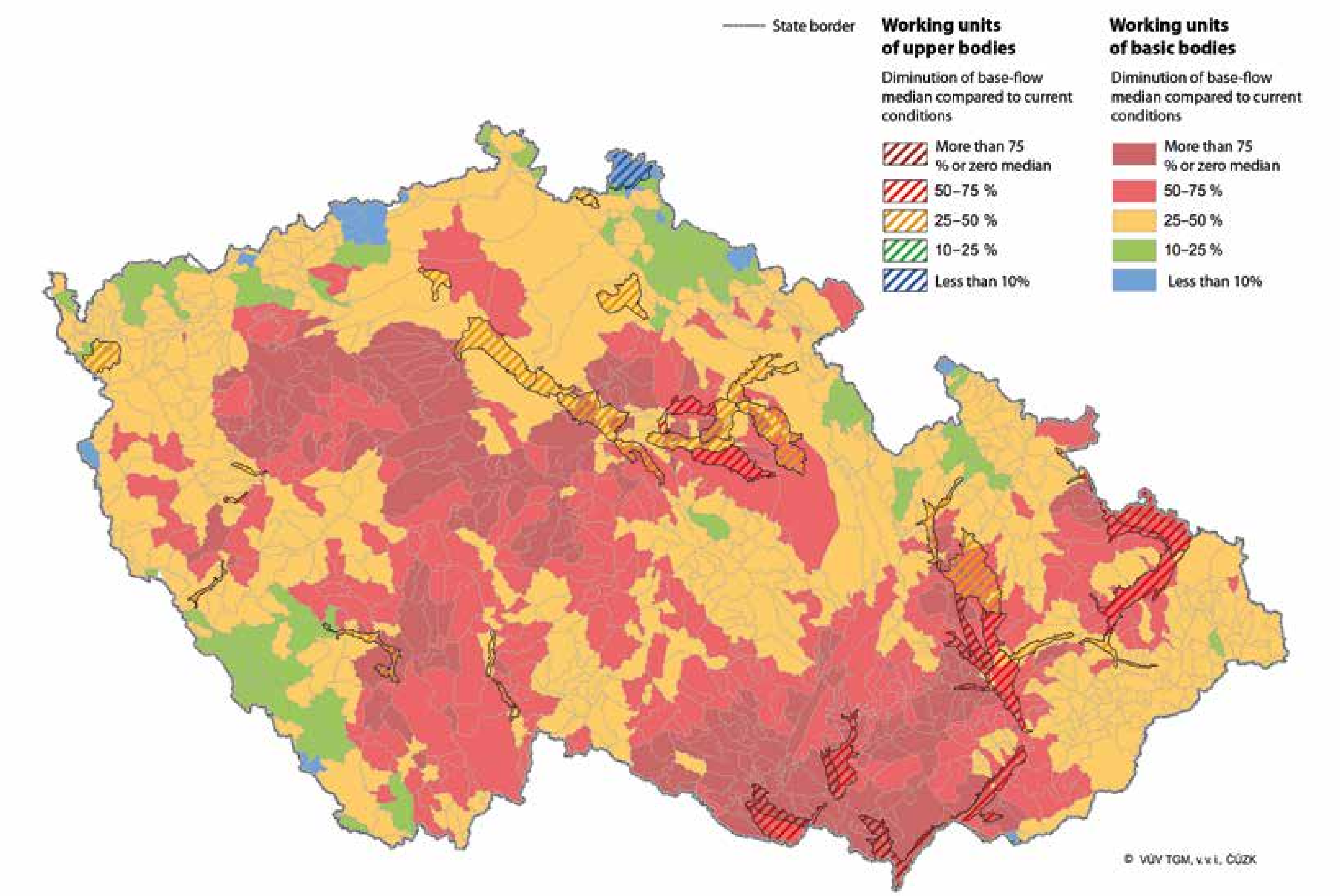


Fig. 4. Diminution of base-flow median in working units of groundwater bodies. Model HadGEM2-ES and time period 2041–2060

It expresses the basic balance relationships on the basin surface, in the aeration zone (which also includes the vegetation cover of the basin), and in the groundwater zone. Air temperature is used as an indicator of energy balance, which significantly affects hydrological balance. By calculation, potential evapotranspiration, territorial evaporation, infiltration into the aeration zone, percolation through this zone, water supply in the snow, water supply in the soil, and groundwater supply are modelled. Runoff is modelled as the sum of three components: two components of direct runoff (including hypodermic runoff) and baseflow [5–7]. The procedure for modelling the impact of climate change on the hydrological regime is presented, for example, in the article [8].

Fig. 2 shows observed air temperatures for the Czech Republic and the individual time horizons considered: reference period (1981–2010) and prospective periods 2021–2040, 2041–2060, 2061–2080, and 2081–2100. Analogously, precipitation totals and monthly means for individual time periods are shown in *Fig. 3*.

In this context, a data set describing the impact of climate change on hydrological characteristics in the aggregation of surface water bodies (processed as part of the *„Drought I"* (2017–2018) and *„Drought II"* (2019–2021) projects funded by the Ministry of the Environment) was used to assess the possible impact of climate change on the replenishment of groundwater supplies (partial outputs are available on *www.suchovkrajine.cz* and *hamr.chmi.cz*). Changes in hydrological characteristics due to the impact of climate change relate to current conditions represented by the time period 1981–2020. In order to assess the potential impact of climate change on replenishment of groundwater supplies and the prospective balance of groundwater resources and needs (abstraction), data on the change in the values of base-flow median for the time period 2041–2060 were used.

Given that the data set was processed for relatively detailed areas of inter-basin areas of surface water bodies (there are 1,118 of them in the Czech Republic), the data was converted not to 174 groundwater bodies, but to 1,220 working units of groundwater bodies using geographical analysis [9]. *Fig. 4* shows the result of the change in base-flow median, expressing the natural resources of groundwater, in the period 2041–2060 compared to the current situation. Although the result is very negative – most areas saw a decrease of at least 25% – it does not in itself say how this decrease in basic runoff may affect demands on groundwater resources for drinking purposes, as it does not consider their size.

Balance of the current amount of groundwater per working units of groundwater

In the balance of the amount of groundwater, the sum of abstraction is compared to the values of natural groundwater resources in the area unit. In the water management balance, this unit is the hydrogeological zone, and hydrogeological units are defined by the Czech Hydrometeorological Institute (CHMI) as natural resources. Other data on natural resources – Hydrogeological zoning [10] and

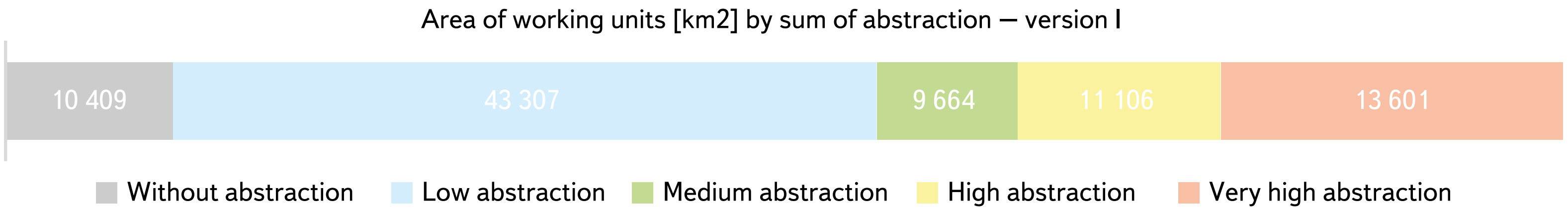


Fig. 5. Area of working units [km^2] by sum of abstraction – version I

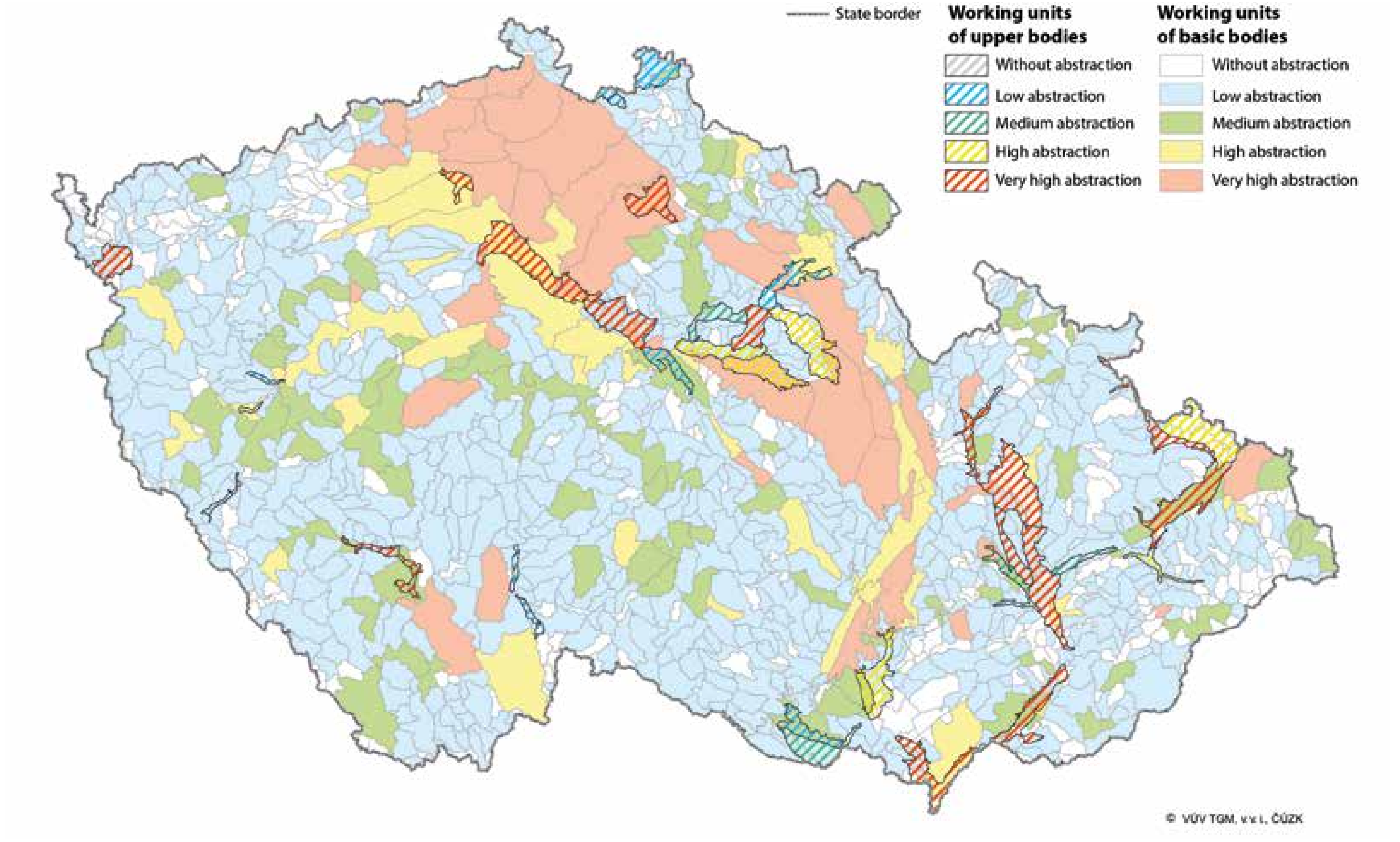


Fig. 6. Working units by sum of abstraction – version I

Rebalancing of underground water reserves [11] have always been determined for hydrogeological zones, while more detailed data are not available. In contrast, groundwater abstraction can be differentiated into almost any areal unit. The first step in this project was the division of data on current abstraction and natural groundwater resources (both from the period 2013–2018) into working units. According to the size of the sums of abstraction, the working units were then divided into units without abstraction, with low, medium, large, and very large abstraction. In this division, two versions of the distinction of the size of abstraction were used: in version I, the average annual absolute size of abstraction was decisive (the threshold values were 10, 20 and 50 l.s^{1}); in version II, it was the specific size of abstraction, i.e., the conversion of abstraction per unit of area (the threshold values were values of 0.05, 0.5 and 1 l.s^{-1}.km^{-2}). The results are shown in *Fig. 5* and *6* (version I) and *Fig. 7* and *8* (version II). It is clear from the maps that version II is better at taking into account the size of working units (most of the large and very large abstraction from version I fell within the category of medium abstraction); on the other hand, the absolute size of abstraction is more important for supplying the population (i.e., version I).

Although the majority of groundwater abstraction is used to supply the population, it is not the case for all abstraction. For that reason, a map of working units according to the size of abstraction for drinking purposes was also created (the previous maps include all abstraction, regardless of use), see *Fig. 10.* Since it is only a supplementary map, it is shown here in version I only, i.e., according to the absolute size of abstraction. The same applies to the graph with the size of the areas (*Fig. 9*).

If we compare the graphs in *Fig. 5* and *9*, it can be seen that when taking into account abstraction only for drinking purposes, the areas of working units without abstraction and with low abstraction increased slightly and, similarly, working units with medium, high and very high abstraction decreased slightly. However, the results are not significantly different. Therefore, for further research, all abstraction was taken into account.

For natural resources, the same sources were used as in the assessment of the quantitative status of groundwater (i.e., data from CHMI, data from the Hydrogeological Zoning and from the Rebalancing of Groundwater Supplies). This data was then calculated in the same proportion as the baseflow values were modelled.

