ASSESSMENT OF DEFICIT VOLUMES UNDER CLIMATE CHANGE AND POSSIBLE ADAPTATION BY TECHNICAL MEASURES IN THE CZECH REPUBLIC

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ABSTRACT

Climate change scenarios for the Czech Republic indicate the increase in frequency and volume of the deficit discharges (defined as the volume under given threshold). The Czech water management legislation considers a number of protected areas potentially suitable for construction of reservoirs for flood protection and/or improving the water balance in the drought periods. In present study we use hydrological modelling to quantify the volume of the deficit discharges as projected by an ensemble of transient regional climate model (RCM) simulations. Derived deficits are subsequently compared to the potential volume of the considered reservoirs. It is concluded that for many RCM simulations the deficits are significantly larger than the available volume of water in the reservoirs, therefore different adaptation measures should be considered also. The uncertainty is, however, large.

KEYWORDS

Climate change; adaptation measures; deficit discharges

INTRODUCTION

It is generally accepted that the climate change could have serious impacts on water resources (Bates, 2008), especially due to possible changes in the amount and timing of precipitation and temperature increase leading to larger losses of water through evapotranspiration. Nevertheless, the extent of these changes and the severity which the water resources could be affected with, is uncertain. Therefore the assessment of future water resources and the design of possible and reasonable adaptation measures is rather challenging. In the past years much effort has been given to the assessment of possible changes in the hydrological cycle in the global (Meehl et al., 2007; Schefield and Wood, 2007; Vörösmarty et al., 2000) and regional (e.g. Christensen et al., 2007; Arnell, 1999; Lehner et al., 2006) or local scale (Graham et al., 2007; Fowler et al., 2007). The adaptation measures has been addressed also (Dessai and Hulme, 2007; Smith et al., 2000) and supported by expert guidance (EC, 2009; USAID, 2007).

In the Czech Republic, the climate change and its impact on water resources has received public and scientific attention since early 90's (Kašpárek et al., 2006). Recently, the research on adaptation in the water sector has been accelerated due to the problems with water availability in a number of relatively small catchments over the Czech Republic, which might be attributed to the ongoing climate change (e.g. Kašpárek and Mrkvičková, 2009; Kašpárek et al., 2011). The possible adaptation measures can be classified (e.g. EEA, 2009) as (1) water demand management including technical, economic, educational, and legal measures that all aim at limiting especially the wasteful use of water (e.g. improving irrigation efficiency, leakage control and reduction of water distribution system, raising public awareness for water saving behaviour, introducing water saving devices in households etc.); (2) water allocation and planning (e.g. catchment abstraction management strategies, drought management plans, allocating water resources to trigger water saving irrigation practices); (3) water supply management, i.e. increasing the amount of water available (e.g. wastewater re-use, rainwater harvesting, artificial groundwater recharge, water transfers and reservoirs). The first two classes of adaptation measures in general require action on national level and are supported by a strategic document of the Ministry of the Environment of the Czech Republic (MZPCR, 2004), however, the practical implementation will obviously take years.

Practical experiences from the case studies mentioned above indicated that fast solution for the relatively small-scale problems with water availability can be achieved by considering measures which increase water supply (in our cases specifically reconstruction of old or design of new reservoirs or the water transfers). In present paper, we therefore primarily focus on the assessment of the effectiveness of technical measures, specifically we consider the construction of new reservoirs at localities potentially suitable for this purpose. The list of such localities (further denoted as LASW, i.e. Localities potentially suitable for Accumulation of Surface Water) in the Czech Republic exists from the beginning of 20th century and originally had more than 400 items. The main purpose for this list was to protect localities potentially suitable for building infrastructure for drinking water supply and flood protection. Today, this purpose can be extended to climate change adaptation. However, since the LASW are protected by national law, which limits regional development in the area (especially technical and transport infrastructure with international, national or other supra-regional importance or industrial, energy and mining facilities etc.), the list has been reduced several times (with respect to both the number and extent of the localities) and its current version, which is recently under discussion, contains less than 70 localities and further reduction is still proposed by local authorities and ecological initiatives. However, the list of LASW is not intended as the basis for construction of reservoirs but rather a framework for protection of these localities for the case that some of the pessimistic climate change scenarios would become actual. This is compliant with the recommendation of European Environmental Agency (EEA, 2009) for handling uncertainty related to the climate change projections within planning of the adaptation measures, i.e. preference for measures allowing for later adjustment. The main objective of the research presented in this paper is to stress the need for continuation of LASW protection by presentation of possible future need of some of these localities for the compensation of future discharge deficits. Our study continues the research of Novický et al. (2006) and extends it by consideration of the actual list of LASW, more climate change scenarios, discharge deficit levels and basins.

