

# Potential of areas protected for surface water storage to mitigate the impacts of climate change on drinking water supply

ADAM VIZINA, PETR VYSKOČ, ROMAN KOŽÍN, HANA NOVÁKOVÁ

**Keywords:** water resources – water scarcity – drinking water supply – water balance – climate change – adaptation

## ABSTRACT

In the Czech Republic, areas morphologically, geologically and hydrologically suitable for surface water storage to mitigate the adverse effects of floods and droughts are defined through the *General Plan for Surface Water Accumulation Areas*. In the context of climate change, these locations create potential for possible adaptation measures. This article describes the assessment of the potential of selected sites for water supply under climate change conditions by means of hydrological and water balance modelling.

## INTRODUCTION

The Czech Republic has a tradition in water resource planning. The *State Plan of the Czechoslovak Republic* (1954) was the first comprehensive list of possibilities for water management use of water resources in CR. It also became the basis for spatial planning. In 1975, the *Indicative Water Management Plan* (Směrný vodohospodářský plán, SVP) was published, where increased attention was paid to the analysis, documentation of the condition, and the possibility of using water resources. It includes the claimed water needs and their outlook for the next 30 years. A total of 581 potential dam profiles suitable for the construction of water reservoirs were selected as part of the SVP, of which 286 sites suitable for this construction were documented in more detail. In 1988, the *SVP Publication* followed, which updated the data on sites. Due to the limitation of claims for the occupation of agricultural land, protection was cancelled for 253 sites, and 97 sites were completely eliminated. In 1995, another SVP was written, in which it was necessary to take into account the new socio-political situation and the introduction of environmental approaches in water management. The number of protected sites has narrowed to just 35. In 2007, the *Plan of the Main River Basins of the Czech Republic* was created, which served as a long-term concept in the field of water resource planning. One of its goals was the updating of the existing range of prospective reservoir sites and their territorial protection. The updated list included 186 sites, however, due to public opposition and the interests of nature and landscape conservation, the plan could not be approved. Therefore, in 2011, the document *General Plan for Surface Water Accumulation Areas* (hereinafter SWAA General Plan) was prepared. The SWAA General Plan was developed following the territorially protected sites in the SVP 1988. Property law, socio-economic and environmental aspects were assessed for individual sites, and the SWAA General Plan in its final form contains 65 protected sites. In 2020, the next and so far last update of the SWAA General Plan took place. The need to update the SWAA General Plan is included in the "Concept of protection against the consequences of drought for the Czech Republic",

which was approved by the government in 2017 and also resulted from the meeting of the National Coalition Against Drought in May 2019. Both the concept and the National Coalition were created as a response to the long-term drought in 2014–2019. As part of the update, the SWAA General Plan is being expanded by another 21 sites. The SWAA General Plan 2020 [1] thus registers a total of 86 sites. Of these, 31 are included in category A, i.e. among sites potentially intended for water supply reservoirs.

In the Czech Republic and in the world, considerable attention is paid to proposals for adaptation measures that should mitigate the effects of climate change. One such measure is the long-term sustainable management of water resources. It should be mentioned that adaptation measures should be comprehensive and complement each other. However, it follows from previous studies [2–5] that in the case of ensuring reliable water supplies for industry and the population, one of the appropriate measures is the use of water reservoirs. However, potential reservoirs need to be examined in the context of climate change. In particular, increasing air temperature affects evaporation from the water surface and overall evapotranspiration in the landscape, and as it was shown, for example, in [5], reservoirs in vulnerable sites may have a problem in the future to fulfil supplies with the required reliability. SWAA General Plan 2020 contains only basic data on the possible (potential) volume of reservoirs. In view of the ongoing climate change, it is necessary to check the basic water management function of potential reservoirs on SWAA (Sites for storage of surface water), namely whether these potential reservoirs would be able to compensate for negative changes in the respective catchments. A similar issue was already dealt with [6, 7], however, the results do not include the significant drought period 2014–2019. Therefore, as part of the project "*Water management and water supply systems and preventive measures to reduce risks in the supply of drinking water*", 17 potential water reservoirs from SWAA category a were selected and their assessment was carried out using new data until 2020 and new climate change scenarios. Implementation follows on from the partial outputs of the mentioned project, mainly the evaluation of the security of water abstractions from existing water reservoirs [5] and the balance of resources and needs of groundwater for drinking purposes [8].

## METHODOLOGY AND MATERIAL

The assessment of the possible impact of climate change on the provision of water supply by water reservoirs is based on methodology [9]. The procedures from the methodology for processing the hydrological and water management balance are applied, including simulation modelling of the storage function of water management systems. The assessment was prepared for the prospective

