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Climate change impacts and responses in the Czech Republic and Europe

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Abstract The paper discusses the development of European policies and measures aimed at securing water demands by replenishing, saving and protecting the European water resources. Recent European policies and legislation give preference to soft solutions and measures for water quality protection, rather than hard solutions, such as construction of water storage reservoirs, which were formerly used for meeting water demands. A case study from the Czech Republic describes results showing possible reservoir storage capacities which could be necessary in future for compensation of climate change impacts on flows, and particularly on low flows. The required storage capacities are derived from drought deficit volumes calculated from monthly flow series simulated for natural climate conditions and for the conditions affected by climate change. For the derivation of the deficit volumes, the discharge whose probability of exceedence is 70% ($Q_{70\%,}$) was used as the threshold.

Key words deficit volume; BILAN model; climate change; water resources; reservoir storage capacity; EU water legislation; Water Framework Directive

INTRODUCTION

Spatial and temporal variability in the availability of water resources, together with the high increase in the European water demands during the second half of the last century, were reflected in a number of measures that were taken to improve the unfavourable conditions.

In the mid twentieth century (EEA, 2001), the measures were aimed at improving the performance of water distribution systems (hard solutions). Political support for hydraulic structures was reflected in the construction and use of storage reservoirs, which helped to overcome the uneven distribution of water resources and the increasing demands.

Lately, there has been a rapid development of strategies, policies and legislation (soft solutions) in the water sector. The focus has gradually changed from replenishment of water resources to their saving by reducing the demands, and during the last thirty years attention has increasingly been paid to water resource protection.

The development of the European water policy was reflected in adopting a number of water-related EC directives. The most substantial piece of water legislation today is the Water Framework Directive (Directive 2000/60/EC). This Directive establishes a legally binding framework to promote sustainable water consumption based on the long-term protection of available water resources. Rational decision making in water management is predominantly based on a proper permanent water planning and preparation of programmes of measures at a Europe-wide scale.

The new European policy is associated with great investments but the European hard solutions will predominantly focus on the protection of water and mainly its quality (infrastructure is aimed at meeting emission and pollution requirements). Water resource replenishment by using hard solutions (particularly by construction of reservoirs) is not intended or desired.

The feasibility of this European policy is probably conditioned by two assumptions, i.e. a stable water demand and a normal range of climate variability in future. Clear stabilization of the demand in Europe was substantiated in recent assessments (EEA, 2001) but the future climate conditions are much less predictable. It was shown, using historical series (Novický & Kašpárek, 2006), that we could experience a much higher natural climate variability than in past decades, and, in addition, we increasingly live under potential threat of climate change. The drought that affected much of Europe during 2003 (EurAqua, 2004) is one of the warning events.

Future natural climate development is unknown, while the possible climate changes are predicted by running climatic models. The impact of climate change on hydrological conditions can, however, be assessed by using hydrological models with different climate change scenarios. European projects, assessing impacts of the scenarios on hydrological cycle, were focused mainly on changes in mean runoff. The results (EEA, 2001; Reynard *et al.*, 1997; Kašpárek *et al.*, 2003) suggest that the general tendency is towards an increase in the annual average runoff in northern Europe and a decrease in southern Europe. In some areas changes of 30% in the mean runoff by 2050 are feasible. It was also demonstrated that the main impact of climate warming is on low flows, which tend to become more extreme across most of Europe.

Few studies that are focused on the implications of climate change on water resources were reviewed in IPPC (2001). The results of the review include the conclusion that different systems respond very differently to climate change but generally in systems with large reservoir capacity, changes in resource reliability may be proportionately smaller than changes in river flows.

Water management in the Czech Republic (CR) is traditionally based on long-term planning, which involves the development of Master Water Management Plans of the CR. Their 1988 version included an updated list of intended water reservoirs (at 210 river sites in the Czech Republic). The need for these additional reservoirs is a controversial issue as part of the preparation of background materials for river basin district planning, which is required by the Water Framework Directive. Another factor was the concern that the existing water resources could be insufficient in future due to the impacts of climate change.

In 2005, the T. G. Masaryk Water Research Institute was commissioned by the Ministry of Agriculture of the Czech Republic to carry out a study, which was aimed at estimating reservoir storage capacities that would be necessary in future to compensate for climate change impacts on flows in the Czech Republic.

The territory of the Czech Republic (Fig. 1) is drained by three main rivers, the Elbe, Odra and Morava, and, accordingly, the country is located on the water divide of three seas, the North Sea, the Baltic and the Black Sea. The paper describes the results of the study (Peláková & Boersema, 2005) for the part of the Czech Republic drained by the Elbe River.