The projections of future climate from climate models for the Czech Republic are not consistent, especially with respect to the changes in precipitation and thus the whole hydrological regime. For instance, around half of the climate models considered in the IPCC AR4 () project increase and the second half a decrease in precipitation. Still, the hydrological simulations indicate that due to temperature increase the overall effect on water resources in the area is negative for most of the climate model simulations despite a slight precipitation increase in part of these simulations. This emphasizes the need for a multi-model assessment. Present study use the ensemble of regional climate model simulations conducted within the EU funded project Ensembles. The projections are used to quantify the future discharge deficits. These deficits are subsequently compared with the volume of potential reservoirs at the LASW. The LASW and the calculation of the future discharges are described in the Methods section. The resulting deficits and their possible compensation by potential reservoirs at the LASW are discussed in Findings and Discussion together with the uncertainty in the estimates and limitations of the methodology. The conclusions are presented in the last section.

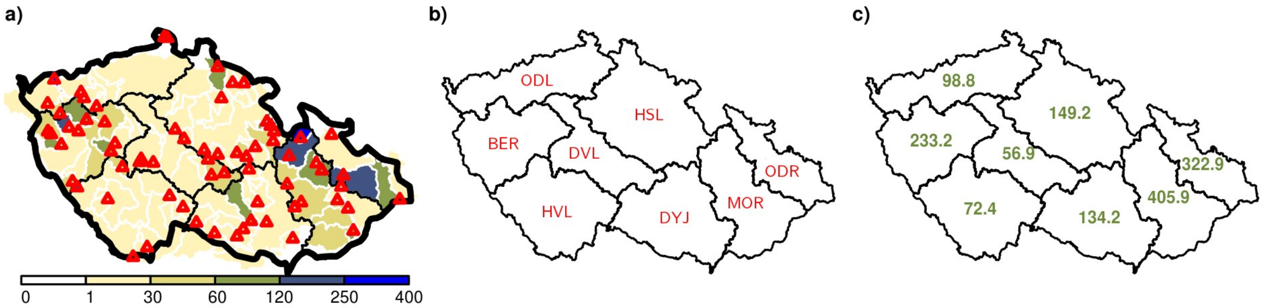

Figure 1 Localities suitable for accumulation of surface water (LASW): (a) location of the potential reservoirs (red rectangles) with color expressing the amount of available water in the catchments of the reservoirs; (b) the river basin districts (RBD); (c) the capacity of the potential reservoirs aggregated to the area of RBD in mil. m^3.

METHODS

The location of the LASW is given in Figure 1 together with the capacity of the potential reservoirs. The spatial distribution of LASW and their capacity is uneven. Considering the eight river basin districts (RBD) in the Czech Republic the largest capacity is in the north-east of the Czech Republic (MOR and ODR), the lowest in the south-west (HVL, DVL). This is partly due to a relatively large number of already existing reservoirs in those two RBD.

The hydrological model BILAN (Tallaksen and van Lanen, 2004) has been used for assessing water balance components of a catchment in a monthly time step, since data in finer temporal resolution are not available for the whole area of interest. The structure of the model is formed by a system of relationships describing basic principles of water balance on ground, in the zone of aeration, including the effect of vegetation cover, and in groundwater. Air temperature is used as an indicator of energy conditions, which affect significantly the water balance components. The input data of the model are monthly series of basin precipitation, the air temperature and relative air humidity, which are obtained by interpolation of the station data to the area of the basin considering the distance from the centre of the basin and orography. For calibration of the eight model parameters, a monthly runoff series at the outlet from the basin is used. In total we calibrated the hydrological model for 100 basins that would be affected by reservoirs at LASW. The input data were provided by the Czech Hydrometeorological Institute. For the most of the stations at least 27 years of data were available only at few stations the length of the record was, but at least 20 years.