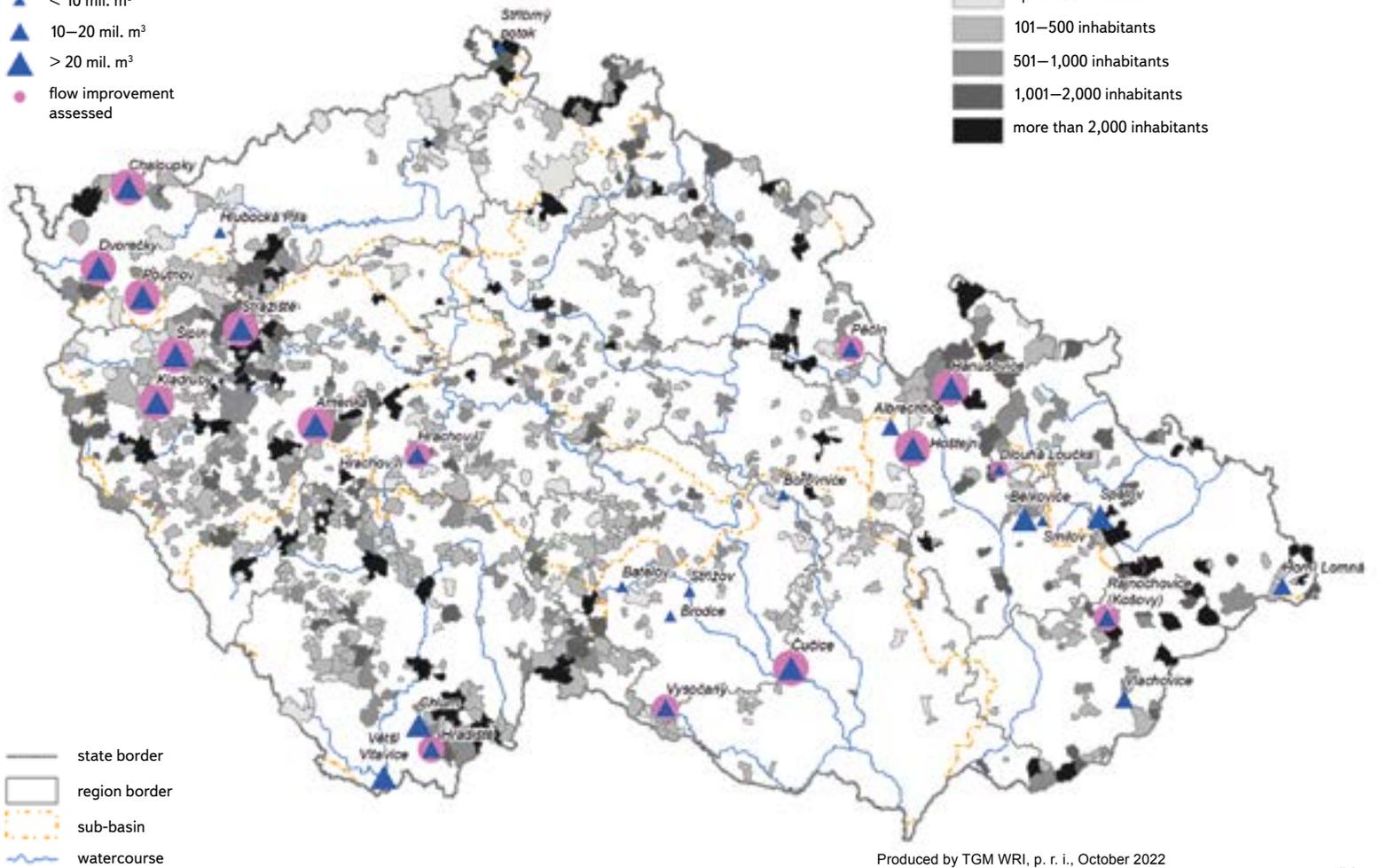
**Areas protected for surface water storage category A**

**Total controllable capacity  $V_0$**

- ▲ < 10 mil.  $m^3$
- ▲ 10–20 mil.  $m^3$
- ▲ > 20 mil.  $m^3$
- flow improvement assessed

**Municipalities affected by drought in terms of drinking water supply according to the number of inhabitants**

- up to 100 inhabitants
- 101–500 inhabitants
- 501–1,000 inhabitants
- 1,001–2,000 inhabitants
- more than 2,000 inhabitants



Produced by TGM WRI, p. r. i., October 2022  
 Data sources: MoA, TGM WRI, p. r. i., Povodí State Enterprises, CHMI, ČÚŽK

Fig. 1. Areas protected for surface water storage category A and municipalities affected by drought in terms of drinking water supply; polygons represent municipalities and population affected by drought

period of 2050, the hydrological balance modelling was also carried out for time horizons with centered year 2035 and 2085.

With regard to the solution to the problem of drinking water supply, the selection of evaluated sites was limited to SWAA category A. Out of a total of 31 SWAA recorded in this category, 17 sites were selected. The selection was based on the location of these sites near potentially problematic areas. Fig. 1–3 show the selection. The selected and evaluated sites are highlighted in purple. Fig. 1 shows the location of SWAA category A, in which municipalities affected by the drought in 2015 in terms of drinking water supply were identified as part of the Plans for development of water supply and sewerage for the Czech Republic [10] (the vast majority are problems with groundwater supply). Fig. 2 shows the location of SWAA in relation to ensuring the current requirements for water supply by water reservoirs in conditions of climate change [5]. For easier orientation, abstractions are divided into four groups according to the security achieved by duration and marked using a colour scale, as follows:

- a) water abstractions with reliability of current and permitted abstractions in all evaluated scenarios are marked in blue,
- b) medium-risk abstractions reliability of only current abstractions in all evaluated scenarios are marked in green,
- c) abstractions reliability of current abstractions are marked yellow only in the more favourable scenario of the impact of climate change HadGEM2,
- d) abstractions where reliability is not achieved in any of the climate change impact scenarios are marked red as high risk.



Fig. 3 shows the location of the SWAA in relation to the areas – the so-called working units of groundwater bodies –, that are evaluated as (potentially) at risk in terms of the balance of available resources and groundwater abstractions in current conditions or in conditions of climate change [8]. Selected SWAA and their characteristics are shown in Tab. 1.

**Current climate conditions**

Climate data for the period 1961–2020 was used for the actual assessment of current conditions, time series of air temperatures and precipitation. During this period, a significant increase in temperatures can be observed, especially in recent years. This increase reaches high statistical significance. The increasing temperature affects the amount of potential evapotranspiration and, if water

### Areas protected for surface water storage category A

#### Total controllable capacity Vo

- ▲ < 10 mil. m<sup>3</sup>
- ▲ 10–20 mil. m<sup>3</sup>
- ▲ > 20 mil. m<sup>3</sup>
- flow improvement assessed