METHOD AND DATA

The basin of the Elbe River on the territory of the Czech Republic is shown in Fig. 1 and Table 1 gives its basic hydrometeorological characteristics. For the purpose of the study, the Elbe basin was divided into 12 upper basins, each represented by data for one water gauging station, and three `intermediate basins between the upper basins and downstream closing river sites on the Elbe and Vltava mainstreams. The required reservoir capacities were calculated from data derived for the water gauging stations in the upper basins and stations representative for the downstream river sites. The results for the intermediate basins were derived from those calculated for the upstream and downstream stations. Basic information and data on the basins are given in Table 2.

Derivation of the storage that is required in a reservoir for ensuring the specific yield (abstraction and outflow) with a given probability is usually based on the yield storage method. Such a detailed solution was not applicable for the purposes of the study, whose intention was to estimate possible impacts of climate change across a number of river sites. It was therefore desirable to develop a rapid method that would be sufficiently accurate compared to other uncertainties, such as those in climate change scenarios.

The method was based on derivation of deficit volumes, which are runoff volumes below a threshold discharge in the time flow series. The threshold can be interpreted as the desired yield from a reservoir, and the drought deficit volume defines the required storage in a given period (e.g. Tallaksen & Lanen, 2004). The idea of the method was that the deficit volumes could be derived from natural flow series and flow series affected by climate change. The greatest difference between the deficit volumes before and after the change indicates the volume that would be necessary in a reservoir to compensate the possible impacts of the change. For the study, the discharge whose probability of exceedence is 70% ($Q_{70\%,}$) was used as the threshold.

In terms of data, the study was based on monthly series of mean air temperature (ºC), relative air humidity (%), basin precipitation (mm month^{-1}) and runoff (mm month^{-1}) from the period 1932–1990. These series were used as input for calibration of the parameters of the BILAN water balance model in the individual basins.

The model, which was developed by the T. G. Masaryk Water Research Institute, simulates time series of monthly potential evapotranspiration, actual evapotranspiration, infiltration across

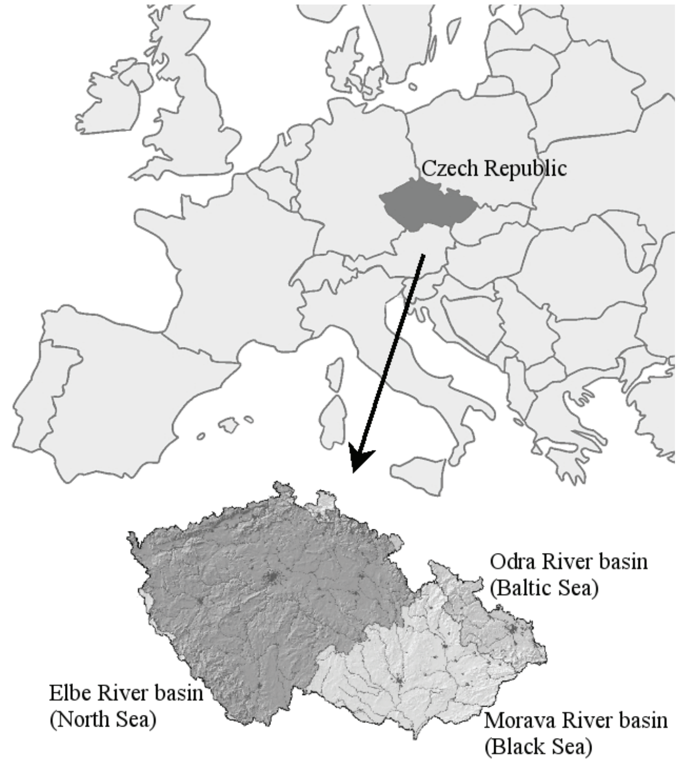

Fig. 1 Three main river basins in the Czech Republic.

Table 1 Basic characteristics of the Elbe River basin in the Czech territory.

Basin area	51394 km^2
Mean altitude	446 m a.m.s.l.
Mean air temperature	7.1ºC
Mean flow	313 m^3 s^{-1}
Specific runoff	6.1 l s^{-1} km^{-2}
Mean annual runoff	192 mm
Mean annual precipitation	653 mm

Table 2 Study basins and representative water gauging stations in the Elbe River basin.