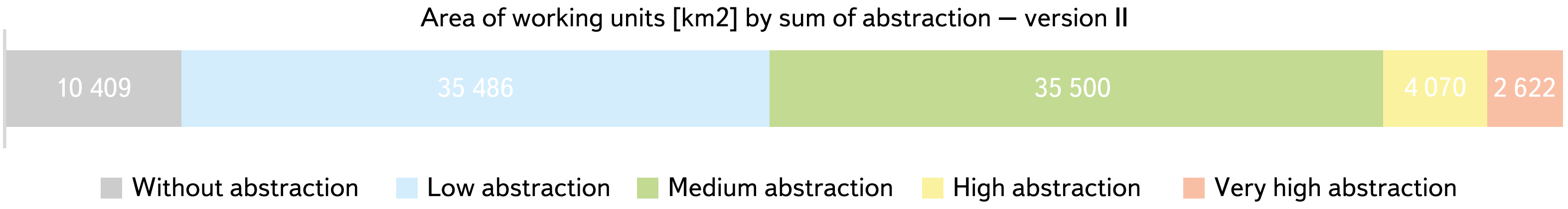


Fig. 7. Area of working units [km^2] by sum of abstraction – version II

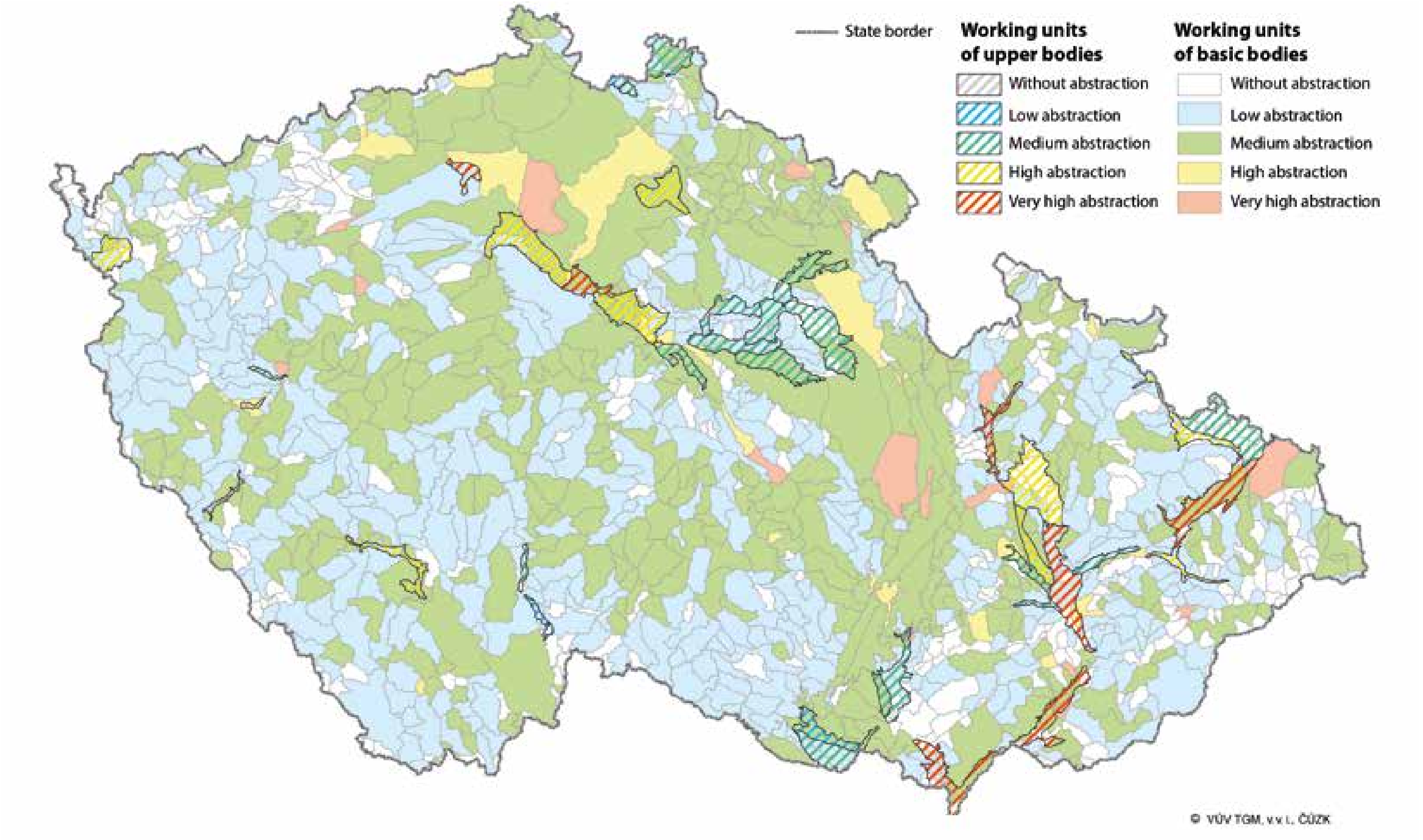


Fig. 8. Working units by sum of abstraction – version II

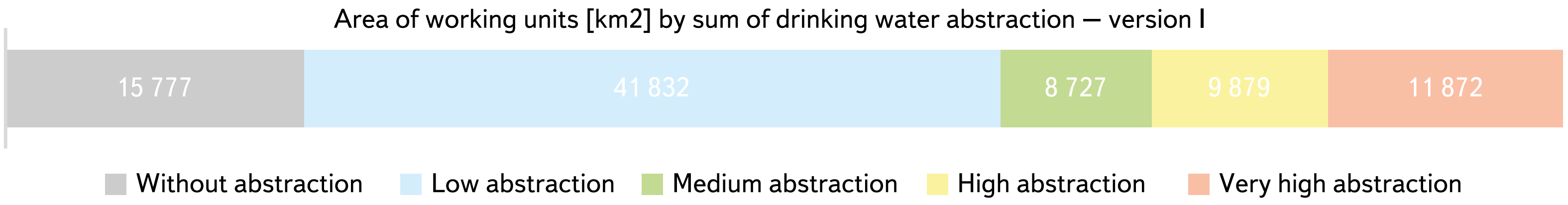


Fig. 9. Area of working units [km²] by sum of drinking water abstraction – version I

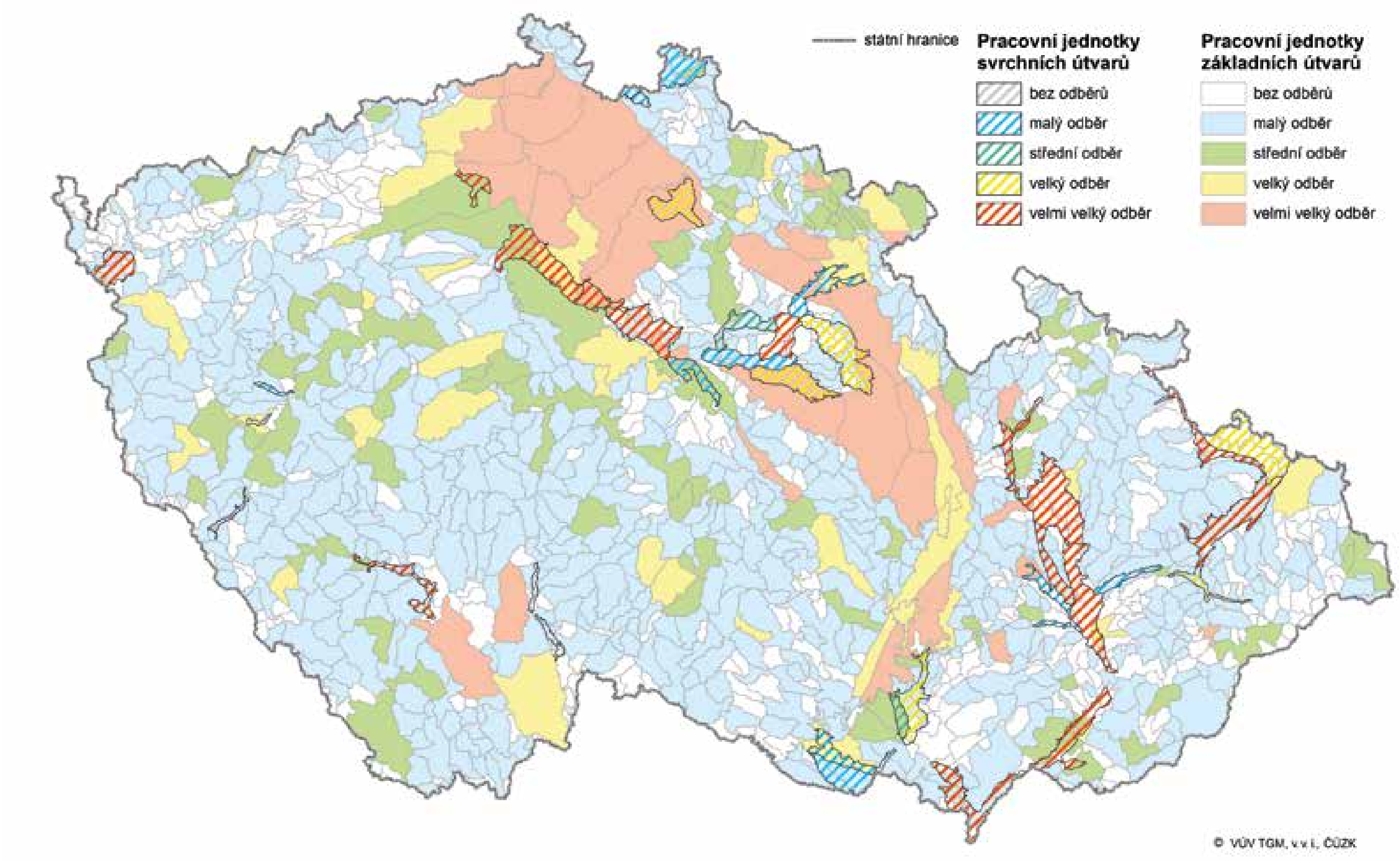


Fig. 10. Working units by sum of drinking water abstraction – version I

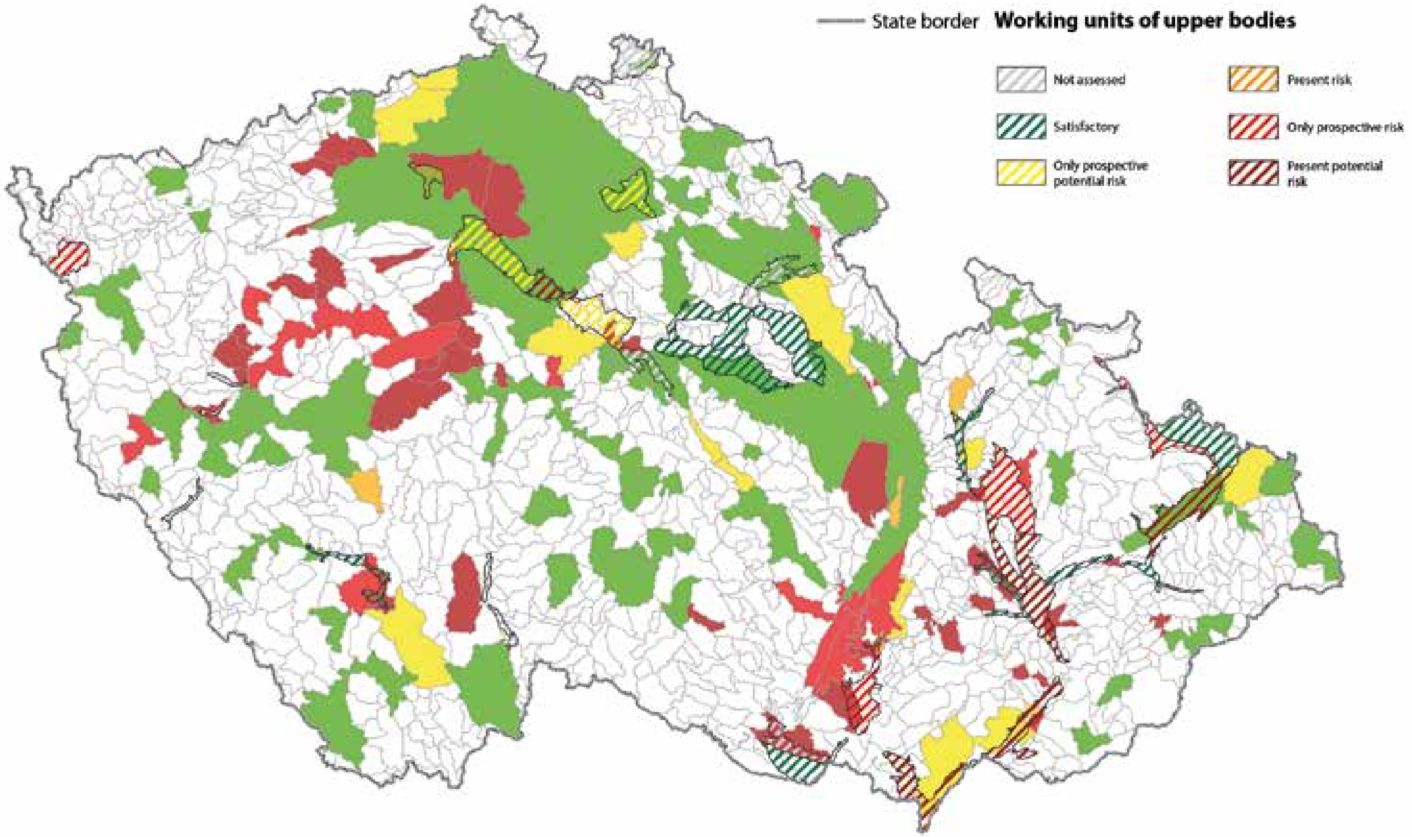


Fig. 11. Risk assessment of working units – version I

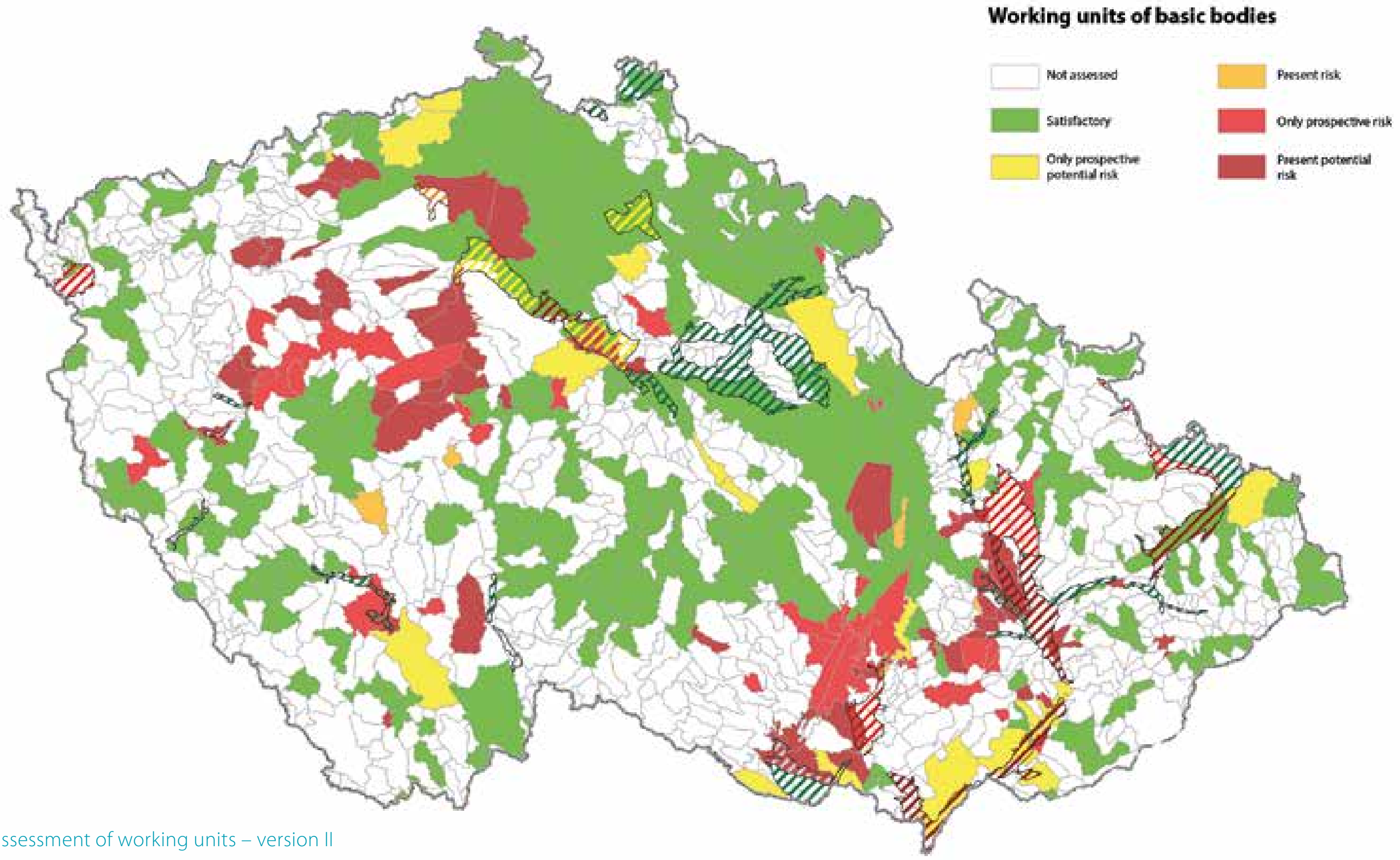


Fig. 12. Risk assessment of working units – version II

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The actual comparison of abstraction and natural resources in working units was carried out in the same way as the assessment of the quantitative status of groundwater bodies; however, working units with low abstraction were not evaluated because, with such low abstraction, the comparison is very imprecise. Equally, working units where the natural resources of the current status were zero (and, simultaneously, the amount of abstraction was at least medium) were not evaluated – however, this was the case with only two working units for version I and five for version II.