#### Current annual abstraction [thousand m<sup>3</sup>]

- up to 1,000
- 1,000–10,000
- more than 10,000

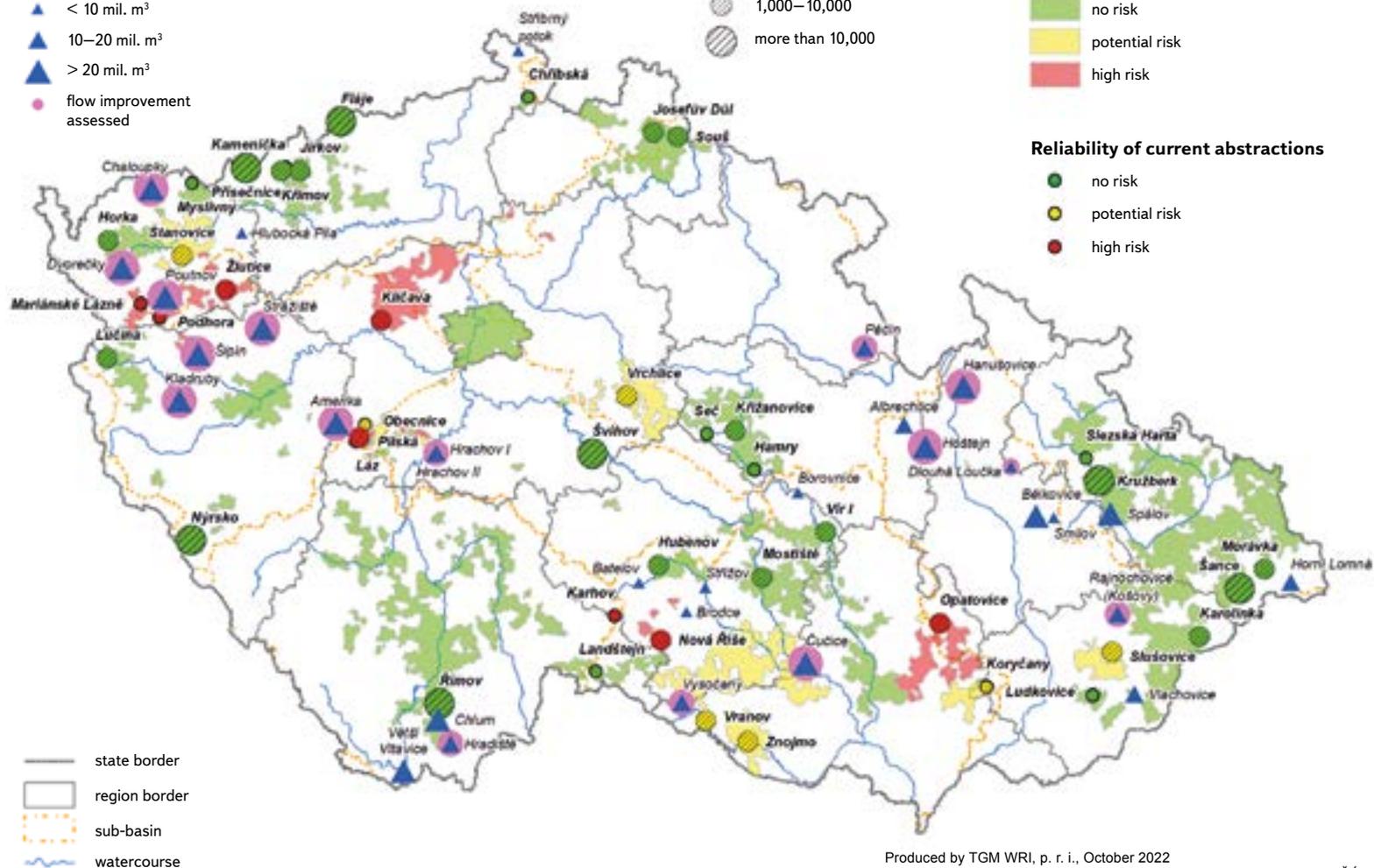
#### Supplied areas (cadastral areas)

##### Security of abstractions provided by water reservoirs

- no risk
- potential risk
- high risk

##### Reliability of current abstractions

- no risk
- potential risk
- high risk



Produced by TGM WRI, p. r. i., October 2022  
Data sources: MoA, TGM WRI, p. r. i., Povodí State Enterprises, CHMI, ČÚZK

Fig. 2. Areas protected for category A surface water storage and reliability of water abstractions by reservoirs

is available in the soil profile, then also the current evaporation. The reduced availability of precipitation totals was mainly in the periods 1969–1974, 1989–1994, and 2014–2017. When evaluating annual precipitation totals, it is not possible to trace a trend that would be statistically significant. The same applies for outflows, where no statistically significant trend can be found in the long-term average annual outflows (average for the whole of the Czech Republic). In recent years, however, a significant decrease in runoff can be observed in the summer and spring months and an increase in January, which is mainly due to liquid precipitation and snow melting due to increased temperatures.

### Climate change scenarios in water management

For the preparation of climate change scenarios in the context of changes in the hydrological balance, the delta change method is used as standard in the Czech Republic, especially for studies in monthly time steps. This method consists in transforming the observed data so that the changes in the transformed quantities correspond to the changes derived from climate model simulations. Changes in average monthly precipitation totals and average monthly temperature are normally considered in the monthly step. In the daily step,

it is also necessary to consider changes in the variability of quantities. Therefore, the advanced delta change method (ADC) was used to create climate change scenarios. The essence of the ADC method is to transform the observed data in a way that guarantees that the changes between the transformed and the original series are the same as the changes derived from the regional climate model. For precipitation and temperature (especially in the daily step) it is desirable that the considered transformations take into account changes in both mean and variability. Simply put, this means that the extremes can change differently than the average. When deriving precipitation changes from the climate model, the ADC method also considers systematic simulation errors. Since the temperature is transformed linearly, systematic error has no effect on the resulting temperature transformation [11].

Selected [12] *Global Circulation Models* (GCM) for sub-basins were transformed by the chosen method, namely:

- NorESM1-M +
- MPI-ESM-LR + HadGEM2-ES +
- GISS-E2-H + MRI-ESM1 +
- CanESM2 + GFDL-CM3



Tab. 1. Selected sites and their basic characteristics

SWAA	Watercourse	Basin area [km <sup>2</sup> ]	Total controllable space $V_0$ [mil. m <sup>3</sup> ]	DBC ANLGN	River/stream ANLGN	Area ANLGN [km <sup>2</sup> ]	Calibration period	KGE
<b>Amerika</b>	Klabava	69.7	30.9	187500	Klabava	158.45	2002–2011	0.68
<b>Čučice</b>	Oslava	791	53	474000	Oslava	861.03	1961–2011	0.61
<b>Dlouhá Loučka</b>	Huntava	27	5.2	362000	Loučka	80.8	1961–2011	0.71
<b>Dvorečky</b>	Libava	45	30.75	206800	Libava	68.22	1961–1988	0.76
<b>Hanušovice</b>	Morava	217.2	135	345000	Morava	349.9	1961–2011	0.81
<b>Hoštejn</b>	Břežná	126.5	166	353000	Břežná	130.03	1961–2011	0.74
<b>Hradiště</b>	Černá	125.3	13	112500	Černá	133.24	1971–2011	0.65
<b>Hrachov I</b>	Brzina	132.6	10.5	153800	Brzina	133.24	1984–2011	0.73
<b>Hrachov II</b>	Brzina	115.5	6	153800	Brzina	133.24	1984–2011	0.73
<b>Chaloupky</b>	Rolava	20.1	36.5	209100	Rolava	20.1	1967–2011	0.69
<b>Kladruby</b>	Úhlavka	277.3	27.26	173000	Úhlavka	296.59	1961–2011	0.67
<b>Pěčín</b>	Zdobnice	72.2	17.1	027000	Zdobnice	84.3	1961–2011	0.76
<b>Poutnov</b>	Teplá	91.4	28.1	210900	Teplá	256.12	1961–2011	0.58
<b>Rajnochovice (Košovy)</b>	Juhyně	19.3	11.2	387500	Juhyně	20.24	1978–2011	0.78
<b>Strážiště</b>	Střela	629.8	78.01	190000	Střela	775.02	1961–2011	0.64
<b>Šipín</b>	Úterský potok	173.6	39.7	175000	Úterský potok	297.45	1961–2011	0.66
<b>Vysočany</b>	Želetavka	369.4	17.8	432000	Želetavka	367.69	1961–2011	0.69

ANLGN – hydrological analogue, DBC – database number of CHMI water gauging station, KGE – Kling-Gupta efficiency.