For the modelling of the climate change impacts we used simple delta change method, in which the observed data are transformed to show the same mean monthly changes between reference (1961-1990) and future periods as derived from the regional climate model. The transformed observed series are then run through the calibrated hydrological model. The resulting time series represent the future conditions. For the derivation of the delta factors we consider periods 2011-2040, 2041-2070 and 2071-2099 which are further referred to by the centre of these periods, i.e. 2025, 2055 and 2085, respectively.

In total we considered 15 transient RCM simulations all covering the period 1961-2099. All simulations were forced by the global climate model simulations under SRES A1B emission scenario and have horizontal resolution of 25 km x 25 km. Most of the simulations (14) were conducted within the Ensembles project. The CHMI_ARP simulation was produced by the Czech hydrometeorological institute. The overview of the RCM simulations is given in Table 1.

The deficit volumes were derived with the threshold level method (Hisdal et al., 2004): the drought starts when the discharge drops under predefined threshold and continues until the threshold is exceeded again. In present study the threshold was set to the 70% quantile from the flow exceedance curve similarly as in Novicky et al. (2006). The threshold was for each basin derived from observed data and the observed deficit volumes were calculated. For the future climate, the deficit volumes were calculated using the same threshold (based on observed data). Then the deficit volumes for the present climate are subtracted from those for the future climate for each drought event. To keep the analysis simple we further considered only median (Δ_{MED}DEF) and maximum (Δ_{MAX}DEF) of these estimated changes in deficit volumes for each basin, period and RCM simulation. The estimated median and maximal changes in deficits were subsequently compared to the volume of potential reservoirs. Finally, the results are averaged over the RCM simulations to obtain the ensemble mean. The methodology is demonstrated in Figure 2. The present approach is substantial simplification of correct assessment of chronological water balance of the reservoirs. We do not evaluate how likely it is that the reservoirs are full when necessary. This simplified approach was applied mainly because of limited data available.

Table 1 Overview of the RCM simulations

Acronym	RCM	Period available	source
	ECHAM5 driven		[1] Royal Netherlands Meteorological Institute (KNMI) [2] Max Planck Institute for Meteorology (MPI), Germany [3] Swedish Meteorological and Hydrological Institute (SMHI) [4] Abdus Salam International Centre for Theoretical Physics (ICTP), Italy [5] Danish Meteorological Institute (DMI) [6] Met Office Hadley Centre, UK [7] Swiss Federal Institute of Technology Zurich (ETHZ) [8] Community Climate Change Consortium for Ireland (C4I) [9] National Centre of Meteorological Research (CNRM), France [10] Czech Hydrometeorological Institute (CHMI), Czech Republic
RACMO_EH5 [1]	RACMO2.1	1950–2100	
REMO_EH5 [2]	REMO5.7	1951–2100	
RCA_EH5 [3]	RCA3.0	1951–2100	
RegCM_EH5 [4]	RegCM3	1951–2100	
HIR_EH5 [5]	HIRHAM5	1951–2100	
	HadCM3Q0, HadCM3Q3, HadCM3Q16 driven		
HadRM_Q0 [6]	HadRM3.0	1951–2099	
CLM_Q0 [7]	CLM2.4.6	1951–2099	
HadRM_Q3 [6]	HadRM3.0	1951–2099	
RCA_Q3 [3]	RCA3.0	1951–2099	
HadRM_Q16 [6]	HadRM3.0	1951–2099	
RCA_Q16 [8]	RCA3.0	1951–2099	
	ARPEGE4.5 driven		
HIR_ARP [5]	HIRHAM5	1951–2100	
CNRM5_ARP [9]	CNRM-RM5.1	1951–2100	
CHMI_ARP [10]	ALADIN-CLIMATE/CZ	1961–2100	
	BCM2.0 driven		
RCA_BCM [3]	RCA3.0	1961–2100	