Balance of the amount of groundwater in the prospective status per working units of groundwater

For the prospective status – that is, for the period 2041–2060 with considered climate change – natural groundwater resources were reduced by the same percentage as baseflow in working units of surface water bodies for the HadGEM2-ES model. As for abstraction, they were considered in the same range as in the period 2013–2018. The comparison of abstraction and resources was then processed in the same way as the balance of the amount of groundwater in the current status.

RESULTS AND DISCUSSION

The result of this assessment was individual working units being at risk, both in the current and prospective status, where the risk refers to the possibility that the natural resources of groundwater due to drought (currently) or climate change (in the future) will decrease to such an extent that it will not be possible to meet the requirements for consumption for drinking purposes. Working units were divided into unassessed (i.e., no abstraction, only with low abstraction and, exceptionally, with at least medium abstraction, but zero natural resources), then into satisfactory both in the current and prospective status, then into potentially at risk or already at risk, and finally again to at risk only in the future. Units potentially at risk differ from units at risk, as in the case of the results of the quantitative status of groundwater bodies – the result at risk occurred either only for maximum but not for average abstraction, or the results differed for differently determined natural resources. Therefore, working units potentially at risk have lower credibility.

The risk was processed for both versions of classification of the level of abstraction, for which the procedure does not differ, but the number of unassessed working units does due to the different method of classifying the size of abstraction.

The results for version I (i.e., for absolute values of annual average abstraction) are shown in the map in *Fig. 11*, and for version II (for abstraction recalculated according to the areas of working units) in *Fig. 12*. A comparison of the results of both versions is shown in *Fig. 13*.

According to the maps, the results of the two versions look quite different; however, it is clear from the graph that the difference is due to the fact that there are fewer unassessed working units in version II, while most of the unassessed units in version I are satisfactory in terms of risk in version II.

It is also interesting to compare the results of the current status at the level of groundwater bodies (quantitative status assessment) and risk for working units – see *Fig. 14*. There were no unassessed groundwater bodies in the quantitative status assessment, but even so the proportion of poor areas is the highest (12.5%), while in terms of risk it is only 6.2% for version I and 7.3% for version II of areas at risk or potentially at risk. Thus, evaluation in smaller units seems to allow better identification of problem areas. On the other hand, it is necessary to keep in mind that the inaccuracy of data on natural resources, which is considerable (e.g., the determination of natural resources of hydrogeological zones according to the CHMI and according to the results of Rebalance often differ significantly), can worsen when recalculated to smaller units. This procedure assumes that natural resources are more or less homogeneous within the hydrogeological zone, which also does not correspond to reality; for example, the places of concentrated drainage where groundwater is most often abstracted are not taken into account at all. Groundwater abstraction also shows a certain inaccuracy (albeit smaller than with natural resources) both in terms of localization (some large abstracted areas are identified by only one point, even if in reality they would extend into several working units), but also in terms of classification to the horizon; quite often groundwater is abstracted both from the upper horizon (i.e., from the Quaternary) and from basic bodies. In some cases, groundwater abstraction, if located in river alluvium, is subsidized by surface water, and thus – in addition to negative impact on the quality of the water used – worsens the balance assessment result. *Fig. 15* shows the last output of the project, which is an overview of working units that are expected to deteriorate in the future – that is, that the current satisfactory status will change to potentially at risk or at risk. Since the comparison of the two versions showed that there are fewer unassessed working units in version II, we consider the results according to version II to be relevant (although, for certainty, the deterioration in version I was also evaluated). The area of deteriorated working units is only 8.8%; therefore, from this point of view, only 16.1% of the total area would be at risk in the future. However, it is necessary to point out that the mentioned inaccuracy of the data for the current status is increased by approximation for a longer period of time. In addition, it is not clear what the prospect is for working units with low abstraction (excluded due to significant inaccuracy in the assessment) which for option II amounts to 40.7% of the total area.

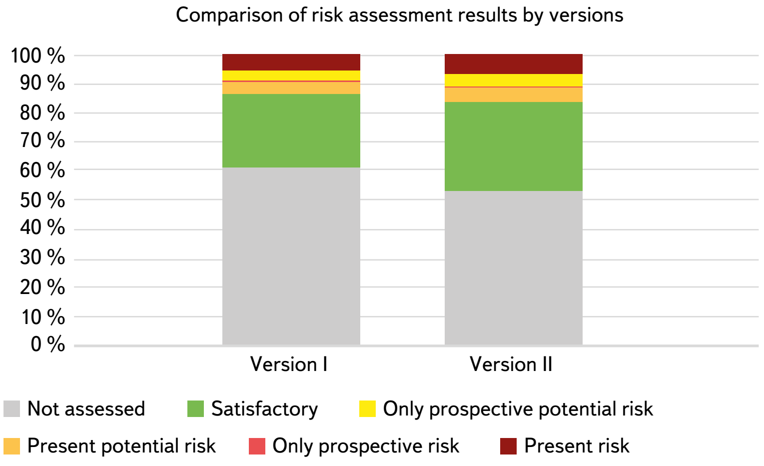

Fig. 13. Comparison of risk assessment results by versions
Note: The areas of working units potentially at risk are currently very low (only 0.37% – version I or 0.29% – version II), so they are not visible in the graph.

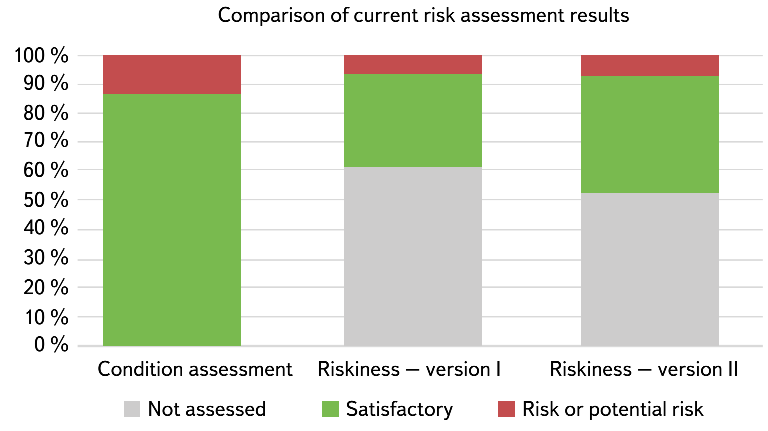

Fig. 14. Comparison of current risk assessment results

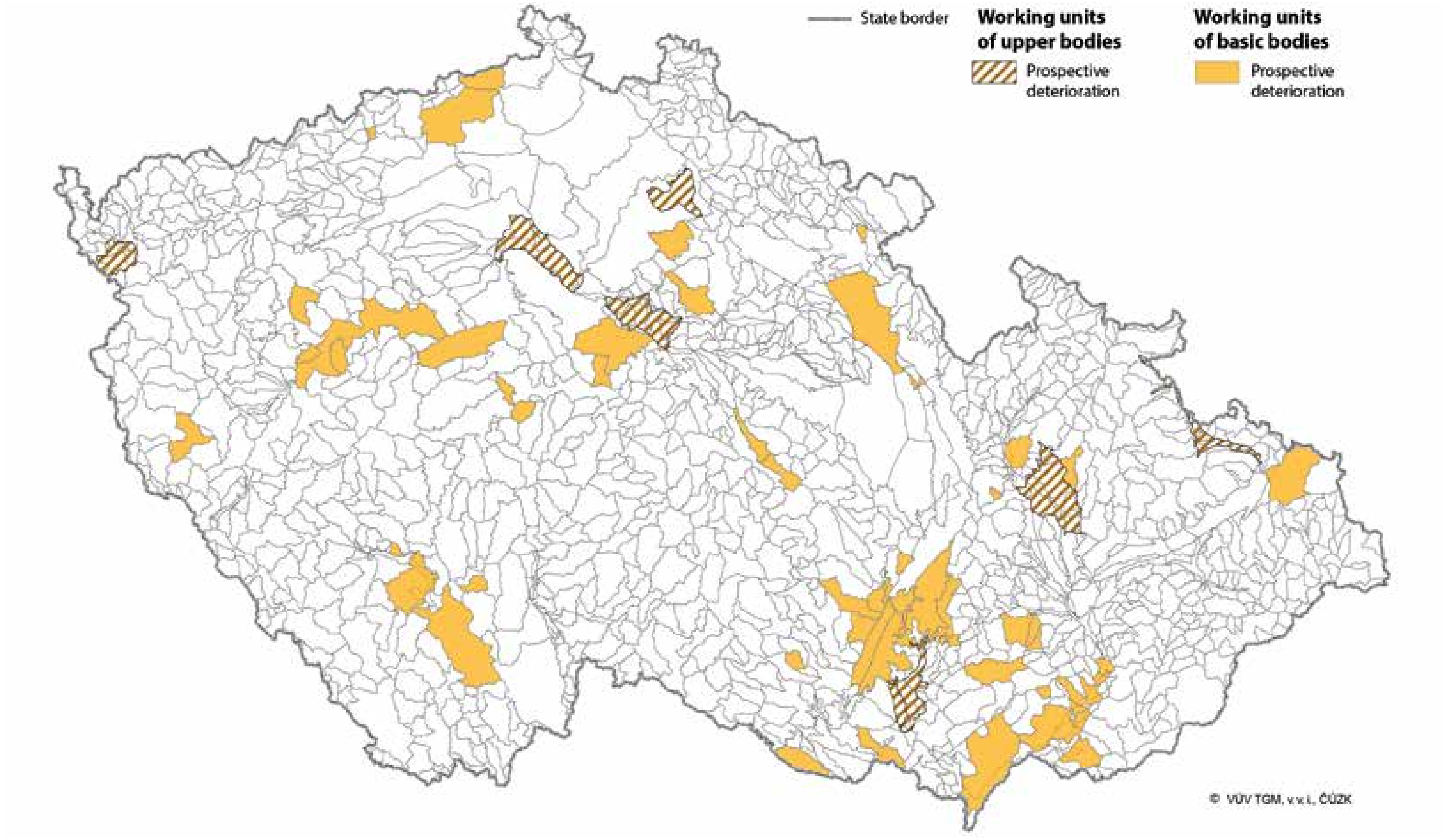

Fig. 15. Deterioration of risk assessment in prospect

CONCLUSION

The aim of the project was to find out how significantly climate change will affect the possibilities of groundwater abstraction for drinking purposes by 2050. Given that the modelled changes in baseflow, represented by natural resources for most groundwater bodies, were processed into significantly smaller area units than hydrogeological zones and groundwater bodies, groundwater abstraction was also aggregated in more detail. In this way, the balance of the amount of groundwater of the current status could be processed on 1,220 working units of groundwater bodies in contrast to 174 water bodies. The methodological solution is based on the procedures of water management balance and assessment of the quantitative status of groundwater bodies. The balance assessment made it possible to evaluate working units potentially at risk and at risk for the current status and their expected deterioration for the period 2041–2060.

When aggregating abstraction into working units, the units were categorized according to the size of the sum of abstraction – both according to the average annual absolute numbers (version I) and according to the conversion to the area of working units (version II). Based on this division, working units without abstraction, with low, medium, high, and very high abstraction were distinguished. In the assessment of risk, units with no abstraction but also with low abstraction were excluded, as there is either no problem for them (if the natural resources are large enough) or the comparison of low abstraction and low natural resources is very imprecise. Due to the fact that the identification of small abstractions was different for the two versions, the results of the risk were also different. When comparing the results, version II turned out to be more satisfactory. According to this version, 7.3% of areas are at risk or potentially at risk for the current status, and 16.1% of areas for the prospect. When assessing the quantitative status of groundwater bodies, which in terms of methodology and period corresponded to the balance assessment of the current status, 12.5% of areas came out as poor or potentially poor, so a more detailed assessment probably means the possibility of better identifying problematic areas. On the other hand, it is necessary to keep in mind that the inaccuracy of the original data is already quite large and may continue to increase when the results are more detailed. Simultaneously, it may later turn out that local problems will occur in some groundwater working units with low abstraction and low natural resources that were excluded from the assessment.

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Assessment of the possibility of changing the use of dry reservoirs

PAVEL BALVÍN, PETR SMRŽ, JIŘÍ ŠVANCARA, VERONIKA TÁBOŘÍKOVÁ, MARCELA MAKOVCOVÁ

Keywords: dry reservoir — change of use — database — multicriteria analyses — methodological guidance

ABSTRACT

The main objective of the project *"Potential use of dry reservoirs in landscape water management"*, implemented between 2019 and 2021, was to develop methodological guidance describing the procedure for changing the use of dry reservoirs, for example, to retain water in the landscape. This methodological guidance is based on a two-level multi-criteria analysis (hereinafter MCA). Another aim of the project was to make a complete record of implemented dry reservoirs and polders in the Czech Republic and to present it in the form of a database and a map with professional content. Documentation of the technical condition of some existing dry reservoirs was also an important output of the project.

INTRODUCTION

In the second half of the 20th century and the beginning of the 21st century, a number of significant flood events occurred in the Czech Republic. The response to them was, among other things, an effort to increase flood protection of threatened areas, for example by building dry reservoirs and polders. On the other hand, between 2014 and 2019, our country was plagued by drought. For these reasons, a discussion arose as to whether it was possible to use dry reservoirs to retain water in the landscape without impairing their protective function. The Ministry of the Environment responded to this discussion by announcing a project entitled *"Potential use of dry reservoirs in landscape water management"*, financed by the Beta 2 programme of the Technological Agency of the Czech Republic.

DATA COLLECTION FOR THE PROJECT NEEDS

The initial step in the project was the collection of data on implemented dry reservoirs in the Czech Republic. The primary basis was the database of dry reservoirs (hereafter also DR) created in connection with the categorization of waterworks for the purposes of technical safety supervision and provided by one of the project researchers VODNÍ DÍLA – TBD, a. s. Considering the fact that this database also contains a significant number of hitherto unimplemented DR, it was necessary to supplement the database with other sources of information. The following sources were used to collect data on DR and verify them [1]:

- information from state river basin enterprises,
- documents from the Ministry of Agriculture, Ministry of the Environment, and State Environment Fund programmes,
- a research team questionnaire at the water authorities of the Czech Republic,
- information from municipalities,
- intensive field survey of DR by the research team,
- maps (e.g., Basic map of the Czech Republic, Orthophoto map of the Czech Republic, Cadastral map of the Czech Republic).

Although data collection mainly took place in 2019, it gradually continued until the very end of the project in order to find and verify the largest possible set of existing DR for the needs of creating a DR database and map (see *Fig. 1* and *2*). The representation of DR in the Czech Republic is uneven. They are abundant in the east of our territory, that is in the regions of Moravia, Silesia, and eastern Bohemia. Towards the west, their number decreases. In the Karlovy Vary region, there are no waterworks of the DR type at all.