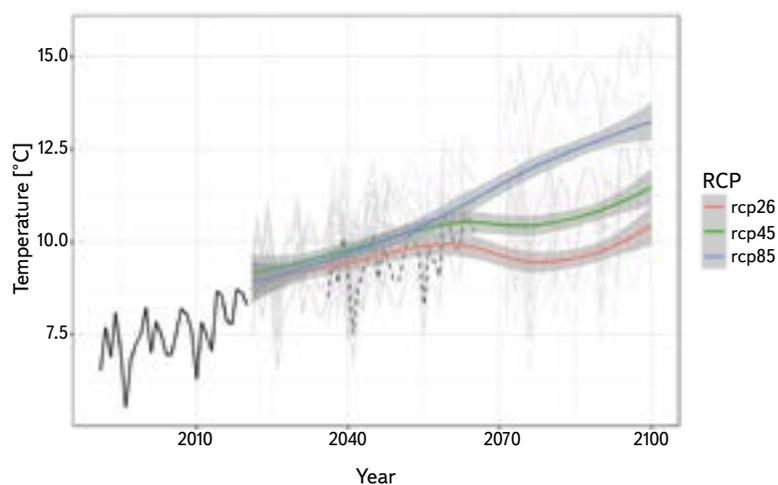


Fig. 4. Air temperatures according to observations, individual GCM and emission scenarios RCP (grey lines describe the simulations of individual climate models, coloured lines the mean of simulations for the selected emission scenario)

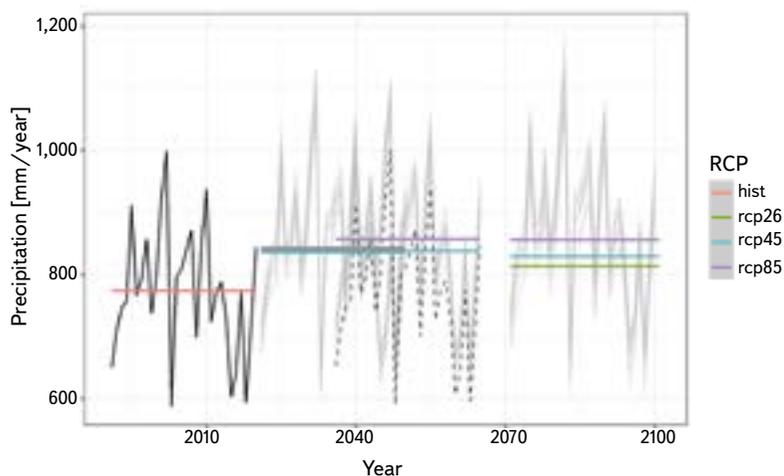


Fig. 5. Precipitation according to observations, individual GCM and emission scenarios RCP (grey lines describe the simulations of individual climate models, coloured lines the mean of simulations for the selected emission scenario)

## Hydrological balance modelling

To model the hydrological balance, the BILAN conceptual model was used, which has been developed for more than 15 years in the TGM WRI Department of Hydrology. The model calculates the chronological hydrological balance of the basin or area in daily or monthly time steps. It expresses the basic balance relationships on the surface of the basin, 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 the energy balance, which significantly affects the hydrological balance. Potential evapotranspiration, evapotranspiration, infiltration into the aeration zone, seepage through this zone, snow water storage, soil water storage, and groundwater storage are simulated during the calculation. Runoff is modelled as the sum of three components: two components of direct runoff (including hypodermic runoff) and base runoff [14–16]. The monthly version of the model, which is controlled by eight parameters, was used to model the hydrological balance. The model uses linear and non-linear reservoirs to transform precipitation into runoff. The main inputs of the model are precipitation and air temperature (also measured runoff for calibration), the output is the modelled runoff from the basin and other components of the hydrological balance.

In order to assess the impact of climate change for future outlooks, it is necessary to have a built and calibrated hydrological model for the SWAA profiles, which will allow performing variant calculations according to climate change scenarios. As there is usually no direct discharge observation for the SWAA basins, hydrological analogies must be used. The BILAN model is calibrated to an analogue that overlaps with the original basin, and the resulting parameters are transferred to the SWAA basin. Using these parameters and the new precipitation and temperatures, which are interpolated exactly to the SWAA basin, it is then possible to simulate the outflows directly for the profile of the potential reservoir. A similar procedure is used to simulate the affected outflows according to climate change scenarios. In this case, the inputs are formed by the affected precipitation and temperatures according to climate change scenarios and already known model parameters from the previous calibration.

Model calibration was performed on monthly data obtained by interpolation from a regular grid (25 × 25 km) of precipitation and temperatures for the Czech Republic [18]. The period used to calibrate the model on the analogue is shown in *Tab. 1*; except for SWAA Amerika, a calibration period achieved more than 20 years. When calibrating the model, emphasis was placed on a more accurate simulation of outflows in the area of lower quantiles. The goodness of fit between the observed and modelled runoff was assessed by the Kling-Gupta metric [19], the values of which are shown in *Tab. 1*. In general, it can be said that the closer the value is to 1, the greater the fit between modelled and observed runoff.

## Hydrological modelling of climate change

The procedure for modelling the impact of climate change on the hydrological regime (*Fig. 6*) can be briefly summarized as follows:

1. The selected hydrological model is calibrated for the selected catchment using observed data. A hydrological model should be based on physics to guarantee that it will provide acceptable results even for unobserved conditions.
2. The input quantities from the global and regional climate model are converted into scenario series for individual basins, namely by:
  - (a.i.1.a) statistical downscaling,
  - (a.i.1.b) post-processing of the output of the climate model, i.e., using the incremental method or correction of systematic errors.

It is often necessary to use spatial interpolation to relate the data from the calculation cells of the climate model to the centre of gravity of the given basin. For the correct use of all methods (a–b), it is necessary to have the observed data available.