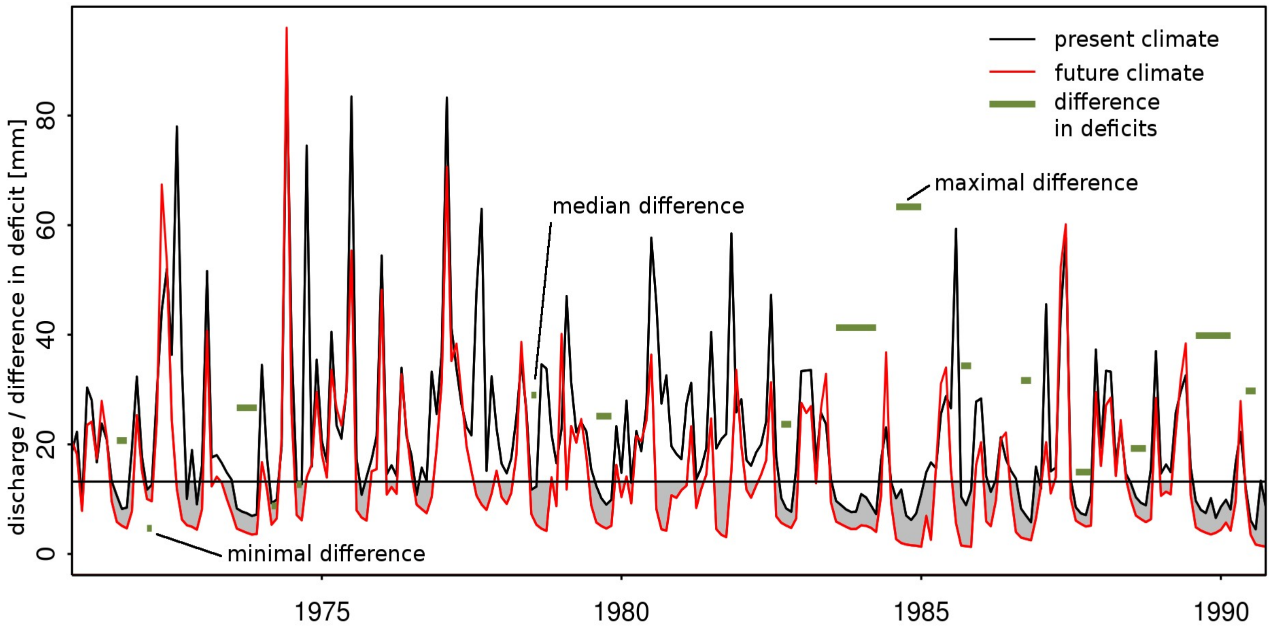

Figure 2 Derivation of the differences in the deficits (gray polygons). Green lines correspond to the volume of the differences in the deficits. (Example for the Olše basin with future climate based on the CHMI_ARP simulation for the scenario period 2085.)

FINDINGS AND DISCUSSION

The projected ensemble mean discharge deficits are larger than discharge deficits for the present climate for all of the considered basins in all three scenario periods (Figure 3a-b). The increase between the first two scenario periods is remarkably larger than that between the last two scenario periods. This might be related to the emission scenario SRES A1B which projects largest emissions around the half of the 21st century leading to faster increase of greenhouse gas concentrations in the first half of this century. The Δ_{MED}DEF and Δ_{MAX}DEF are largest in the Vltava (HVL and DVL), Ohře (ODL) and Elbe (HSL) basins and smallest in the eastern part of the Czech Republic, i.e. Morava (MOR), Dyje (DYJ) and Oder (ODR) basins. The different spatial distribution of the changes in the deficit discharges is most likely due to the increase in winter precipitation recharging the ground water reservoirs in parts of the Czech Republic. However, further research on this topic is required.