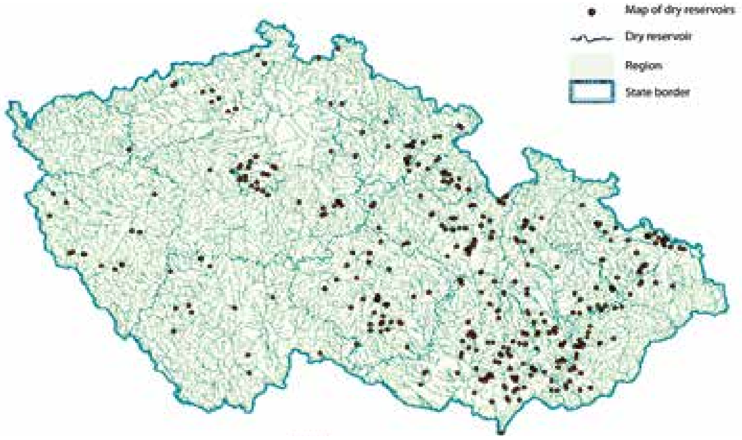

Fig. 1. Map of dry reservoirs in the Czech Republic

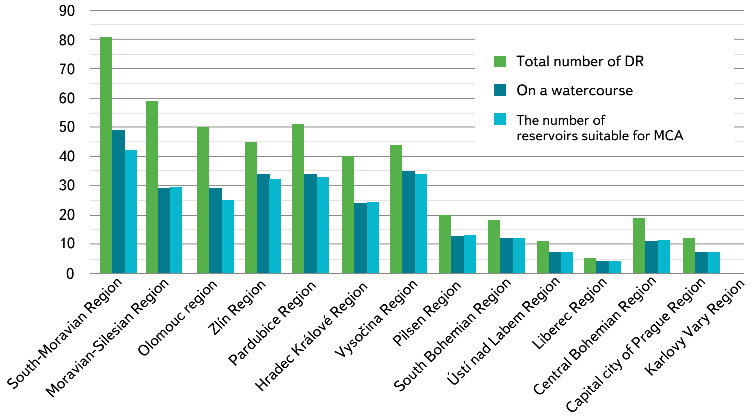

Fig. 2. Occurrence of dry reservoirs and polders in regions of the Czech Republic

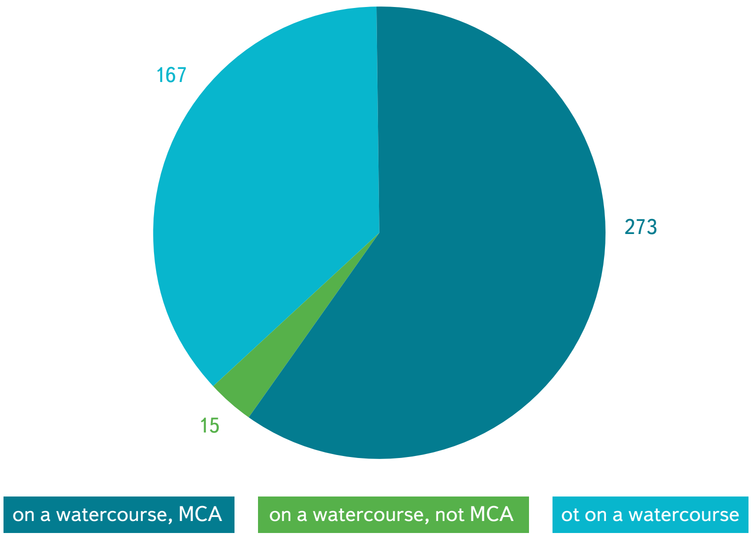

Fig. 3. Number of dry reservoirs suitable for MCA in terms of location on a watercourse

METHODOLOGICAL APPROACH

As part of the project, it was necessary to choose a suitable and optimal methodological approach that would enable the achievement of the desired outputs. The DR database and map are the output of data collection and verification. The methodological guidance itself is a tool intended for DR managers and owners, employees of water authorities, and officials of state and local governments, but above all also designers, who will have to answer a number of technical and environmental questions and verify the validity of the proposed solutions as part of the process of changing the use of DR.

Changing DR use means using part of the volume of the DR protective space for water accumulation, namely by defining a space for permanent storage, or a storage space. In extreme cases, it is assumed that the purpose of waterworks may change, for example, the transformation of a DR into a small water reservoir. As part of the methodological guidance, no change of use is considered for DR not located on a watercourse. Therefore, only DR located on a watercourse and for which the necessary data have been collected are included in the assessment of change of use (*Fig. 3*).

During preparation of the methodological guidance describing the process of assessment of DR change, it was decided to develop a two-level multicriteria analysis (MCA). It is necessary to mention that the methodological guidance serves as an auxiliary tool when deciding to change DR use. It contains the recommended procedure for assessing change of use in the form of MCA, a catalogue of technical measures, and examples of the application of the procedure for assessing change of use in the form of MCA at pilot locations.

The purpose of the methodological guidance is to provide an overview of the activities needed to assess the suitability of a DR to change its use. The actual assessment should be carried out by a professionally qualified person (as necessary, in cooperation with other experts), who will evaluate the specified parameters and criteria and then either recommend, or not, a change of use.

Tab 1. Categories of dry reservoirs with regard to their retention potential allowing consideration of change of use

$Y = V_{kor}/V_{100}$	$0 < Y < 1$	$1 < Y < 5$	$5 < Y < 10$ $10 < Y$
Category in terms of suitability of DR change of use	not very suitable	suitable	very suitable

By evaluating possible alternatives from the point of view of multiple criteria, MCA creates a valuable tool for making decisions about DR change of use [2].

FIRST LEVEL OF MULTICRITERIAL ANALYSIS

The first level of MCA categorizes DR for the needs of the first assessment of their suitability for change of use with regard to the need to preserve the anti-flood (protective) function. The ratio of the volume of the DR to the crown of the dam and the volume of the design flood wave can provide an approximate idea of DR retention potential. The ratio of the selected volumes is determined according to equation 1:

$$Y=\frac{V_{kor}}{V_{100}}$$

where Y [-]	is	ratio
V_{kor} [m^3]		volume of dry reservoir to crown of dam
V_{100} [m^3]		volume of the design flood wave with a recurrence period of N = 100 years

Dry reservoirs are divided into three categories based on the ratio of volume parameters (*Tab. 1*):

- not very suitable,
- suitable,
- very suitable.

The "not very suitable" category represents a group of DR with a retention potential that will very probably not allow change of use without limiting the protective function of the waterworks. Since the ratio does not take into account the transformation of the flood wave in time, even a DR with a Y ratio below 1.0 can fulfil its protective function sufficiently. The "not very suitable" category also includes DR with a small retention potential, meaning that the reservoir fulfils the retention function only up to the design flow of N-years with a certain recurrence time, or negligible during the considered transformation of the flood wave. For these DR, it is possible to consider changing the function of the waterworks, for example to a small water reservoir. This may ultimately mean that even such a DR from the "not very suitable" category will be expedient to assess in the second level of MCA.

The "suitable" category represents a group of DR with a retention potential that meets the prerequisites for assessing change of use with the aim of ensuring permanent water retention.

The "very suitable" category represents a group of DR with the highest potential for change of use. With regard to the retention volume of the reservoir, this category also offers the potential for creating storage space for further water management use. The potential for creating permanent water storage and storage space must be assessed within the second level of MCA. Distribution of available DR according to *Tab. 1* is shown in *Fig. 4*.

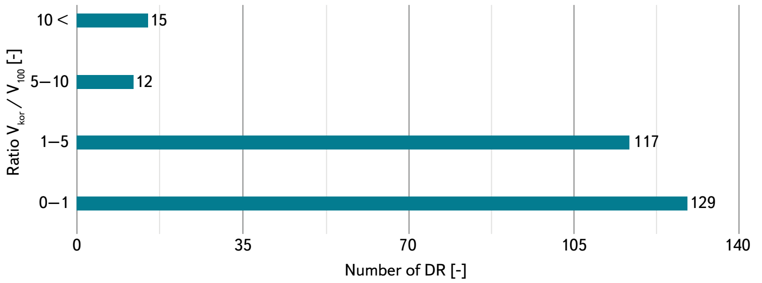

Fig. 4. Representation of dry reservoirs for individual categories in the first level of MCA

SECOND LEVEL OF MULTICRITERIAL ANALYSIS

The second level of MCA is used for detailed assessment and evaluation of selected aspects, which can be divided into three groups:

1. Safety and function of the waterworks

This category assesses the characteristics of DR before and after the proposed change of use. The group deals, for example, with the assessment of the change in the transformational effects of DR and the stability of the dam under changed load conditions, the technical solution of the functional objects of the waterworks, and so on. *Fig. 5* shows an example of the assessment of the transformational effect of DR for the design flood wave [3].

2. Environmental aspects

This category deals with the benefits, effects, and impacts of the intended change of DR use on the affected area. The assessment of environmental effects includes physical, chemical, biological, and other aspects; it is also recommended that the evaluation of individual partial aspects by relevant specialists is considered [4].

3. Economic aspects and property relations

This category assesses change of use in terms of expected economic costs, which include, for example:

- reconstruction of functional objects,
- research work,
- property settlement,
- modification of flood areas.

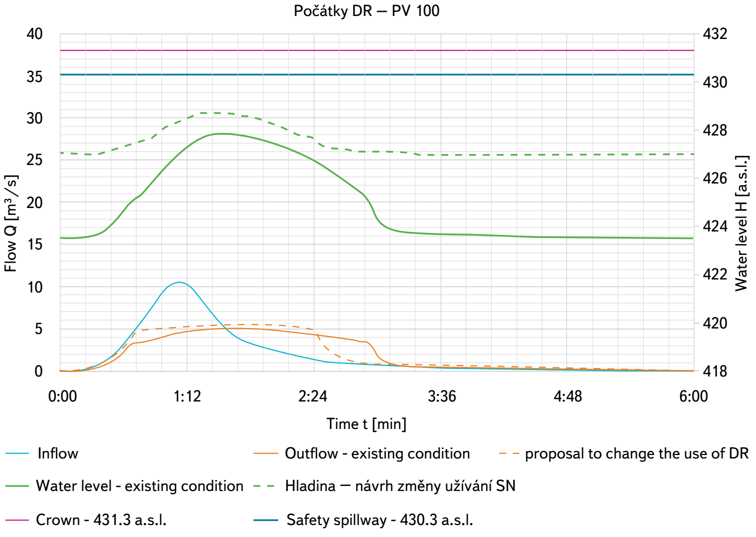

Fig. 5. Example of assessment of existing transformation effects on selected dry reservoirs and transformation effects after the proposed change of use of the reservoir (the change is creation of partial swelling at 427 m a.s.l.)

EVALUATION OF THE METHODOLOGICAL APPROACH, PROJECT OUTCOMES

The assessment procedure was verified at 16 pilot locations. The pilot DR were selected to cover the largest possible range of possible cases that may occur when assessing change of DR use. As part of the assessment process, there was, for example, a case where a DR was not recommended for change of use after the MCA evaluation, even though it was generally suitable for change of use by creating permanent storage while maintaining the protective function of the waterworks; implementation of the change was not recommended due to disproportionately high economic costs. A case was also assessed when a DR in the "not very suitable" category was marked as suitable for change of use by converting it from a DR to a small water reservoir after the MCA evaluation. The reason was its existing, completely insignificant protective function.

Based on the results achieved at 16 pilot locations, it can be concluded that the proposed MCA procedure is suitable as a general tool for assessing changes in DR use.

The procedure for assessing change of DR use is documented in a comprehensive methodological guidance, which describes in detail the entire decision-making process and evaluates individual criteria. The methodological guidance contains appendices in the form of a catalogue of technical measures and a sample form, where the procedures and solutions at selected pilot locations are listed.

An inventory of 455 waterworks – DR was made as part of the records and for the requirements of the database. Of the total number of 455 DR, 288 are located on a watercourse, while for MCA, due to the absence of data on the volume of the design flood wave or on the volume of the reservoir at the crown of the dam, a set of 273 DR was used. Most are in the "not very suitable" category, then the "suitable" category, with the least in the "very suitable" category. From the point of view of catchment size, DR represented by smaller catchments up to 5 km^2 were dealt with in the first level of the MCA, as shown in *Fig. 6*.

Thanks to an extensive field survey, one of the secondary outputs of the project was detection of the technical condition of some DR. It turned out that for some DR, the current technical condition of functional objects is problematic.

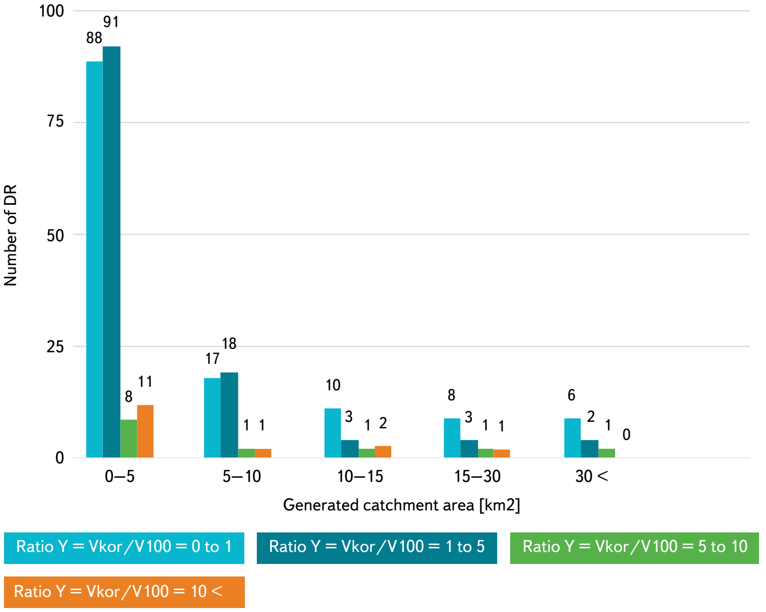

Fig. 6. Representation of dry reservoirs in individual categories with respect to the size of the catchment and to the categorization of the first level of multicriteria analysis

Fig. 7. Example of a completely clogged inlet part to the bottom outlet of the DR – Polder N5 (AQUATIS, a. s.)

Fig. 9. Dry polder Želeč, referred to as a reservoir with flood protection purposed, but operated as fully filled (AQUATIS, a. s.)

Fig. 8. Used tyres dumped in the outflow corridor downstream from DR safety spillway – Všemina II (AQUATIS, a. s.)

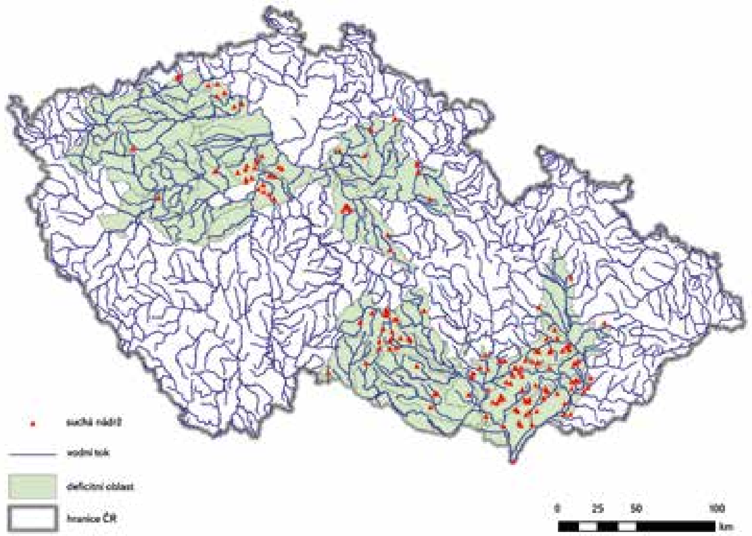

Fig. 10. View of dry reservoirs in deficit areas defined in the the "*Water Centre*" project

Examples of defects and deficiencies include the clogging of the bottom outlet, or overgrown safety spillways and swales in the crowns of the dam (see *Fig. 7* and *8*). In several cases, it was discovered that DR were filled up to the edge of the safety spillway (see e.g. *Fig. 9*). The causes and reasons of the mentioned phenomena were not investigated in the project.