3. Using a calibrated hydrological model and scenario series, a simulation of the hydrological balance for the scenario period is carried out.
4. Modelled discharge for the present and prospective periods are corrected in individual months using the quantile method [17].

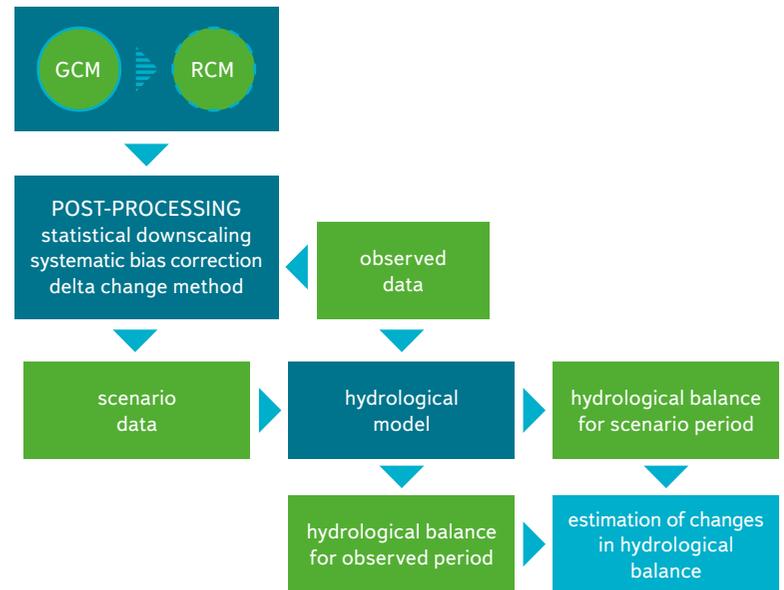


Fig. 6. Scheme of hydrological modeling of climate change impacts

## Water management balance

The potential volume of water that can be provided by selected sites with a given reliability for water abstraction or minimum discharge was evaluated using a simulation model of the water management system storage function [20]. The simulation was processed in a monthly step for a total of 39 years (i.e., 468 months) for time series of unaffected monthly mean discharge and evaporation. The time series were processed using the above-mentioned hydrological balance modelling procedure. Variants representing both current hydrological conditions (scenario 0) and climate change impact scenarios were evaluated: the HadGEM2 scenario for the reference year 2050, and a warming by +2 °C scenario (scenario 2). The total controllable volume of the water reservoir listed in the SWAA General Plan [1] was considered as active storage capacity. In this regard, it is necessary to consider the resulting values of reliable abstractions (or improved discharge) as theoretical. Despite this fact, the results give an idea of the possible impact of climate change scenarios on the potential capacity of the assessed sites. In addition to the volume of water, or of the improved discharge, that can be provided by sites with a given level of reliability, other characteristics were also evaluated (see below).

## RESULTS AND DISCUSSION

The result of the solution procedure described above was the quantification of the possible impacts of climate change on hydrological characteristics (discharge and evaporation from the water surface and evapotranspiration of the landscape)

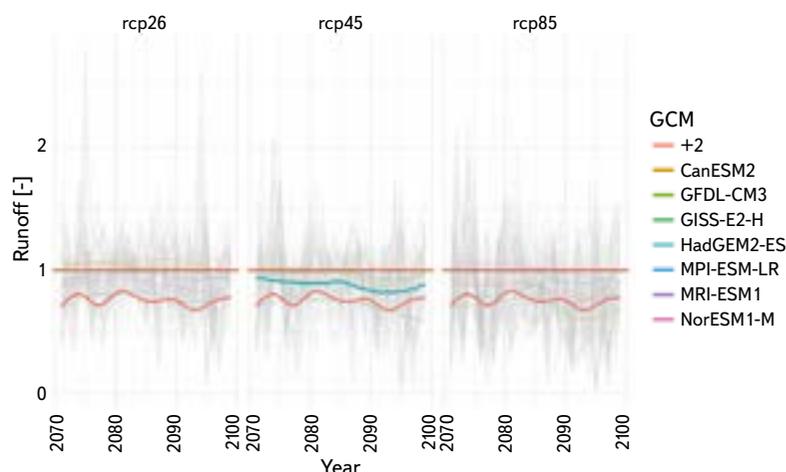


Fig. 7. Reduction of runoff from the catchment area of potential water reservoirs (rcp26, rcp45 and rcp85 indicate groups of emission scenarios, the grey lines describe the individual climate model simulations, the thick red line the + 2 °C warming scenario and the thick turquoise line the selected HadGEM2 scenario)