The uncertainty in the projected changes in discharges is, however, remarkable. This is demonstrated in Figure 4 showing the spatial average differences in the discharge deficits between the control and scenario period 2085 for the individual RCM simulations. Obviously, the projected changes in deficit discharges are to a large extent determined by the driving GCM. For instance, all simulations driven by the ECHAM5 global model show only relatively small changes in deficits, while the changes in simulations driven by ARPEGE are much larger. There are also simulations projecting negative median change (Δ_{MED}DEF) in deficit discharges (e.g. HIR_EH5), i.e. the simulation for the future is less dry than that for the control climate. However, the maximal change (Δ_{MAX}DEF) in deficit discharges is always positive (i.e. these deficits are more serious for the future climate for all RCM simulations). The changes in deficits in the HadRM_Q16 simulation are about twice as large as the maximum of the rest of the simulations. Larger increases in the deficits are generally expected in the simulations driven by HadCM3_Q16 since this version of the global climate model contains parameter perturbations giving the highest temperature response to external forcings (as opposed to HadCM3_Q3 giving the lowest response). The reason for such extremely negative results for the HadRM_Q16 simulation is the pronounced temperature increase (around 1°C larger than for the maximum of the rest of the simulations) in combination with a decrease in precipitation (largest decrease with respect to the annual precipitation sum in the whole RCM ensemble). It is not clear, however, why the second HadCM3_Q16 driven RCM simulation (RCA_Q16) does not resemble this behaviour and indicates only moderate increase in deficit discharges.

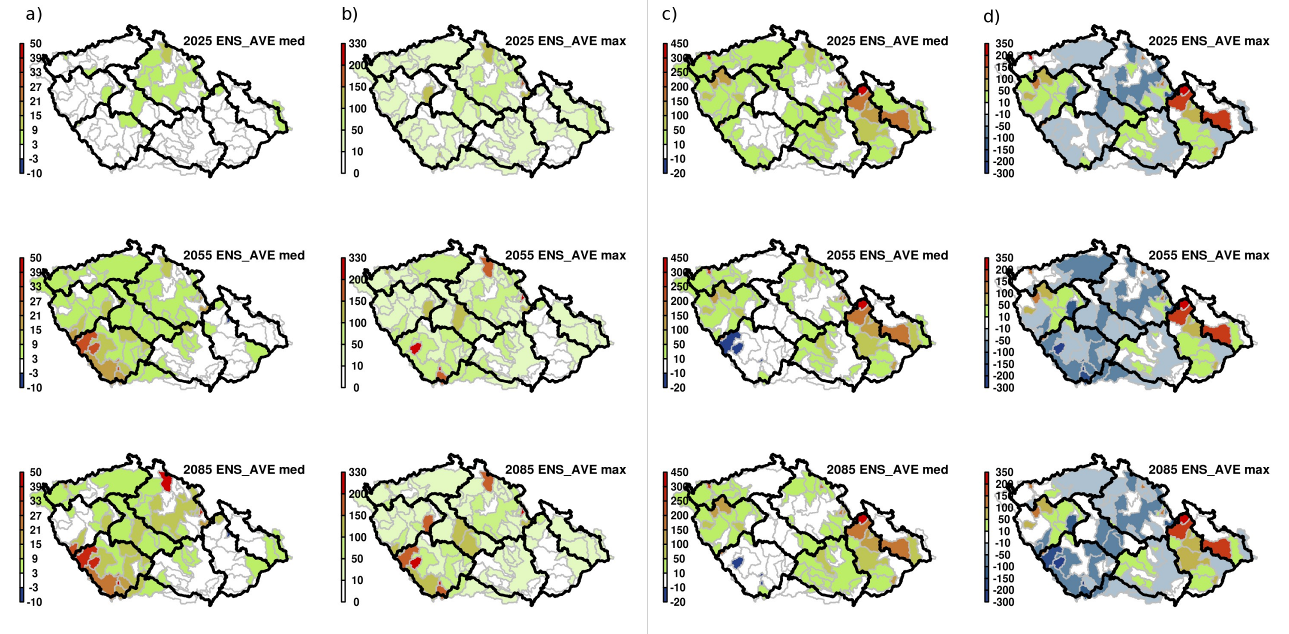

Figure 3 Ensemble average (a) median and (b) maximal differences in depth [mm] of the deficit discharges for the three scenario periods. Ensemble average difference between the capacity of potential reservoirs and the (c) median and (d) maximal discharge deficits.