OTHER USE OF PROJECT OUTPUTS

With the need to retain water in the landscape, the discussion on the use of the results of this project in subsequent projects has intensified. An example of the possible use of outputs and accumulated experience is the current TGM WRI project "*Water Centre*", led by TA CR and under the auspices of the Ministry of the Environment. The project focuses on comprehensive research in the field of water management, while individual topics are assessed and evaluated within the so-called work packages (WP). For example, the WP3 includes, among other things, solutions to the problem of the so-called deficit areas of the Czech Republic, which were defined as the boundaries of hydrogeological zones and surface water basins. Attention is paid, for example, to issues of water transfer, artificial infiltration of groundwater, restoration of small water reservoirs, as well as the possibility of increasing storage volume of existing water reservoirs or water retention in DR. The last-mentioned area dealing with changing the use of DR will use project outputs, primarily in the form of a two-level MCA and methodological guidance. Within the deficit areas, based on the mentioned procedures, not only will all implemented DR be assessed and evaluated, but possibly also those that are located outside these areas but which can positively influence their hydrological regime. *Fig. 10* shows DR in deficit areas.

DISCUSSION AND CONCLUSION

The procedure for assessing change of DR use can only be applied to waterworks located on a watercourse. Changing DR use without the existence of a permanent inflow of water is not considered because inflow is a fundamental prerequisite for the creation and maintenance of a permanent storage or storage space. Similarly, it is not appropriate to deal with a change for DR protecting populated areas, for example, against concentrated runoff and the consequences of erosion from adjacent agricultural land and industrial zones. A multicriteria analysis for change of DR use was designed at two levels. The first one contains the basic division of DR from the point of view of the suitability of change of use with an emphasis on preserving the original anti-flood function of the waterworks. The second level deals with a detailed assessment of DR based on a number of parameters and aspects that can significantly influence the decision-making process of assessing changes in use. The output of the second level of MCA is a recommendation, or non-recommendation, to change DR use. Through the proposed DR change of use assessment procedure, it is possible to determine relatively quickly and reliably whether a particular DR is suitable for change of use or not because it takes into account most of the decisive aspects (e.g. economic, safety, environmental).

In the course of the project, it was possible to collect information on the existence of 455 DR in the Czech Republic.

Changing a DR can only be clearly recommended under the condition of preserving the safety of the waterworks during floods and its necessary protective function. From the point of view of technical measures, it is recommended to consider the possibility of future DR change in the design preparation of the DR type of waterworks, which would lead to a reduction in the costs of technical adjustments when implementing a change of use of the waterworks. We consider it optimal that, from the beginning, newly prepared reservoirs for flood protection are conceived as multi-purpose.

From the research results in the pilot locations, it follows that only very few DR will be able to fulfil the storage function in the event of a change of use. Their function, if their use changes, will therefore consist rather of retaining a certain volume of water in the landscape, in improving the microclimate, and in subsidizing groundwater at the DR location. However, even this will be of great benefit as part of adaptation measures designed to reduce the impact of climate change. In addition, the field survey showed that the technical condition of some DR is unsatisfactory. As a result, DR cannot reliably perform their protective function; on the contrary, they can even pose a certain threat in the form of the possibility of so-called special floods. Therefore, it is necessary to consider the technical condition of existing DR.

Acknowledgements

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Measuring annual precipitation with a radar rain gauge in severe mountain conditions

MARTIN VOKOUN, VOJTĚCH MORAVEC

Keywords: radar rain gauge — snow — Šumava — WS100 — precipitation measuring

ABSTRACT

The aim of this article is to describe the experience gained while using alternative technology for measuring annual precipitation in severe mountain conditions without a source of electrical energy. For this purpose, a Lufft WS100 radar precipitation sensor was installed in Šumava in 2020 at an altitude of 1270 m above sea level. The measurements so far have shown evident advantages; for example, maintenance free sensor, detailed measurement step, and distinction of the type of precipitation. The question remains how accurate the measurement is, when during some precipitation episodes the radar precipitation sensor probably overestimates its measurements. Accurate comparison with other measurements is difficult in these mountain ridge conditions. On the other hand, the radar sensor also gives accurate measurements during some precipitation episodes, which we verify by a non-heated tipping bucket rain gauge located within the station and also by measuring the height of the snow. Using these proxy data, systematic error was excluded. Measurements will continue for a more detailed evaluation. The radar sensor is, among other things, part of the monitoring of Kaplický potok in Boubín *National Nature Reserve,* where runoff is also monitored. From this point of view, information about precipitation and its type is important for the evaluation of the hydrological properties of the basin.

INTRODUCTION

Measuring year-round precipitation, especially winter precipitation, is problematic in remote mountainous areas due to the absence of an electricity source for heating rain gauges and other sensors recording the intensity and amount of precipitation. Radar estimates can be distorted by a number of measurement errors, such as shielding by mountain massifs or high vertical and horizontal variability of precipitation, which can lead to an underestimation of hydrological risks [1]. At the same time, it is precisely in the mountain ridge areas that precipitation totals are the highest, and the impossibility of monitoring them in real time is a disadvantage, for example, from the hydro-prognosis point of view. Automatic weather stations operating from a battery source are most often equipped with non-heated tipping bucket or weighing rain gauges and ultrasonic measurement of snow height. The information from these sensors does not provide a valid overview of the precipitation total and certainly not of the intensity and type of precipitation in winter. A possible solution to the above-mentioned problems can be the use of a Lufft WS100 sensor (*Fig. 1*). This sensor works like a radar rain gauge with a heated housing with relatively low power consumption. Due to the relatively short time since its introduction to the market, there has not been enough experience with its application and accuracy. For example, it was tested in Peru in a recent

Fig. 1. View of the radar rain gauge installation and detail of the WS100 sensor

study [2], where the measured amounts of precipitation were approximately 100% higher than the actual values. The reason was probably faulty detection of raindrop size. A similar device under the name Micro Rain Radar was also tested by Peters et al. [3]. The detected inaccuracies were probably caused by turbulence, i.e. sudden vertical and horizontal changes in wind speed in the measured field. This article describes experience with pilot installation of a radar rain gauge in mountainous conditions and provides an initial evaluation of the accuracy of the rain gauge and its behaviour in typical precipitation situations. The results will serve to direct further use of this sensor and to maximize its effectiveness in terms of the accuracy of measured data.

INSTALLATION

A weather station from FIEDLER AMS, s. r. o., located on the border of Boubín National Nature Reserve (NNR), below Basumský hřeben peak at an altitude of 1,270 m, was chosen for the installation. The station is in a clearing created after storm Herwart in 2017 (*Fig. 2*). The radar rain gauge mounted on the arm at the top of the mast is 15 cm wide and 19 cm high (*Fig. 1*). Its power consumption ranges from 0.4 VA (economy mode) to 1 VA; if shield heating is active, consumption increases to 9 VA. The measurement principle consists of a Doppler radar that scans an area of 9 cm^2 above the sensor [4]. Based on the measured size and speed of precipitation particles, the intensity of precipitation is calculated using the diagram shown in *Fig. 3* [5]. In the case of precipitation detection, totals are recorded at intervals of one minute. Another feature is the distinction of the type of precipitation according to six categories: rain, snow, mixed precipitation, freezing rain, hail, and drizzle. Measurement accuracy in the case of liquid precipitation is stated by the manufacturer to be ± 10%. A distinct advantage of the rain gauge is that it is completely maintenance-free; there is no need for cleaning, emptying, or any other regular management. Although electricity consumption is low compared to other heated sensors, due to the energy-demanding conditions, an island system was installed with the weather station consisting of a 280 W solar panel and an AGM 12 V/125 Ah battery.

The station is also equipped with other sensors for measuring hydrometeorological variables. In addition to the WS100 sensor, liquid precipitation is also measured by the MR3 rain gauge from Meteoservis, v. o. s., with a capture area of 500 cm^2; this is commonly used by the Czech Hydrometeorological Institute (CHMI). Snow height is measured by a US42000 ultrasonic sensor. The station also records air temperature and relative humidity, global radiation with a Kipp & Zonnen CMP3 pyranometer, wind speed with a WS103 sensor, and soil temperature and humidity at depths of 15, 30, and 60 cm with a CS650-DS sensor. All data is recorded by the H7-G-TA4-SZ monitoring unit and transferred online using a SIM card.

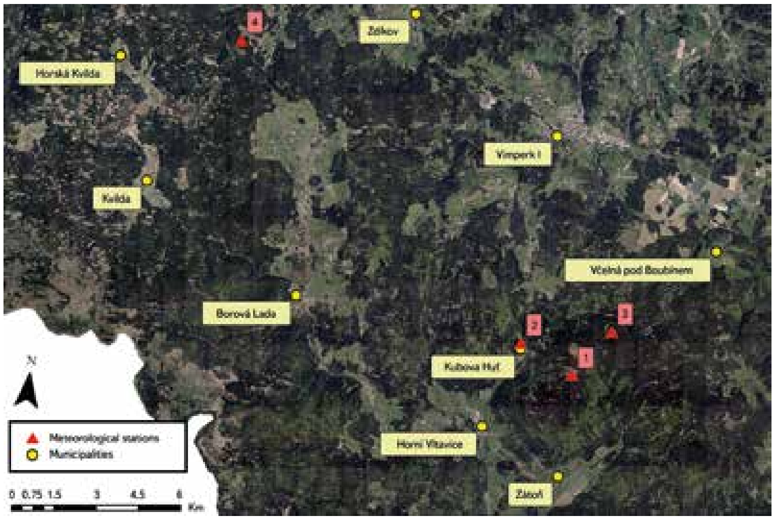

Fig. 2. Locations of meteorological stations used as source of precipitation data. 1 – Basum, 2 – Kubova Huť, 3 – Boubín, 4 – Churáňov

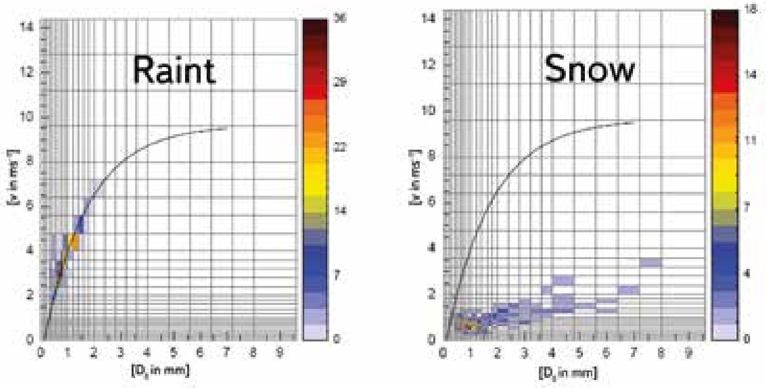

Fig. 3. Diagram for rainfall intensity calculation [5]

MEASUREMENT

Measurement started in the autumn of 2020. A non-heated tipping bucket rain gauge was also installed to compare the precipitation measurements and, in the summer of 2021, an ultrasonic snow height measurement was also installed. The current goal is to evaluate the reliability of measurement by the WS100 sensor, to determine approximate deviation of the measurement, and to define the weather situations that have an adverse effect on accuracy of measurement of the precipitation amount. Comparison of winter precipitation is most problematic, as the reported loss for heated tipping bucket and weighing rain gauges reaches values of up to 30% during snowfall due to evaporation from the heated parts and the effect of wind circulation. This effect should be eliminated with the WS100 sensor.

During 2021, the WS100 radar rain gauge measured a total of 1,435.5 mm of precipitation at an altitude of 1,270 m above sea level (a.s.l.). For comparison, the surrounding stations measured the following values: Churáňov 1,109.2 mm (1,118 m a.s.l.); Filipova Huť 1,279.2 mm (1,110 m a.s.l.) [6]. Unfortunately, year-round precipitation is not measured at a similar altitude and the same time outside the border ridge, which is richer in precipitation, but where Basumský hřeben does not fall into. The non-heated tipping bucket rain gauge measured an annual total of 836.9 mm. Here, we can expect a significant underestimation, especially of snowfall (which occurred until the end of May). In addition, the station is located in a very windy place on a north-south oriented part of the ridge. However, the winter period was below average in terms of precipitation, and most of the precipitation fell in the summer half of the year.

LIQUID PRECIPITATION

If we look at the totals for the rainfall-rich period June–August 2021, the radar rain gauge measured 562.8 mm and the tipping bucket rain gauge 390.1 mm. Churáňov, located 152 m lower, recorded 450.4 mm [6].

The following conclusions can be drawn from the comparison of individual daily totals. The overestimation of precipitation compared to the tipping bucket gauge does not appear to be systematic and the percentage overestimation is highly variable. The advantage of the tipping bucket rain gauge is that it also partially records settled precipitation, where on some days it shows totals in the range of 0.1–0.2 mm during the morning hours. The radar

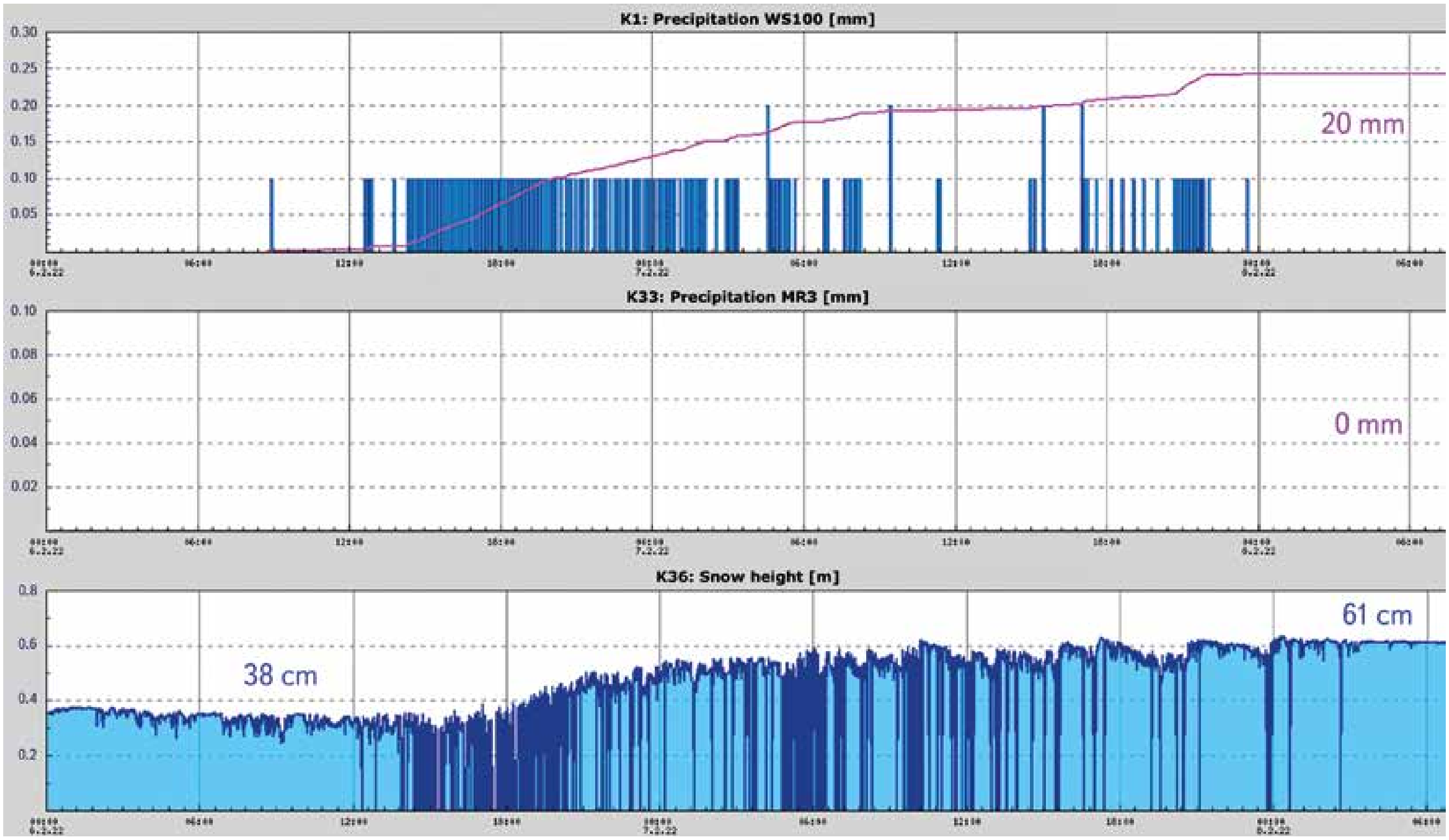

Fig. 4. Outputs of the WS100 radar rain gauge (first graph), the non-heated SR03 tipping bucket rain gauge (second graph), and the ultrasonic snow height measurement (third graph) during moderate snowfall on 6–7 February 2022

rain gauge does not record precipitation in these cases. Rain gauges sometimes reach surprisingly similar values during short, high intensity rainfall, such as on 8 July 2021, when almost 20 mm fell in about 15 minutes. The whole event lasted 40 minutes, and both rain gauges showed the same 23.6 mm, despite, for example, wind gusts reaching 18 m/s. The next day, just after midnight, steady five-hour rain came. While the radar rain gauge showed a total of another 23.6 mm, the tipping bucket rain gauge only showed 14.2 mm, i.e. 40% less, while wind gusts were only in the range of 0–5 m/s. If we evaluate the percentage overestimation of the radar rain gauge in these three months for daily precipitation higher than 5 mm, we get a value of 36.5%. However, if we compare daily amounts less than 5 mm and more than 0.5 mm (to eliminate settled precipitation), we find that the radar rain gauge underestimates by 36.2%. A question remains about the accuracy of a tipping bucket rain gauge in such demanding weather conditions.