River name	Basin	Basin area (km²)	Basin annual precipitation (mm)	Station name	Station basin area (km²)
Elbe	Above the Úpa tributary	712	947	Království	532
Úpa	Above its discharge into the Elbe	514	939	Česká Skalice	461
Metuje	Above its discharge into the Elbe	539	799	Hronov	248
Orlice	Above confluence of the Divoká and Tichá Orlice River	1 536	863	Týniště n. O.	1 591
Jizera	Above its discharge into the Elbe	2 193	858	Tuřice	2 159
Elbe	Intermediate basin between the upstream river sites and the Jizera tributary	7 520	626	–	–
Elbe	Elbe and Jizera above the confluence	13 014	730	Brandýs n. L.	13 111
Vltava	Above the Malše tributary	1 823	880	Vyšší Brod	999
Lužnice	Above its discharge into the Vltava	3 896	667	Bechyně	4 046
Otava	Above the Lomnice tributary	2 996	733	Písek	2 913
Sázava	Above its discharge into the Vltava	4 348	668	Poříčí n. S.	4 000
Berounka	Above its discharge into the Vltava	8 854	612	Dobřichovice	8 720
Vltava	Intermediate basin between the upstream river sites and the Berounka tributary	4 390	571	–	–
Vltava	Vltava and Berounka above the confluence	26 307	655	Praha-Modřany	26 690
Ohře	Above its discharge into the Elbe	4 820	699	Louny I.	4 983
Ploučnice	Above its discharge into the Elbe	1 195	757	Benešov n. P.	1 156
Elbe	Intermediate basin between the upstream river sites and the Ploučnice tributary	4 523	601	–	–
Elbe	Elbe and Ploučnice above the confluence	49 859	676	Děčín	51 104

the land surface, recharge from the soil to the aquifer, the amount of water that is stored in the snow pack, the soil and aquifer, and three runoff components, i.e. surface runoff, interflow and groundwater flow. Eight free model parameters are obtained by applying an optimization algorithm that compares time series of monthly simulated and observed streamflow. The model is described in Tallaksen & van Lanen (2004).

For the study, the natural conditions were represented by the runoff series that were simulated from the unchanged input series. The calibrated parameters and identical period (1932–1990) but with changed precipitation, air temperature and relative humidity input series were applied for simulation of the monthly flow series affected by climate change.

For the simulation of the affected flow series, the climate conditions were changed by using a climate change scenario that was the most extreme alternative of those that were derived for the Czech Republic (ECHAM4 General Circulation Model, SRESA2 emission scenario and high climate sensitivity). The scenarios (IPCC, 2001), which have the year 2050 as a reference, are implemented by adapting the original time series of air temperature, precipitation and water vapour pressure in the individual months. The largest changes are in the air temperature. For the climate change scenario used, its annual mean value increases by approximately 3°C.

RESULTS

Figure 2 shows results of the assessment of climate change impacts on flows for the study basins. For conditions before climate change, basin annual precipitation varies between 570 and 950 mm, evaporation is almost constant at a level of 500 mm and consequently the annual runoff is between 80 and 465 mm. After climate change, the annual runoff decreases to values between 35 and 365 mm. The main cause for the runoff decrease by about 50 to 100 mm is an increase in evaporation. Decrease in precipitation does not exceed 12 mm. The evaporation increases with an increase in precipitation (spatial variability between 515 and 595 mm). The most vulnerable areas are lowlands, where even a small increase in evaporation can be responsible for a high relative (40%) decrease in runoff, which was originally already low.

Results of the deficit volume analysis are shown in Figs 3 and 4. Figure 3 compares the deficit volumes before and after climate change in relation to the potential reservoir storage capacities in individual study basins. These results show that the storage capacities (between 0 mm and 344 mm) are at approximately the same level as the deficit volumes (between 19 mm and 292 mm) before climate change. The deficit volumes after the climate change exceed highly the potential reservoir storage capacities. Such capacities would not even be fully sufficient for compensating for an increase in the deficit volumes due to the climate change (difference between the deficit volumes after and before the change).

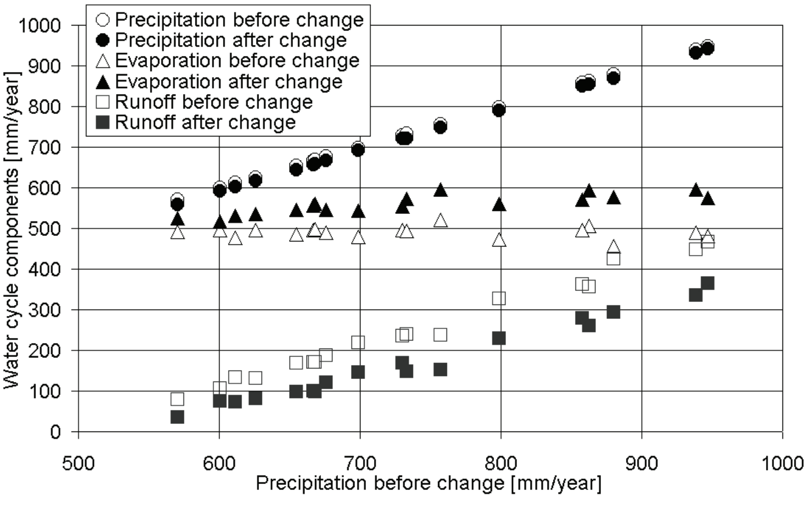

Fig. 2 Water cycle components for natural conditions and conditions affected by climate change in the study basins.