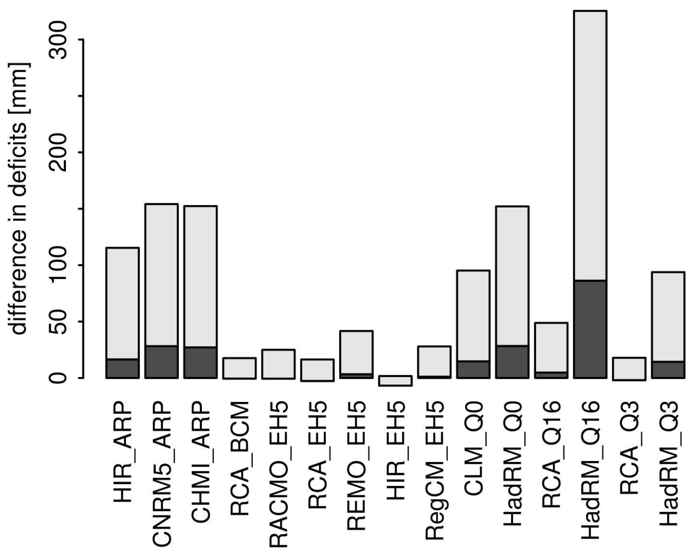

Figure 4 Difference in discharge deficits [mm] for individual RCM simulations for the scenario period 2085 averaged over the Czech Republic. Dark bars correspond to Δ_{MED}DEF and light bars to Δ_{MAX}DEF.

The differences between the volume of potential reservoirs at LASW and projected increase in deficit discharges are given in Figure 3c-d and in Table 2 (Δ_{MED}DEF) and Table 3 (Δ_{MAX}DEF) for the individual river basin districts. For the compensation of the Δ_{MED}DEF the volume of potential reservoirs is sufficient almost in the whole Czech Republic (few exceptions are located in the HVL river basin district). Compensation of the Δ_{MAX}DEF would be problematic in most of the basins in the Czech Republic. Only for the eastern basins (ODR, MOR and part of the DYJ river basin district) the volume of the potential reservoirs is larger than the increase in deficits. Note, that the results relate to the ensemble mean Δ_{MED}DEF and Δ_{MAX}DEF. The results for individual RCM simulations might be very different and thus multi-model assessment is in general preferred.

In the first scenario period the median increase in deficits could be compensated in all river basin districts (Table 2). In the next scenario periods (2055 and 2085) problems are met in the ODL, DVL and especially in the HVL river basin districts. While in the ODL and DVL the median difference in deficit discharges is in the order of the potential storage, for the HVL the difference in deficits are 3-4 times larger than potential storage. The situation is even worse for the maximal difference in deficit discharges Δ_{MAX}DEF (Table 3). For the most of the river basin districts the Δ_{MAX}DEF are significantly larger than the potential storage even in the scenario period 2025 (except BER, MOR and ODR). In the scenario periods 2055 and 2085 are the results negative for all but two (ODR, MOR) or one (MOR) river basin districts, respectively. In some of the river basin districts the projected Δ_{MAX}DEF are more than ten times larger than the potential storage (e.g. HVL). This is partly due to a negative coincidence of large increase in deficit discharges together with relatively small potential storage.

Table 2 Potentially available storage at LASW, ensemble mean Δ_{MED}DEF and the ensemble mean difference between the potential storage and Δ_{MED}DEF [mil. m^3]. The river basin districts and scenario periods with negative balance are emphasized.