SOLID PRECIPITATION

Snowfall can only be compared with the measurement of snow height by ultrasonic sensor. The results are quite satisfactory, although there are not many valid events to compare because the height of snow cover was up to 20 cm during most of the winter and could be affected by the wind in rugged terrain. Nevertheless, some of the most significant snowfalls in the winter season can be mentioned: 25 December 2021 – total of 6 mm and snow + 7 cm; 6–7 February 2022 – total 20 mm and snow + 23 cm (*Fig. 4*); 31 January 2022 – total 18 mm and snow + 13 cm (strong wind). More detailed conclusions cannot be established without knowledge of the water value of new snow. For comparison, the values of winter precipitation for the period December 2020 to February 2021 on the radar rain gauge – 260.8 mm and Churáňov – 210.2 mm [6] can be shown.

PRECIPITATION TYPE DISTINCTION

Differentiating the type of precipitation helps to recognize, for example, the beginning of the occurrence of liquid precipitation on the snow cover (so-called rain-on-snow situation), when snowfall often turns into rain. The sensor sends a precipitation type code based on its own evaluation. In the graphical display, the detection of precipitation is shown in red; other colours show the type of precipitation detected.

Fig. 5 shows the arrival of a cold front on 1 November 2021, when it cooled from 15 °C to 0 °C during the day. The synoptic situation from this date is shown in *Fig. 7*. At the beginning it is rain, which turns into mixed precipitation and snow. The sensor evaluates the type of precipitation continuously and determines only one type of precipitation at any given time. Under boundary conditions, it can alternately detect different types of precipitation, the occurrence of which appears to be simultaneous in the graphical display. *Fig. 6* shows the situation as captured by the radar rain gauge, the non-heated tipping bucket rain gauge, and the snow height measurement sensor. At the beginning the temperatures were above zero, but with a decreasing tendency, and after the first hour the rain changed to mixed precipitation and snow. The temperature stayed above zero, so the snow was melting in the tipping bucket rain gauge, and simultaneously, a layer of wet snow up to 2 cm was forming on the ground

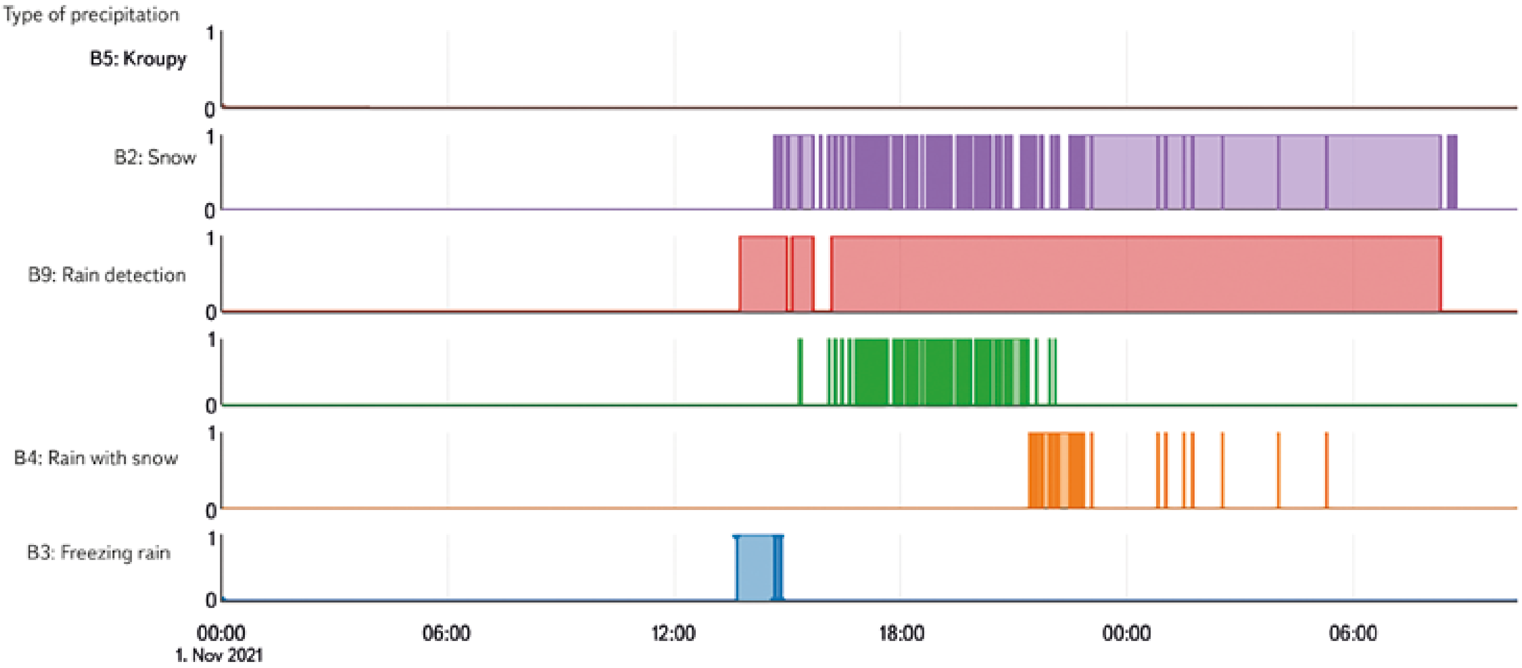

Fig. 5. Graphical representation of precipitation type detection during a cold front on 1 November 2021

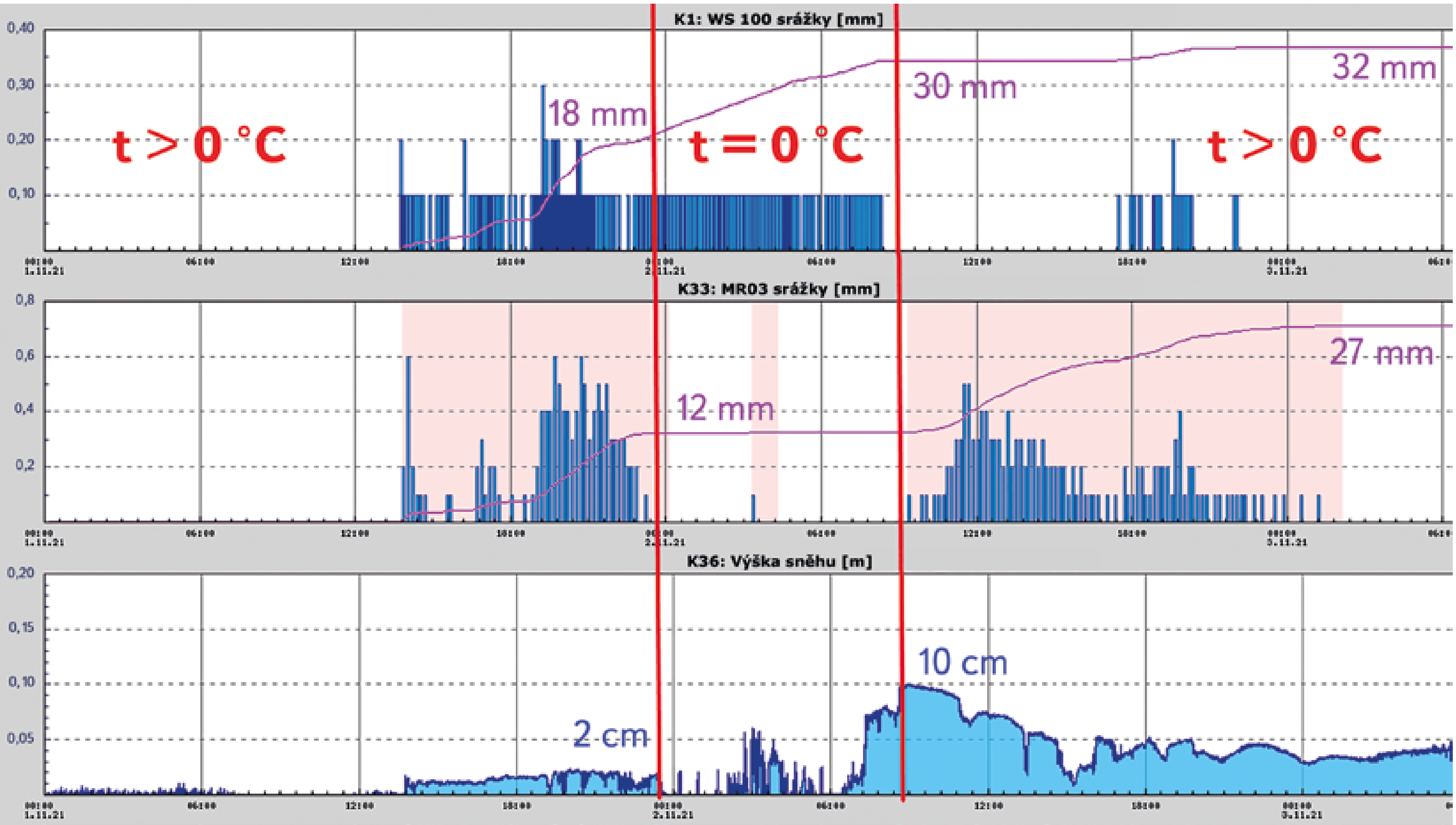

Fig. 6. Outputs of the WS100 radar rain gauge (first graph), the non-heated MR03 tipping-bucket rain gauge (second graph) and the ultrasonic snow height measurement (third graph). The red vertical lines separate the period of time when the temperature dropped to freezing point. Subtotals of precipitation and snow depth are shown numerically.

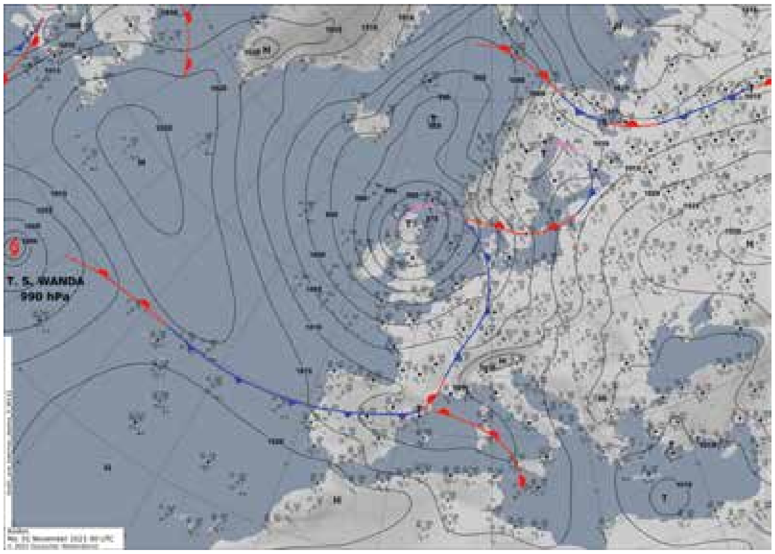

Fig. 7. Synoptic situation on 1 November 2021 [7]

surface. Just before midnight, the temperature dropped to 0 °C and the tipping bucket rain gauge stopped detecting precipitation. The value stopped at 12 mm, but it can be assumed that part of the precipitation was caught by the funnel in the form of wet snow (at least to the amount that was lying on the ground). By then, the radar rain gauge had detected 18 mm of precipitation. The temperature stayed at freezing point until 9 o'clock in the morning; precipitation stopped just before that. During this time, the radar rain gauge detected another 12 mm of rain, and the height of snow increased by 8 cm to 10 cm. Considering the fact that the snow fell wet, the ratio of 12 mm of water to 8 cm of snow is relevant. After 9 o'clock in the morning, the snow in the tipping bucket rain gauge started to melt, and after it melted (with the inclusion of lower precipitation in the evening), the amount of precipitation stopped at 27 mm. The radar rain gauge reported 32 mm. The tipping bucket rain gauge measured 5 mm less. This is an acceptable figure and difference, considering the snowfall and wind conditions on the ridge clearing. However, it should be noted that the wind did not exceed an average speed of 3 m/s and gradually decreased to 0.5 m/s.

Evaluation of WS100 rain gauge accuracy

Based on longer-term measurements, systematic overestimation by the radar rain gauge is evident. *Tab. 1* (below) compares monthly totals from the nearest rain gauge stations at Boubín (1,353 m a.s.l.), where year-round rainfall is measured by a combination of an MR3 non-heated tipping bucket rain gauge and a Metra886 manual rain gauge [9], and from Kubova Huť station (1,010 m a.s.l.) and the more distant Churáňov station (1,118 m a.s.l.), where precipitation is measured using the most accurate method – a MRW500 weighing rain gauge [6]. The comparison is burdened by the uncertainty of the high variability of precipitation totals in mountain conditions, both from the point of view of altitude and the distance between the stations and the influence of windward precipitation and lee behind the main Šumava ridge. The average value of overestimation of precipitation totals is 36%. This value may realistically be slightly lower due to higher losses when measuring by tipping bucket rain gauges, with which the values are compared. In mountainous areas, losses on heated tipping bucket rain gauges and manual rain gauges can be 15–66%, depending on wind conditions [8]. The problem of wind circulation influence on measurement accuracy can also be expected with the weighing rain gauge at Churáňov station; simultaneously, this station is located in the lee and it lies at an altitude 152 m lower. This fact should be negligible in this case due to the small size of the WS100 sensor.

Tab. 1. Comparison of monthly totals measured at the Basum station and at the Boubín, Kubova Huť and Churáňov stations. The average percentage deviation of the WS100 sensor is also shown.