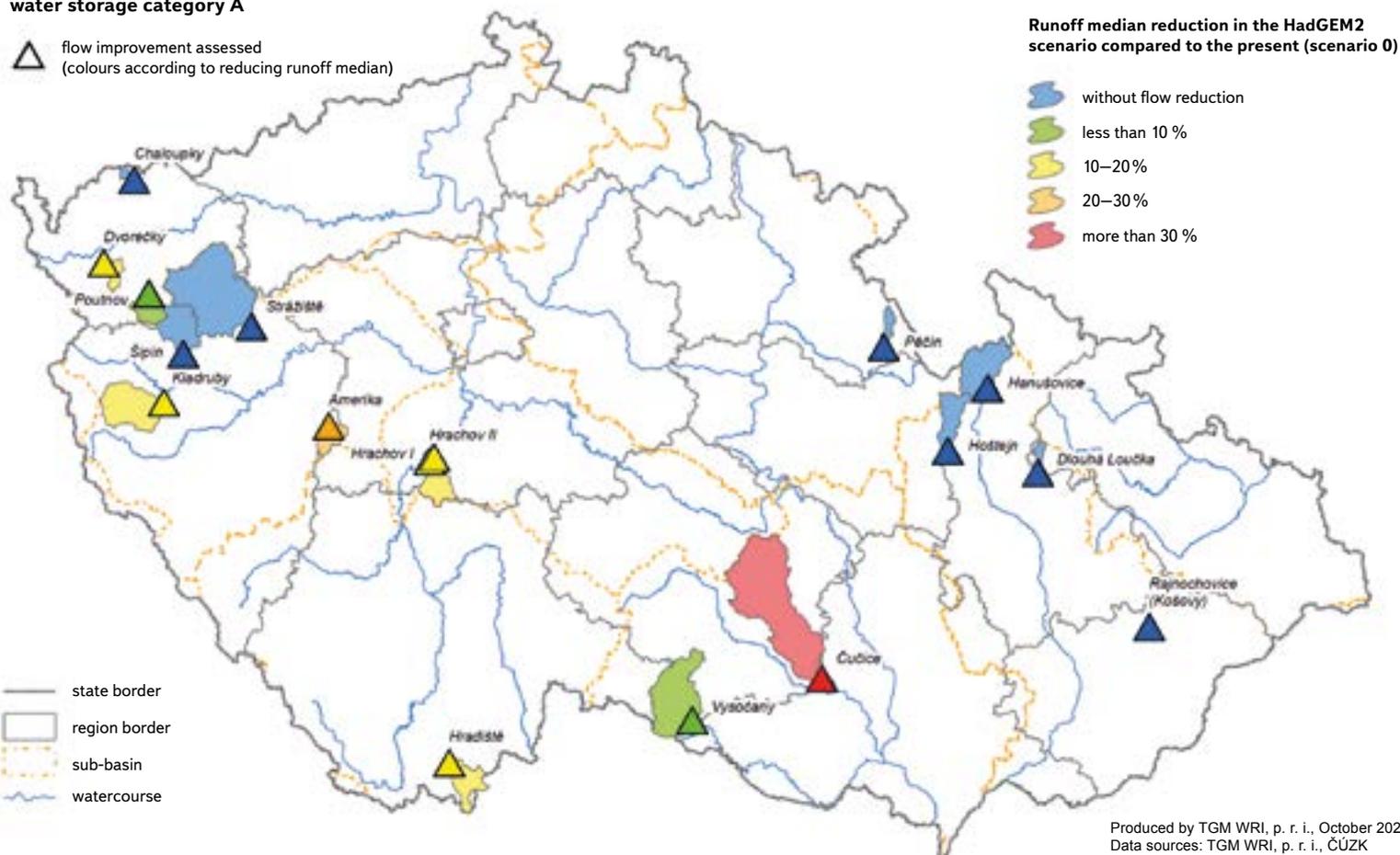
and the subsequent evaluation of the reliability of water abstractions provided by water reservoirs in these conditions. Fig. 7 shows the changes in natural runoff (scenario/present) for individual simulation scenarios and emission scenarios, in this case for the period 2071–2100. The grey lines are partial simulations for the given

sites, the coloured lines are summaries for individual climate models, and the highlighted ones are the simulations used for water management evaluation. A significant variability of changes can be observed, which are mainly determined by the input climate data and uncertainties in the hydrological model simulations. The latter is calibrated on the basis of available input data, while a number of studies and research deal with the calibration strategies themselves. Fig. 8 also shows the reduction of runoff from the catchments of the assessed sites due to climate change for the HadGEM2 scenario to the reference year 2050.

Using the simulation of the storage function of water management systems, a uniform improved discharge  $Q_n$  was evaluated for individual SWAA and scenarios with reliability according to the duration  $pt = 99.5\%$  [21]. The results are shown in Tab. 2. The use of SWAA capacity (or the evaluated improved discharge  $Q_n$ ) for water abstraction is limited by the need to maintain the minimum residual flow rates (MRF) below the water reservoirs. The indicative value of MRF was calculated according to equation (1), where  $Q_{10}$  represents the 90 % quantile of mean monthly discharge. The equation was derived from the analysis of the MRF relationship calculated from daily discharge and the relevant quantile of monthly discharge for most water gauging stations in the Czech Republic. As additional characteristics, Tab. 2 also shows the values of the long-term mean discharge  $Q_a$ , (which is calculated here as the arithmetic mean of a series of modelled mean monthly discharge), the improvement coefficient  $\alpha$  calculated according to equation (2), the coefficient of variation of annual mean discharge  $Cv$  and the standardized inflow  $m$  calculated according to equation (3). According to [22], reservoirs with  $m \geq 1$  or  $m \geq Cv$  have a seasonal nature of management, otherwise multi-year nature of management.

**Areas protected for surface water storage category A**

△ flow improvement assessed (colours according to reducing runoff median)



Produced by TGM WRI, p. r. i., October 2022  
Data sources: TGM WRI, p. r. i., ČÚZK

Fig. 8. Reduction of runoff from the catchment area of potential water reservoirs in the HadGEM2 scenario

Tab.2. Potential for flow enhancement

Location Watercourse	Scenario	$Q_a$ [ $m^3 \cdot s^{-1}$ ]	$Q_n$ at $p_t = 99,5$ [ $m^3 \cdot s^{-1}$ ]	MRF [ $m^3 \cdot s^{-1}$ ]	$\alpha$	$C_v$	$m$
<b>Amerika Klabava</b>	0	0.592	0.479	0.065	0.81	0.41	0.46
	2	0.479	0.375	0.041	0.78	0.46	0.47
	HadGEM2	0.519	0.396	0.045	0.76	0.43	0.55
<b>Čučice Oslava</b>	0	2.872	1.389	0.249	0.48	0.48	1.07
	2	1.984	0.894	0.108	0.45	0.55	1
	HadGEM2	2.362	0.875	0.126	0.37	0.55	1.13
<b>Dlouhá Loučka Huntava</b>	0	0.271	0.211	0.05	0.78	0.23	0.97
	2	0.241	0.183	0.038	0.76	0.24	1.01
	HadGEM2	0.273	0.196	0.04	0.72	0.23	1.21
<b>Dvorečky Libava</b>	0	0.494	0.438	0.062	0.89	0.29	0.4
	2	0.419	0.371	0.043	0.89	0.32	0.36
	HadGEM2	0.45	0.381	0.044	0.85	0.35	0.45
<b>Hanušovice Morava</b>	0	3.729	3.463	1.087	0.93	0.21	0.35
	2	3.393	3.166	0.918	0.93	0.22	0.31
	HadGEM2	3.852	3.425	0.918	0.89	0.22	0.51
<b>Hoštejn Břežná</b>	0	1.569	1.522	0.238	0.97	0.23	0.13
	2	1.425	1.377	0.185	0.97	0.25	0.13
	HadGEM2	1.684	1.579	0.189	0.94	0.25	0.25
<b>Hradiště Černá</b>	0	1.448	0.875	0.423	0.6	0.32	1.23
	2	1.204	0.651	0.291	0.54	0.37	1.23
	HadGEM2	1.223	0.704	0.273	0.58	0.34	1.25
<b>Hrachov I<sup>1</sup> Hrachov II Brzina</b>	0	0.459	0.352	0.037	0.77	0.47	0.5
	2	0.328	0.247	0.023	0.75	0.58	0.43
	HadGEM2	0.395	0.285	0.025	0.72	0.52	0.54
<b>Chaloupky Rolava</b>	0	0.385	0.352	0.101	0.91	0.22	0.39
	2	0.347	0.32	0.071	0.92	0.23	0.35
	HadGEM2	0.376	0.346	0.071	0.92	0.24	0.33
<b>Kladruby Úhlavka</b>	0	1.345	0.866	0.191	0.64	0.36	1
	2	1.097	0.584	0.126	0.53	0.42	1.1
	HadGEM2	1.302	0.723	0.152	0.56	0.42	1.06
<b>Pěčín Zdobnice</b>	0	0.817	0.693	0.227	0.85	0.23	0.67
	2	0.744	0.647	0.171	0.87	0.25	0.53
	HadGEM2	0.781	0.618	0.137	0.79	0.25	0.84
<b>Poutnov Teplá</b>	0	0.703	0.594	0.104	0.84	0.28	0.55
	2	0.578	0.487	0.068	0.84	0.33	0.48
	HadGEM2	0.634	0.487	0.086	0.77	0.34	0.69
<b>Rajnochovice (Košovy) Juhyně</b>	0	0.239	0.202	0.047	0.84	0.29	0.54
	2	0.211	0.171	0.035	0.81	0.3	0.62
	HadGEM2	0.253	0.198	0.037	0.78	0.29	0.74
<b>Strážiště Střela</b>	0	2.899	2.188	0.527	0.75	0.33	0.75
	2	2.379	1.697	0.402	0.71	0.38	0.76
	HadGEM2	2.84	2.036	0.472	0.72	0.36	0.79
<b>Šipín Úterský potok</b>	0	0.905	0.784	0.107	0.87	0.34	0.4
	2	0.748	0.622	0.074	0.83	0.38	0.44
	HadGEM2	0.971	0.772	0.106	0.8	0.35	0.59
<b>Vysočany<sup>2</sup> Želetavka</b>	0	1.212	0.250	0.205	–	0.45	–
	2	0.927	0.200	0.147	–	0.49	–
	HadGEM2	1.168	0.200	0.219	–	0.47	–