		2025		2055		2085	
	Available volume	Δ_{MED}DEF	balance	Δ_{MED}DEF	balance	Δ_{MED}DEF	balance
HSL	149.20	41.86	107.34	133.19	16.01	144.70	4.50
HVL	72.40	45.09	27.31	209.22	-136.82	302.50	-230.10
BER	233.20	12.73	220.47	68.72	164.48	76.47	156.73
DVL	56.90	18.60	38.30	74.26	-17.36	94.83	-37.93
ODL	98.80	29.55	69.25	118.29	-19.49	171.59	-72.79
ODR	322.90	9.94	312.96	34.90	288.00	57.79	265.11
MOR	405.90	9.07	396.83	48.66	357.24	45.57	360.33
DYJ	134.20	24.78	109.42	66.96	67.24	67.75	66.45

Table 3 Potentially available storage at LASW, ensemble mean Δ_{MAX}DEF and the ensemble mean difference between the potential storage and Δ_{MAX}DEF [mil. m^3]. The river basin districts and scenario periods with negative balance are emphasized.

		2025		2055		2085	
	Available volume	Δ_{MAX}DEF	balance	Δ_{MAX}DEF	balance	Δ_{MAX}DEF	balance
HSL	149.20	708.38	-559.18	1112.70	-963.50	1058.48	-909.28
HVL	72.40	413.55	-341.15	1054.76	-982.36	1174.47	-1102.07
BER	233.20	207.64	25.56	394.80	-161.60	406.23	-173.03
DVL	56.90	215.01	-158.11	480.60	-423.70	493.53	-436.63
ODL	98.80	367.70	-268.90	782.53	-683.73	723.15	-624.35
ODR	322.90	232.36	90.54	277.33	45.57	343.44	-20.54
MOR	405.90	151.07	254.83	294.17	111.73	321.39	84.51
DYJ	134.20	317.86	-183.66	566.63	-432.43	456.59	-322.39

CONCLUSIONS

We assessed the deficit discharges in 100 basins in the Czech Republic for present and future climate as projected by an ensemble of regional climate model simulations. The differences in deficit discharges were compared to the potentially available storage volume at protected localities. From all possible events in which the deficits were experienced we further considered those with the largest and median increase in the volume of the deficit discharge. With respect to the ensemble mean, the projected median changes in deficit discharges are positive for almost all basins in all three scenario periods, the same applies to the projected maximal changes in deficit discharges. However, for some of the individual RCM simulations the results are remarkably different, i.e. there are simulations showing a decrease in median deficit discharges as well as simulations showing twice as large increase in deficit discharges as the maximum of the rest of the simulations. This emphasizes the need for multi-model assessment, especially when decisions with wide impacts have to be made.

Further assessment revealed, that the potential storage volume at localities suitable for accumulation of surface water is sufficient to compensate the projected changes in median deficit discharges in most river basin districts for all of the scenario periods. The maximal increase in deficit discharges is far larger than the potential storage in most of the river basin districts, especially in the scenario periods 2055 and 2085. In general, the eastern part is less affected by climate changes due to smaller increase in the deficit discharges and larger potential storage volume. Opposite applies to the river basin districts in the western part of the Czech Republic, especially in the Vltava basin, since the projections for this basin show large increase in deficit discharges while the potential storage volume is limited.

Further, the study suggests that even relatively efficient technical measures might not be able to compensate the possible negative impacts of climate changes in some situations and different measures would be required. Especially the efficient water use might be relevant in such situations. Uneven distribution of available water and drought events could be overcome by water transfer when reasonable. The results emphasized that the protection of the localities potentially suitable for accumulation of surface water is reasonable and that some of these localities might substantially help with provision of drinking water or compensation of discharge deficits to maintain the ecological discharges.

The paper present results from a pilot study that have several limitations. First of all, the time series used for the assessment of the deficit discharges are relatively short. This limits the evaluation of the probability that a reservoir would be able to compensate larger deficit discharges. Therefore, simulation techniques will be used in following studies. Moreover, the choice of the threshold to define the deficit discharge is somewhat arbitrary (though based on previous studies). It would be in general preferred to base this choice on an official definition of minimal ecological discharge or similar quantity. These are unfortunately available for daily data and their relation to the available monthly data is not clear. Finally, we did not solve the chronological water balance of the reservoirs, thus the probability that the reservoir is full when required is not assessed.

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