2020/2021	**Basum 1 270 m a.s.l. [mm]**		**Boubín 1 353 m a.s.l. [mm]**	**Kubova Huť 1 010 m a.s.l. [mm]**	**Churáňov 1 118 m a.s.l. [mm]**	**Average deviation [%]**
	WS100	**MR3**	**MR3+Metra886**	**MR3H**	**MRW500**	**WS100**
November	37.2		25	22.6	24.2	155
December	52.5		44	35.2	53.2	119
January	144.5		96	73.4	110.6	155
February	63.8		53	37.9	46.4	139
March	103.6		71	55.3	79.3	151
April	79.7		64	61.8	67.3	124
May	240.7	142.9	147	130.2	160.4	166
June	224.1	134.3	138	142.6	155.1	157
July	170.9	120.3	118	140	158.4	127
August	167.8	135.5	128	133.5	136.9	126
September	23.9	17.7	26	19.8	34.5	98
October	29.5	22.3	30	25.8	25.5	114
Total	**1 338.2**		**940**	**878.1**	**1051.8**	**136**

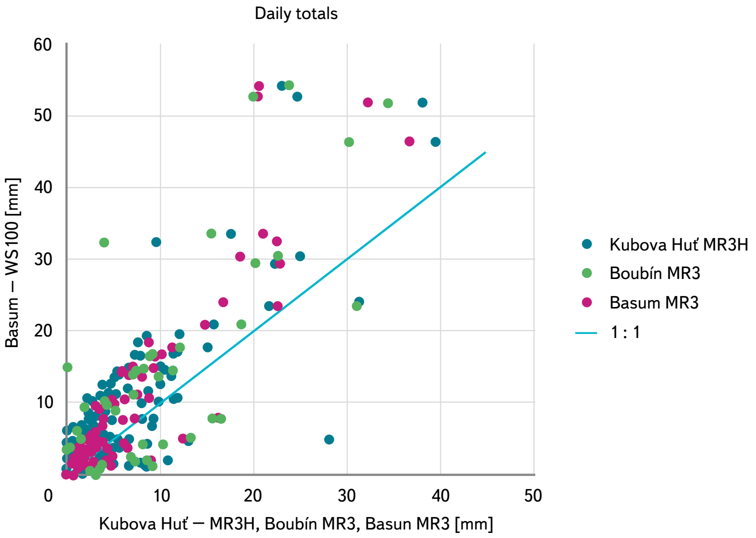

Fig 8. Comparison of daily totals in the hydrological year 2021 measured by the WS100 radar rain gauge, the nearest meteorological stations at Kubova Huť, Boubín, and the tipping bucket rain gauge at Basum station

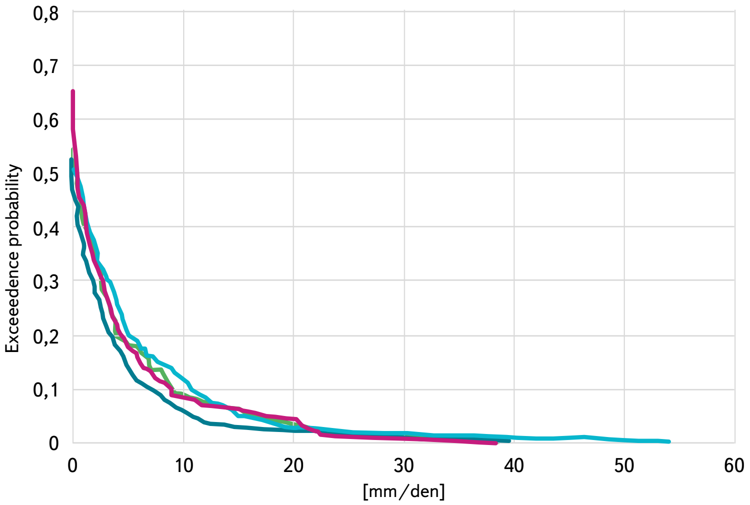

Fig. 9. Exceedance probability of daily totals in the hydrological year 2021 measured by the WS100 radar rain gauge, the nearest meteorological stations at Kubova Huť, Boubín, and the tipping bucket rain gauge at Basum station.

The monthly values in the table also do not confirm seasonal dependence, and measurement deviations are the same throughout the year. During the screening of measured variables at Basum station, other possible weather conditions affecting measurement accuracy of the WS100 sensor were excluded. Influence on measurement deviation was excluded for wind speed, temperature, and air humidity. It will be necessary to subject the intensity of precipitation and the size of the drops to a more detailed analysis. In *Fig. 8*, daily totals in the hydrological year 2021 are compared in the graph. Here, systematicity of the error is confirmed because the differences between measurements at individual rain gauging stations also grow with increasing sum of the daily total. *Fig. 9* shows the probability of exceeding daily totals. The graph clearly shows that the WS100 sensor overestimates regardless of daily precipitation intensity, and the probability of exceeding daily totals is higher in almost all cases with the radar rain gauge.

CONCLUSION

From the experience gained so far, the maintenance-free nature of the radar rain gauge and the amount of information it provides through its measurements can be highlighted. The accuracy of measurements in ridge areas is difficult to assess due to the absence of valid comparative measurements. Nevertheless, an overestimation of precipitation can be observed, which was also detected by Valdivia et al. [2]. As a probable reason in their measurement conditions, they stated inaccurate determination of raindrop diameter, in which the raindrop size distribution measured by WS100 sensor does not correspond to a typical gamma distribution [10]. On the other hand, systematic underestimation of precipitation by the WS100 sensor compared to the heated tipping bucket rain gauge was described by Pishniak et al. [11], who tested different types of rain gauges at a station in Antarctica. The reason for this underestimation may be the prevailing snowfall. Nevertheless, the results of their studies contradict each other. The cause of the inaccuracy can also be individual, caused by, for example, microclimatic conditions. The solution to these inaccuracies can be, for example, a firmware update modifying the measurement methodology (e.g., modification of precipitation intensity diagram) or a statistical correction of systematic errors, the determination of which will be the subject of further research. Nevertheless, this sensor has a number of advantages and the potential to be a suitable tool for measurements in such demanding conditions in remote locations in the future. The next step will be detailed analysis of precipitation events and determination of possible meteorological or other causes in situations where different precipitation totals were measured by tipping bucket and radar precipitation gauges. The results will serve to correct the data and as a basis for further use of radar-type rain gauges. For more accurate determination of the causes of the inaccuracy, it would be advisable to place another WS100 sensor near a weather station with a heated rain gauge and away from the extreme conditions that prevail on a mountain ridge.

Acknowledgements

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Ing. Martin Vokoun , Ph.D., graduated from the Environmental Modelling doctoral programme at the Czech University of Life Sciences (CZU) in Prague. In 2021, he defended his dissertation focusing on the calibration of precipitation forecasts for hydrological modelling using neural networks. Since 2018, he has been an employee of TGM WRI, p. r. i., Hydrology Department, where he has mainly participated in a project assessing the effect of snowfall on the hydrological cycle. He also works at the Meteorology Department of the Institute of Atmospheric Physics of the Academy of Sciences of the Czech Republic, p. r. i., and as a lecturer at CZU, with a focus on meteorology and hydrology.

Interview with Ing. Miroslav Olmer, one of the founders of groundwater zoning in the Czech Republic

Awarding of the Ota Hynie medal at the 14th hydrogeological congress in Liberec 2014 for significant and long-term contribution to Czech hydrogeology

Mr. Olmer, you started your university studies shortly after World War II. Can you tell us about this time from your personal experience and, also, why you chose civil engineering and water management?

I completed my secondary school studies in 1948 when, even at our Reformed Real Gymnasium (RRG) on Velvarská street, it became clear that further studies at university would be associated with certain difficulties. For admission, reviews were required not only from the school, but also from so-called action committees, the Communist Party, and the like. Humanities universities were mainly affected by this, while technical ones were not affected so far.

My motivation was probably a liking for subjects with a distinctly logical basis, for example Latin, mathematics, and optional descriptive geometry, which I chose and then found very useful. Admission to the then University of Engineering Construction, later the Faculty of Engineering Construction, was relatively easier. And the fifth unit of water scouts, the so-called Pětka, certainly contributed to my choice.

Sometimes in life, coincidences decide; how was it in your case? Did you plan to work in research?

I didn't plan to work in research. After completing their studies, some started scientific postgraduate studies; their main aim was to avoid two years of military service. I didn't have this motivation, the scientific career didn't appeal to me at all – I wanted to be on the construction site, and a major obstacle would also be further study of Marxism, which I wouldn't be willing to undertake.

I entered the practice immediately according to the then compulsory placement document, namely at the national enterprise Vodní stavby in Sezimovo Ústí, which was quite a mistake. After a year, I managed to end the two-year commitment and turned to the then Vodohospodářské rozvojové středisko (VRS), where they offered me a position on the construction of Klíčava water reservoir as a construction supervisor. I worked there for two years and I like to remember it – the building was nice, I was my own boss there and, moreover, the working class was mostly made up of persecuted religious people.

Then the lingering effects of an injury from work practice after the third year caught up with me. After surgery on my right leg, I could no longer return to the construction site and transferred to a unit within the VRS, where I already knew it well and earned extra money there during the third year. I was somewhat limited in mobility, with a disability of 45 per cent, but I also got the desired exemption from military service.

And then it went on automatically. The VRS was purpose-built for preparation of the State Water Management Plan (SVP), to which experts from the WRI and the Water Management Office of the Ministry of Construction and Reclamation Department were transferred. My activities were focused on the sector of water supply to the population. After completion of the SVP, the department worked on development of water supply systems and the related survey of groundwater resources, which was then the seed of a later systematic hydrogeological survey and groundwater balance.

Through reorganization ups and downs, the VRS was gradually transformed from the Directorate of Water Streams – Directorate of Water Management Development, the Water Management Development and Construction, until finally, in 1976, the development section was transferred back to the WRI. So it came full circle and I became a "researcher". In connection with other changes after 1990, it was possible to separate the part dealing with groundwater from the development department, which was located in a building on Rohanský ostrov, the so-called "Rohaňák", and connect it with the hydrology department in Podbaba.

As far as we know, you have lived your whole life in Prague 6 – Dejvice. Has it also affected your profession?

Until I was about four years old, we lived in Švecova street, then nearby in Wuchterlova – later also Gneisenauova, Kujbyševova, etc. – near Dejvice railway station. Dejvice was a modern, pleasant neighbourhood; Dejvická street was a shopping street on Sundays, from where I used to bring a tray with pieces of cake from the confectioner Kotrbáček. Today there is a car park, the shops have basically disappeared, replaced by banks and Russian goldsmiths, and on Sundays it is a ghost street. After 1955, I became married to Ořechovka, which was originally Prague XVIII, so also Prague 6.

My teenage years were quite turbulent. SS-Scharnhorst-Kaserne expelled us from the General Boys' School on Dürich Square in the fourth grade, and the Junkers-Werke from the RRG building on Velvarská street after the first year. If the place influenced me in any way, it was probably due to the fact that at the gymnasium in Velvarská I was lucky to have professor of mathematics, prof. Pažoutová, and Latin prof. Václav Čep (brother of the poet Jan Čep). Both of them led me to a fondness for logic, both in maths and Latin, subjects which some other teachers made unattractive for their students. And I must add that the property in Ořechovka made me a caretaker and a gardener.

Almost your entire working life is connected with regional survey and hydrogeological zoning. We are aware of the results of your research, but it is not completely known to public what long development this area went through until the current zoning from 2005.

We operated in the then system of centralized planning and management. Relations between individual workplaces were based more on personal contacts. This was the reason why the contacts between the sectors of water management and geology, regardless of the different departmental affiliations, were very good and close. On the basis of these relationships and the mentioned beginnings of the survey, an opportunity arose to start a regional hydrogeological survey, which was carried out continuously from 1965 until 1990, when it was concluded with the Synthesis of the Czech Cretaceous. There was no further continuation, i.e. the intended Synthesis of the Quaternary.

Twenty years of repeated and unsuccessful attempts to continue this work followed. It was only within the framework of financing from European Union funds that the possibility to continue arose in the form of the project *„Rebalancing of groundwater supplies"*, implemented under the leadership of the Czech Geological Survey (CGS) between 2010 and 2015/2016.

As a preparation for conducting a hydrogeological survey and keeping records of groundwater resources, the first hydrogeological zoning of Czechoslovakia was prepared in the 1960^{s} under the editorship of the VRS original office, later updated in connection with the results of the surveys and changes in the administrative structure. The 2005 version was published in the *Sborník geologických věd (Proceedings of Geological Sciences)*, Series HIG, No. 23, 2006, where the update procedure is also described (see also *Podzemní voda ve vodoprávním* řízení XV, 2019).
It is worth mentioning the comparison of the processing and administration of individual versions, which I am attaching for your interest:

Updates were foreseen in the concept of zoning from the beginning. Since 2016, material documents have been available for updating the latest valid version at the end of the *„Rebalancing of groundwater supplies"* project, but this has not yet happened.

ÚGÚ, ČGÚ – Ústřední/Český geologický úřad (Central/Czech Geological Office), MLVH – Ministerstvo lesního a vodního hospodářství (Ministry of Forestry and Water Management)

Version	Processing	Scale	Approved
1965	1962–1964	500,000	MZLVH a ÚGÚ, 1965
1973	1971–1973	200,000	MLVH a ČGÚ, 1973
1986	1984–1986	200,000	MLVH (SVP protocol), 1986
2005	2001–2005	digital	Decree No. 5/2011 Coll.

We last met at work during the *„Rebalancing of groundwater supplies“* project, where you were one of the consultants for the Czech Geological Survey. How do you perceive this whole project and its results?

The Czech Geological Survey approached me to cooperate as a consultant, initially for part of the hydrological work in activities 2, 4, 6, and offered me good conditions for the entire duration of the project. Subsequently, collaboration has developed with RNDr. Renáta Kadlecová, the main researcher of the *„Rebalancing of groundwater supplies“* project.

On the basis of experience from twenty-five years of regional surveys, control days were introduced, which were beneficial for mutual contact between the contracting authority and the researchers, although they repeatedly took place without the participation of representatives from the contracting parties, i.e. the State Environmental Fund, or the Ministry of the Environment and the Ministry of Agriculture.

The project was completed in 2015/2016 and the results of the assessment of groundwater resources were presented in a standardised form of so-called *Cover Sheets*, which replaced the already completely outdated outline according to Decree No. 369/2004 Coll. Their content essentially fulfills the original purpose of the task, i.e. the rebalancing of groundwater resources in selected important regions, and thus provides uniform data for their updating.

Can you think of some loved ones, colleagues, friends, and other people who influenced you a lot and meant a lot to you?

From my field, they are primarily Karel Zima, František Slepička, Stanislav Klír and Miroslav Kněžek. It was a certain advantage that we were not directly connected from an organizational point of view and thus were not bound to each other in certain respects.

Karel Zima drew attention to the close relationship between hydrogeological research and the practical use of groundwater resources. František Slepička dealt in detail with the manifestations of the underground component in the surface runoff. With Miroslav Kněžek, our relationship was rather specific; our common interest was groundwater, but with his point of view of a hydrologist, and my point of view based on water management. Our relationship went beyond professional cooperation and grew into a personal level. Stanislav Klír was the officer for hydrogeology at the Central Geological Office, and his contribution to the creation and organization of the regional hydrogeological survey is essential. He was an official, educated in the field, who did not hesitate to accept decisions and bear responsibility for them. Again, our relationship was a little more than a working one.

What message would you like to convey to the current young generation of researchers?

I admire the young generation's technical equipment and wide use of modern technologies. But I would still like to remind you that groundwater is an integral part of the hydrological cycle, and thus of the natural environment. The landscape, its character, cannot be known and understood only from satellite images and records of automatic observation stations. You have to go through it and feel it; that's how everyone did it before – Smreker, Hynie, Podvolecký – whose insights we still value and they are irreplaceable.

It took quite a long time before, during the second half of the last century, it was possible to at least partially apply the opinion that surface water and groundwater systems are not separate and that groundwater does not only form the final part at the crossing line (Wundt, Natermann), but also 40 to 50 per cent of total runoff. Together with Miroslav Kněžek, we tried to promote this, and the work of František Slepička also made a significant contribution to this. It will probably take some time before the water management balance, which is still separate for surface water and groundwater, changes, even though mutual influence obviously occurs and the so-called conjunctive balance for certain territories is known and applicable.