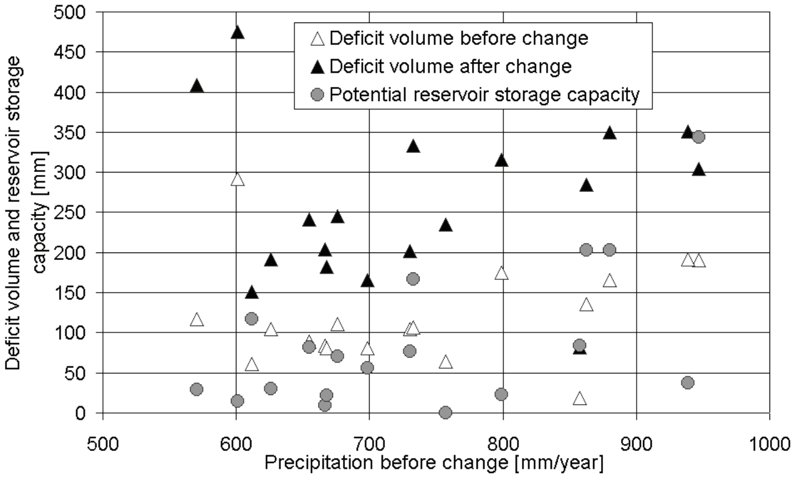

Fig. 3 Maximum deficit volumes for natural conditions and conditions affected by climate change, and potential reservoir storage capacities in the study basins.

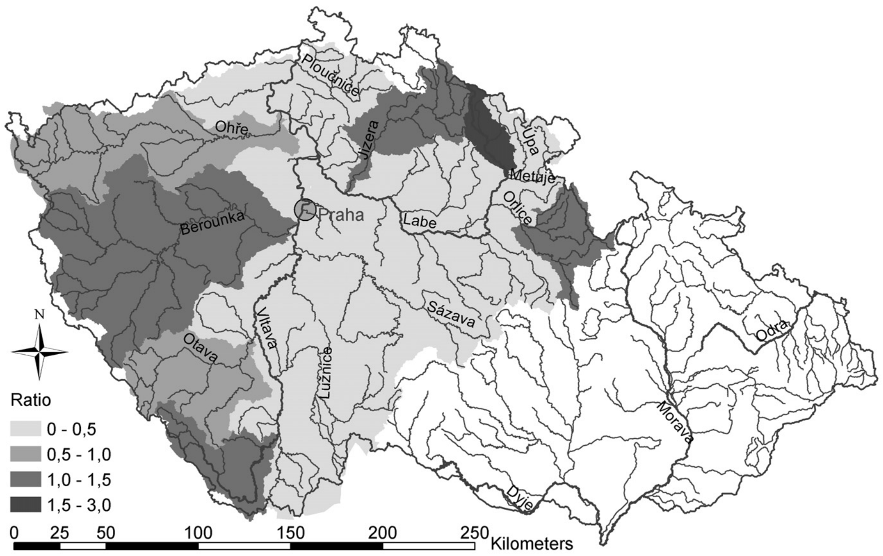

Fig. 4 Map of ratio of the potential reservoir storage capacity to an increase in the deficit volume consequently to the climate change in the study basins.

Figure 4 shows the spatial distribution of a ratio between the potential storage capacity and the increase in the deficit volumes in individual study basins. This ratio for the whole Elbe basin is 70 mm/135 mm = 0.52, which means that the potential storage capacity in the basin could compensate only approximately 50% of the deficit stemming from the climate change. The ratio has high spatial variability (from 0 to 3), which is attributable mainly to the uneven spatial distribution of the potential storage capacities available in some of the highland areas. The ratio category of 0–0.5 covers 54% of the basin area (predominantly lowlands), and is approximately balanced by the conditions where the ratio is 0.5–1.5, that is, over an area covering 45% of the basin. Good conditions occur in the high mountain range in the north (1.4% of the basin area), where the potential storage exceeds the deficit increase by a factor of 3.

CONCLUSION

The climate conditions in Europe, developments in the area of the water infrastructure, particularly in already secured water storage; and current developments in strategies, policies and legislation determined by the EU; all point towards soft solutions which are focused on protecting the quality of water resources.

The results of the study indicate that climate change impacts on future requirements for reservoir storage capacities could be high. They could suggest the need for ensuring a reliable water supply through the construction of new reservoirs to provide additional storage capacity. Such supplementary storage capacities will be needed not only for traditional water supply purposes, but also for the mitigation of climate change, which will impact on flows and particularly on low flows. These needs could also be supported by requirements of the new European water policy, particularly by those stipulations of Water Framework Directive aimed at ensuring minimum acceptable environmental flows. Thus European policies that are focused exclusively on protection of the quality water resources could be insufficient and may well have to be changed towards an adoption of hard solutions focused on water resource replenishment.

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