<sup>1</sup> Considered as a system Hrachov I – Hrachov II.<sup>2</sup> Considered as a Vysočany – Vranov – Znojmo system. The  $Q_n$  value represents the added improvement potential to the existing Vranov – Znojmo system.

$$MZP = 0,73 * Q_{10} \quad (1)$$

$$a = \frac{Q_n}{Q_o} \quad (2)$$

$$m = \frac{(1-a)}{Cv} \quad (3)$$

From the results, by comparing the values of discharge improvement  $Q_n$  in the scenarios of climate change and current conditions (scenario 0), a more significant reduction in the potential of SWAA to ensure water abstractions is evaluated especially at the sites of Čučice (over 30 % in both scenarios), Kladruby, Hradiště, Hrachov I, and Hrachov II. on the contrary, a relatively low reduction (up to 10 %) of the potential to secure water abstractions was evaluated at the sites of Hoštejn, Hanušovice, Chaloupky, and Pěčín.

Due to its location on the tributary of the Želetavka to the Vranov water reservoir, the Vysočany site was assessed in the Vysočany – Vranov – Znojmo water reservoir system. Therefore,  $Q_n$  values in *Tab.2* indicate the added potential for improvement to the existing Vranov – Znojmo system for this site. Considering the total capacity of the Vranov water reservoir (in the current conditions of improvement at  $pt = 99,5\%$ , it exceeds  $4 \text{ m}^3 \cdot \text{s}^{-1}$ ), the added effect of the Vysočany site is relatively low. The Vranov water reservoir is multi-purpose and current water abstractions from the Vranov – Znojmo system make up a smaller share of the total requirements placed on its storage function. Hrachov I and Hrachov II water reservoirs, on the Brzina river, were also considered as a system.

As part of the water management solution for reservoirs, the entire potential volume of the reservoir listed in the SWAA General Plan [1] was considered as active storage capacity. In this regard, it is necessary to take the resulting values of reliable abstractions (or improved discharge) as theoretical. For example, the volume of dead storage, the values of which are not currently available, was not considered. The improved discharge will thus be lower in real terms. However, despite this fact, the results give a good idea of the possible impact of climate change scenarios on the potential capacity of the assessed sites.

## CONCLUSION

The goal of the solution described above was to evaluate the possible impacts of climate change on the capacity of areas protected for surface water storage (SWAA). Considering the significant uncertainties in the prediction of climate change scenarios, a variant solution was chosen: the HadGEM2 climate change scenario for the reference year 2050, and the (less favourable) scenario of a current climate warming of  $2^\circ\text{C}$  were assessed. The evaluation was done for 17 sites considered to ensure water abstractions and located near potentially problematic areas in terms of drinking water supply. Hydrological and water management balance modelling procedures were applied during the assessment of SWAA capacities. The solution results are shown in *Tab. 2*. A more significant reduction in the capacity to ensure water abstractions due to climate change was evaluated especially at the sites of Čučice, Kladruby, Hradiště, Hrachov I, and Hrachov II. In contrast, a relatively low reduction in capacity was evaluated at the Hoštejn, Hanušovice, Chaloupky and Pěčín sites. With the exception of the Čučice and Kladruby sites, the reduction in capacity compared to current conditions did not exceed 30 % for any site. The results in the form of variant scenarios therefore draw attention to a possible reduction of the improved discharge and an increase in the coefficient of variation, which is an indicator of the fluctuation of the hydrological regime. A more detailed study of the area, including possible water transfers, prospective water needs, etc., is needed to decide whether a given reservoir could help a deficit region.

## Acknowledgements

This article was created on the basis of research carried out as part of project VI20192022159 "Water management and water supply systems and preventive measures to reduce risks in the supply of drinking water" of the BV III/1-VS programme, which is financed by the Ministry of the Interior of the Czech Republic.