And just as an afterthought – today's options for publishing and reproduction techniques are very wide, but they also have their limitations. They enable an almost overproduction of the volume of information – at the expense of more concise substantive expression.

Thank you very much for the interview and I wish you good health.

Ing. Anna Hrabánková
Head of the TGM WRI Department of Hydraulics, Hydrology and Hydrogeology

The interview was translated on the basis of the Czech original by Environmental Translation Ltd.

Ing. Miroslav Olmer

Ing. Miroslav Olmer, born 6 July 1929, is one of the founders of hydrogeological zoning in the Czech Republic. He graduated from the Czech Technical University, the University of Engineering Construction – Water Management (1948–1953), but at the same time he also studied English at the Faculty of Philosophy and postgraduate courses dedicated to contemporary philosophy, and later practical hydrogeology. In mid-1960s, he was the main researcher of the first hydrogeological zoning of Czechoslovakia (including Slovakia), and introduced the first detailed record of water supply sources of groundwater in important hydrogeological structures. At the beginning of the 1970s, a more detailed zoning on a scale of 1 : 200,000 was published again under his leadership, and at the same time work was started on the water management balance of the amount of groundwater. In connection with this, he began to put into practice hydrological methods of determining natural sources of groundwater. In the second half of the 1980s, he opposed part of the results of the Synthesis of the Czech Cretaceous – one of the most important hydrogeological surveys of that time – and at the same time, together with a team of authors, he published another hydrogeological zoning, this time clearly aimed at balancing the amount of groundwater. He designed and developed protected areas of natural water accumulation (CHOPAV), which still exist in our legislation today. After 1989, he devoted himself to the general issue of groundwater protection, both in terms of quantity and quality. He is the author of some concepts that were later incorporated into national legislation. Another initiative was the Hydrogeological Zoning of the Czech Republic in 2005, which became the basis for the delineation of groundwater bodies, as well as cooperation on the development of procedures for assessing the state of groundwater bodies, or his essential contribution to the most important hydrogeological project of the last decade *„Rebalancing of groundwater supplies“* (2010–2016).

Photo: shutterstock.com

The current version of the BILAN model

BILAN is a comprehensive conceptual model in a daily/monthly structure (the diagram is shown in *Fig. 1*), simulating the components of the hydrological balance in a basin. Although its development was started at TGM WRI at the beginning of 1990^{s}, it is a model that is still used as a standard in the Czech Republic and remains accessible to the lay and professional public; for example, it is an integral part of the HAMR application/system solution [1], but has also been used elsewhere [2–4]. The main advantages of the model, compared to other solutions, include internal calibration algorithms, the possibility of direct input of water use data, and low computational complexity suitable for variant simulations (e.g., the effects of climate change on water regime). The last text dedicated to the structure of the BILAN model was published in VTEI on 7 August 2015 [5], so we think it is a good time to document that this simulation tool is keeping up with the present and the model structure is being continuously modified based on research and societal requirements. Nowadays, the BILAN model is also used for projects such as Centrum Voda, PERUN, and Interreg CE Thaya.

Naturally, over time, general trends in software development and hydrological modelling have changed, as a result of which the original code was rewritten from the Object Pascal language to C++ and further expanded with a package containing an application program interface to the R environment. A graphical user interface and a web environment were also added at *http://bilan.vuv cz*. The user manual and documentation for the model can also be found here. The package for R was originally housed in the *Comprehensive R Archive Network* (CRAN) repository. Recently, it was decided to establish a versioning system for storing the source code of the software directly hosted on the TGM WRI servers. This solution comes from GitLab Inc. and uses today's standard secure source code management technology – Git. It is possible to find the BILAN model repository at *https://git.vuv.cz/hydrology-department/bilan*. It is also possible for any user to install the R package directly from this website.

BILAN is currently (at the time of writing) in version 2022-07-22 and contains:

- Alternative options for estimating potential evapotranspiration in/for the basin using a smaller or larger number of input variables. These include, for example, daily temperature minimums and maximums, the length of the day or the solar radiation constant, the psychrometric constant or the tension of saturated water vapour. Estimation of potential evapotranspiration is usually the first step in simulating the water balance in a basin; therefore, its accuracy has a direct and fundamental impact on the success of determining the remaining components of the balance.
- The implemented equations that define these estimates are known by the following names: Blaney-Criddle (1) [6], Priestley-Taylor (2) [7], Hamon (3) [8], and Hargreaves-Samani (4) [9]. Until now, a method based only on average daily temperature and latitude was available in the model [10]. These techniques can either provide more adequate values, especially if the quantities mentioned are obtained by precise measurement, or offer greater variability of the required inputs. In addition, their implementation is suitable for comparative studies of models that work with comprehensive data sets, for example from the MOPEX or CANOPEX projects, in which daily temperature ranges are more often available than average daily temperatures.

Complete list of equations:

$$ET_0 = p \cdot (0.457 \cdot T_{mean} + 8.128) \qquad (1)$$

$$ET_0 = \alpha \cdot \frac{\Delta \cdot (R_n - G)}{\lambda_v \cdot (\Delta + y)} \cdot 1000 \qquad (2)$$

$$ET_0 = k \cdot 0.165 \cdot 216.7 \cdot N \cdot \left(\frac{e_s}{T + 273.3}\right) \qquad (3)$$

$$ET_0 = 0.0023 \cdot R_n \cdot (T_{max} - T_{min})^{0.5} \cdot (T_{mean} + 17.8) \qquad (4)$$

where	ET_0	is	estimation of reference evapotranspiration
	p		percentage expression of daily hours of the day
	$T_{mean}, T_{max}, T_{min}$		temperature statistics
	α		empirical constant for water vapour deficit
	y		psychrometric constant
	Δ		the slope of the saturated vapour tension curver
	G		density of the heat flow to the soil
	R_n		radiation balance
	λ_v		latent heat of vaporization
	e_s		saturated water vapour pressure
	N		daylight hours

- *Kling-Gupta efficiency* (KGE) – composite calibration criterion [11]. KGE has been relatively widely used in hydrology in recent years because it addresses the shortcomings of criteria using mean squared error. This is also the case of the better-known and long-used *Nash-Sutcliffe efficiency* criterion [12]. The mean squared error is divided here into three diagnostically significant components – correlation, systematic error, and variability. The relative importance of these components can be adjusted using the weights that are assigned to the internal term, with the default values being equal. In general, the KGE equation (5) contains a correlation term *r* between two time series, then a member α to assess the systematic error, and finally a member β, which compares the mutual variability.

$$KGE = 1 - \sqrt{a(r-1)^2 + b(\alpha-1)_2 + c(\beta-1)^2} \qquad (5)$$

There are multiple implementations of this criterion. In the BILAN model (6), a following variant is used:

$$KGE = 1 - \sqrt{a(r-1)^2 + b\left(\frac{\mu_{sim}}{\mu_{obs}} - 1\right)^2 + c\left(\frac{\sigma_{sim}}{\sigma_{obs}} - 1\right)^2} \qquad (6)$$

where	a, b, c	are	the term weights
	r	is	Pearson correlation coefficient
	μ_{sim} / μ_{obs}		proportion of mean values
	$\sigma_{sim} / \sigma_{obs}$		proportion of standard deviations of both time series

In the coming years, the *https://git.vuv.cz* domain will be used to make available other open-source software originating from the research activities of the TGM WRI hydrology department. By the end of 2022, the graphic version of the BILAN model will also be moved and the same modifications will be made, which will also be transitioned to the new, sixth version of the Qt framework.

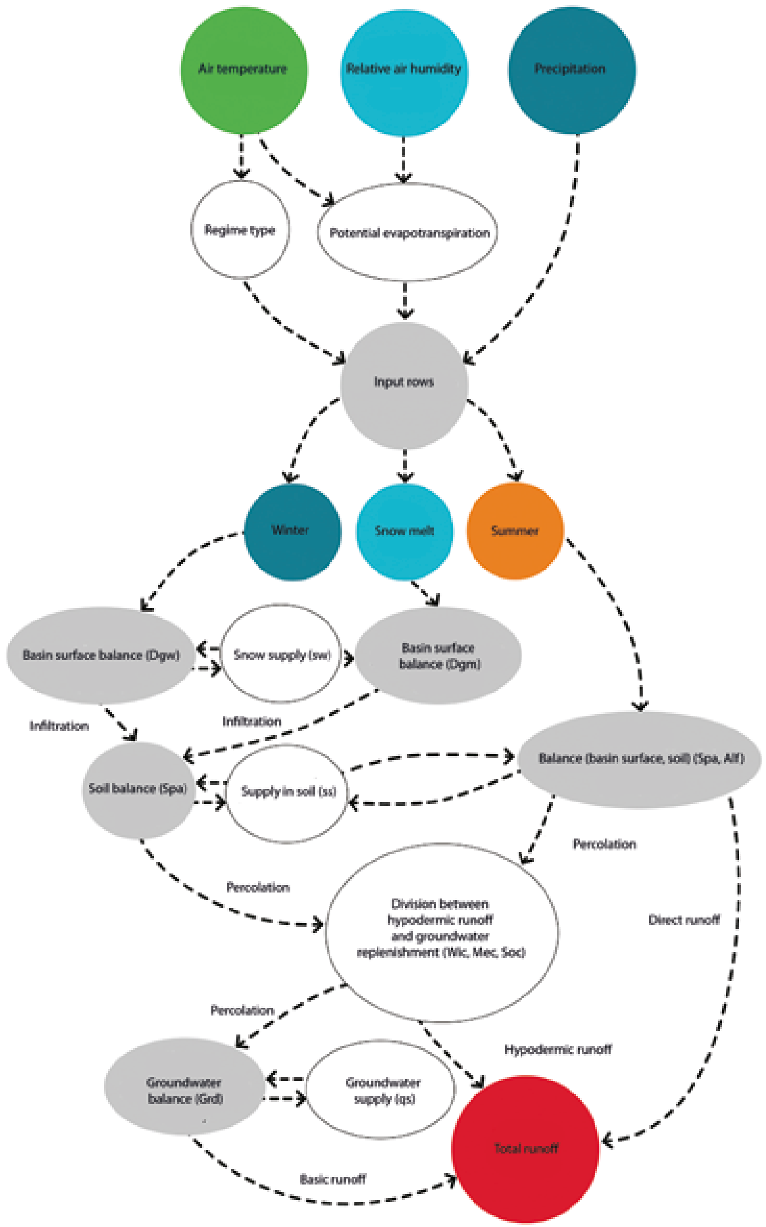

Fig. 1. Diagram describing the structure of the BILAN model in a monthly calculation step

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Invitation to the travelling exhibition *Historical water management objects, their value, function and significance for the present time*

Veľký Kolpašský tajch, Banský Studenec, Slovakia (Photo: Slavomír Červeň, 2021)

Research focused on the evaluation of historical water management objects in the Czech Republic from the point of view of their significance for historic preservation is already in its fifth year. It is broadly conceived interdisciplinary research with the involvement of experts from TGM WRI, Methodological Centre of Industrial Heritage of the National Heritage Institute, Historical Institute of the Academy of Sciences of the Czech Republic, The Silva Tarouca Research Institute for Landscape and Ornamental Gardening, and Faculty of Science, Palacký University Olomouc. The research is carried out within the DG18P02OVV019 project *"Historical water management objects, their value, function and significance for the present time"* financed by the NAKI II programme of the Ministry of Culture.

Historical water management structures represent one of the segments of industrial heritage. They are proof of society's technological development and its approach to managing water in the landscape. The team of experts of the aforementioned consortium tried to document this hitherto rather neglected type of structures, identify their value, and compile a set of criteria for evaluating their historical significance as well as for their protection and restoration.

The exhibition at the end of the project will present the main results and findings arising from the five-year research: methodological approaches regarding this part of cultural heritage as well as their application to specific structures. Various types of water management structures will be presented on examples of five model territories within the Czech Republic (the basins of the Svitava, Upper Morava, Moravice, Ploučnice, and the Čáslav region), which differ from each other in terms of historical development, management methods, and physical-geographical conditions: dams, small hydropower plants, water pipes, supply canals carved in sandstone massifs, water supply facilities and many others. For comparison, specific, heritage-protected water management systems in nearby countries will also be presented, such as the UNESCO monuments – Water management system of the town of Augsburg in Bavaria and the Banskoštiavnické tajchy in Slovakia. The authors' intention is to capture the individual topics in a visually attractive form using maps, reconstructions, and visual material. The exhibition is designed as a mobile one and is intended for the general public. It will also include a catalogue developing the individual topics presented on the exhibition panels and summarizing the project results.

EXHIBITION SCHEDULE:

1–30 October 2022	Hostětín – Community Center Old School
1–11 November 2022	Čáslav – City Library
14–20 November 2022	Opava – Silesian Regional Museum
22–27 November 2022	Olomouc – The Fortress of Knowledge (Interactive Museum of Science UP)
1–31 December 2022	Brno – Technical Museum

On behalf of the consortium research team, we cordially invite you to the exhibition. Miriam Dzuráková (TGM WRI) and Aleš Vyskočil (Historical Institute of the Academy of Sciences of the Czech Republic)

Annotation of the exhibition *Irrigation – rediscovered heritage, its documentation and popularization*

Examples of current irrigation (by sprinklers, Eastern Bohemia) and in the past (a system of irrigation canals from the Morava River, near Chropyně) (Photo: Radek Bachan, WRI TGM, 2021)

As a response to landscape drainage in the modern era, caused by the intensification of agriculture, the drying up of ponds, and land reclamation activities, interest in the opposite process has reappeared, i.e. irrigation. Existing irrigation systems, at present often non-functional and preserved only in parts, have become the subject of interest for this project which tried to capture the historical development of this specific water management field as well as part of the industry associated with the implementation of irrigation and the production of soil irrigation equipment. The research also included defining suitable procedures for identifying irrigation structures and systems in the landscape using modern methods and technical tools. In the broader context of the current fight against the impact of drought, the project and its outputs, including the exhibition itself, should contribute to raising awareness of the history of irrigation planning, construction, and maintenance in the Czech lands and the transfer of this heritage to the present, including at the local level. The authors' intention is to capture individual topics in a visually attractive form using maps, reconstructions, and visual material. The exhibition is designed as a mobile one and is intended for the general public. An accompanying part of the exhibition is a peer-reviewed catalogue, which develops individual topics and presents the localities of historical irrigation systems in our country and abroad listed on the exhibition panels. At the same time, it summarizes the results of the NAKI grant project of the same name, implemented between 2020 and 2022.

EXHIBITION SCHEDULE:

1–30 October 2022	Hostětín – Community Center Old School
31 October – 11. November 2022	Kroměříž – Flower Garden
14–21 November 2022	Olomouc – The Fortress of Knowledge (Interactive Museum of Science UP)
1–31 December 2022	Brno – Technical Museum

On behalf of the consortium research team, we cordially invite you to the exhibition. Miloš Rozkošný (TGM WRI), Zbyněk Sviták (Masaryk University Brno) and Zbyněk Kulhavý (Research Institute for Soil and Water Conservation).

You can find current information, including details of other installation locations at https://heis.vuv.cz/projekty/zavlahy.

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ŠLUKNOV HOOK

Červený potok (‘Red Stream’) flows through Divoká rokle (‘Wild Gully’) near Doubice in northern Bohemia through cushions of sphagnum moss and haircap moss. Along its course, it will lead us to the famous Černá brána (‘Black Gate’) and further into Křinice river gorge, which forms the state border with Saxony here.
Text and photo provided by Václav Sojka, www.vaclavsojka.cz.

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