## References

- [1] MoA and MoE. *Generel území chráněných pro akumulaci povrchových vod a základní zásady využití těchto území*. Prague, August 2020.
- [2] HANEL, M., KAŠPÁREK, L., MRKVIČKOVÁ, M. et al. *Odhad dopadů klimatické změny na hydrologickou bilanci v ČR a možná adaptační opatření*. Prague: T. G. Masaryk Water Research Institute, p. r. i., 2011. 108 p.
- [3] HORÁČEK, S. et al. *Možnosti zmírnění současných důsledků klimatické změny zlepšením akumulační schopnosti v povodí Rakovnického potoka (pilotní projekt)*. Prague: T. G. Masaryk Water Research Institute, p. r. i., 2012. 150 p.
- [4] BERAN, A., HANEL, M., NESLÁDKOVÁ, M., VIZINA, A., VYSKOČ, P., KOŽÍN, R. Climate Change Impacts on Water Balance in Western Bohemia and Options for Adaptation. *Water Supply*. 1 February 2019, 19(1), pp. 323–335. Available from: doi: <https://doi.org/10.2166/ws.2018.080>
- [5] VIZINA, A., VYSKOČ, P., PELÁKOVÁ, M., BERAN, A., KOŽÍN, R., PICEK, J. Zabezpečení odběrů vody z vodárenských nádrží v podmínkách klimatické změny. *Vodohospodářské technicko-ekonomické informace*. 2021, 63(3), pp. 4–18. ISSN 0322-8916.
- [6] KOŽÍN, R., HANEL, M., KAŠPÁREK, L., PELÁKOVÁ, M., VIZINA, A., TREML, P. Možnosti zmírnění dopadů změny klimatu využitím území chráněných pro akumulaci povrchových vod. *Vodohospodářské technicko-ekonomické informace*, 2015, 57(4–5), pp. 11–16. ISSN 0322-8916.
- [7] HANEL, M., KAŠPÁREK, L., PELÁKOVÁ, M., BERAN, A., VIZINA, A. *Evaluation of Changes in Deficit Volumes: Support for Protection of Localities Suitable for Construction of Reservoirs. Considering Hydrological Change in Reservoir Planning and Management*, IAHS-IAPSO-IASPEI Assembly. 2013.
- [8] PRCHALOVÁ, H., VYSKOČ, P., VIZINA, A., NOVÁKOVÁ, H. Bilance zdrojů podzemní vody a potřeb pro pitné účely v podmínkách klimatické změny. *Vodohospodářské technicko-ekonomické informace*. 2022, 64(5), pp. 22–31. ISSN 0322-8916.
- [9] BERAN, A. a kol. *Metodika pro navrhování adaptačních opatření k eliminaci dopadů nedostatku vody*. Prague: T. G. Masaryk Water Research Institute, p. r. i., 2019. MoA certified methodology. ISBN 978-80-87402-70-2.
- [10] *Plán rozvoje vodovodů a kanalizací území České republiky. Revize funkčnosti propojení a zajištění potenciálních možností nových propojení vodárenských soustav v období sucha. A.1.1. Zprávy jednotlivých krajů (2. etapa). Revize 1*. Prepared by Sweco Hydroprojekt a. s. for the Ministry of Agriculture, 12/2020.
- [11] HANEL, M., VIZINA, A., MARTÍNKOVÁ, M., FENDEKOVÁ, M. *Changes of Drought Characteristics in Small Czech and Slovakian Catchments Projected by the CMIP5 GCM Ensemble*. 2014.
- [12] ŠTĚPÁNEK, P. et al. *Očekávané klimatické podmínky v České republice*. 2019. Vydáno v rámci projektu: „SustES – Adaptační strategie pro udržitelnost ekosystémových služeb a potravinové bezpečnosti v nepříznivých přírodních podmínkách“ (CZ.02.1.01/0.0/0.0/16\_019/0000797). ISBN 978-8-87902-28-8.
- [13] VIZINA, A., HANEL, M. et al. *Střední scénář klimatické změny pro vodní hospodářství v České republice. Zprávy pro státní podniky povodí*. Prague: T. G. Masaryk Water Research Institute, p. r. i., 2019.
- [14] TALLAKSEN, L. M., VAN LANEN, H. A. (eds.). *Hydrological Drought: Processes and Estimation Methods for Streamflow and Groundwater*. 2004.
- [15] VIZINA, A., HORÁČEK, S., HANEL, M. Recent Developments of the BILAN Model. *Vodohospodářské technicko-ekonomické informace*. 2015, 57(4–5), pp. 7–10.
- [16] MELIŠOVÁ, E., VIZINA, A., STAPONITES, L. R., HANEL, M. The Role of Hydrological Signatures in Calibration of Conceptual Hydrological Model. *Water*. 2020, 12(12), 3401.
- [17] GUDMUNDSSON, L., BREMNES, J. B., HAUGEN, J. E., ENGEN-SKAUGEN, T. Downscaling RCM Precipitation to the Station Scale Using Statistical Transformations – A Comparison of Methods. *Hydrology and Earth System Sciences*. 2012, 16(9), pp. 3383–3390.
- [18] ŠTĚPÁNEK, P., ZAHRADNÍČEK, P., HUTH, R. Interpolation Techniques Used for Data Quality Control and Calculation of Technical Series: An Example of a Central European Daily Time Series. *IDŐJÁRÁS – Quarterly Journal of the Hungarian Meteorological Service*. 2011, 115(1–2), pp. 87–98.
- [19] KLING, H., FUCHS, M., PAULIN, M. Runoff Conditions in the Upper Danube Basin under an Ensemble of Climate Change Scenarios. *Journal of Hydrology*. 2012, 424, pp. 264–277. Available from: doi: [10.1016/j.jhydrol.2012.01.01](https://doi.org/10.1016/j.jhydrol.2012.01.01)
- [20] PICEK, J., VYSKOČ, P., ZEMAN, V. *Simulační model množství povrchových vod: zásobní funkce vodohospodářské soustavy*. Prague: T. G. Masaryk Water Research Institute, p. r. i., 2008.
- [21] ČSN 75 2405. 2004. *Vodohospodářská řešení vodních nádrží*.
- [22] VOGEL, R. M., BOLOGNESE, R. A. Storage-Reliability-Resilience-Yield Relations for Over-Year Water Supply Systems. *Water Resources Research*. 1995, 31, pp. 645–654.

## Authors

**Ing. Adam Vizina, Ph.D.**

✉ adam.vizina@vuv.cz

ORCID: 0000-0002-4683-9624

**Ing. Petr Vyskoč**

✉ petr.vyskoc@vuv.cz

ORCID: 0000-0002-5006-5414

**Ing. Roman Kožín**

✉ roman.kozin@vuv.cz

ORCID: 0000-0002-5773-6567

**Ing. Hana Nováková, Ph.D.**

hana.novakova@vuv.cz

ORCID: 0000-0002-5946-4796

T. G. Masaryk Water Research Institute, Prague

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

DOI: 10.46555/VTEI.2022.11.004

