Future and recent changes in flow patterns in the Czech headwater catchments

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Zukünftige und gegenwärtige Änderungen im Abflussverhalten tschechischer Quelleinzugsgebiete

Introduction

The effective control of headwater catchments is considered to be an important factor in the sustainable development of water resources (CUTTER and RENWICK, 2003). In addition, headwater catchments, which in central Europe are often forested and located in mountainous regions, are areas of high ecological importance. Recently many studies have been published, focusing on changes in large-scale basins (e.g. DRIESSEN et al. 2010, HURKMANS et al. 2010) or small to medium scale catchments (HORTON et al. 2006, FOWLER and KILSBY 2007). However assessing the impact of anticipated climate change on the hydrological cycle at a small scale remains an important issue for research.

The main objective of this study was to evaluate future changes in hydrological patterns (2071–2100). It included hydrological modelling with locally-corrected regional climate model data, using different A2 and B2 SRES scenario projections (NAKIĆENOVIĆ et al., 2000).

Zusammenfassung

Der Beitrag befasst sich mit Abflussänderungen in kleinen Einzugsgebieten (Ursprungsbereiche) infolge der Klimaänderung. Drei Testeinzugsgebiete im westlichen, zentralen und östlichen Teil der Tschechischen Republik – Lysina, Červík and Litavka – wurden analysiert. Das regionale Klimamodel RCAO wurde für das Downscaling der Klimadaten der Periode 2071–2100 verwendet, wobei die Randbedingungen der GCMs HadAM3H, ECHAM4/OPYC3 und SRES angenommen wurden. Als Untersuchungsszenarien wurden A2 und B2 gewählt. Tageswerte der bias-korrigierten Niederschläge wurden als Eingangswerte für das hydrologische Modell Brook90 verwendet. Es wird prognostiziert, dass der Jahresabfluss um 2–30% abnimmt. Die Monatsabflüsse im Sommer und Herbst nehmen um ca. 60% ab, während der Winterabfluss verglichen mit der Periode 1967–1990 bis zu 250% zunimmt. Diese Änderungen haben auch starke ökologische Auswirkungen, da ein regelmäßiges Austrocknen der untersuchten Flüsse auftreten könnte.

Schlagwörter: Abflussänderung, Tschechische Quellgebiete, Wasserhaushaltsmodell Brook90.

Summary

This paper focuses on changes in flow patterns due to projected climate change at micro-scales such as headwater catchments. Three catchments were investigated – Lysina, Červík and Litavka – which are situated in the western, central and eastern part of the Czech Republic. To estimate hydrological patterns for the period 2071–2100, the regional climate model (RCAO) was used to downscale climatic data. RCAO ran with boundary conditions from two general circulation models, HadAM3H and ECHAM4/OPYC3 and SRES emission scenarios A2 and B2. Bias-corrected downscaled daily outputs were used in combination with the hydrological model Brook90. Annual runoff is projected to decline by 2–30%, and impacts on the distribution of monthly flow are projected to be significant, with summer-autumn decreases of ~60%, and winter increases of up to ~250% compared to mean flow from 1967–1990. These changes would have serious ecological consequences, since streams could regularly dry-up for short periods.

Key words: Headwater catchments, hydrological modelling, regional climate model.

Material and methods

Study sites

Three catchments were selected that belong to the GEOMON network of small forest catchments (OULEHLE et al., 2008): Lysina (LYS, Slavkov Forest, elevation range: 829–949 m a.s.l., area: 0.27 km^2); Červík (CER, Beskydy Mts., elevation range: 640–961 m a.s.l., area: 1.85 km^2) and Litavka (LIT, Brdy Mts., elevation range: 695–843 m a.s.l., area: 1.84 km^2, Figure 1). The Lysina catchment is one of two Czech sites within the international network of forest sites comprising the International Cooperative Programme – Integrated Monitoring (ICP IM), organized under the Economic Commission for Europe of the United Nations (Vuorenmaa et al. 2009). Lysina is managed by the Czech Geological Survey (KRÁM et al., 1999, HRUŠKA et al., 2002), Červík by the Forestry and Game Management Research Institute (BÍBA et al., 2006), and Litavka by the Charles University in Prague (HARDEKOPF et al., 2008).

The hydrological model Brook90

The Brook90 model (FEDERER et al., 2003) is a deterministic, process-oriented, lumped parameter hydrological model that was designed to be applicable to any land surface at a daily time step year-round. Meteorological data for the studied catchments (minimum and maximum daily air temperature, daily precipitation amounts, average daily wind speed and sunshine duration) for the period 1961–2006 were taken from climatic stations of the Czech Hydrometeorological Institute (CMHI, located within the 5 km radius). In order to represent the average catchment altitudes, air temperature data was corrected based on a local lapse rate for minimum and maximum temperature. The lapse rates for individual months were calculated by linear regression relationships using data from 5 representative climatic stations (within a radius of 100 km) ranging in elevation from 519–1118 m. The decrease varied between 0.1–0.3 °C per 100 m for the minimum temperature and 0.3–0.7 °C for maximum temperature. Daily precipitation amounts (for Lysina and Červík) were corrected by a factor calculated from the difference between average annual precipitation measured by bulk precipitation collectors at the investigated catchments and precipitation measured at CHMI climatic stations. Daily global radiation was calculated from the sunshine duration (Klabzuba et al., 1999). All three catchments are equipped with water-level recorders, installed in combination with either V-notch weirs (Lysina, Litavka) or with a flume (Červík). The calibration of Brook90 and validation of the model performance were based on daily discharge data from the catchment outlets for the period 1990–2006 (Lysina) and 1993–2006 (Červík). Calibration periods were 1990–1999 (Lysina) and 1993–1999 (Červík). The scheme of experimental design is presented on the Figure 2.

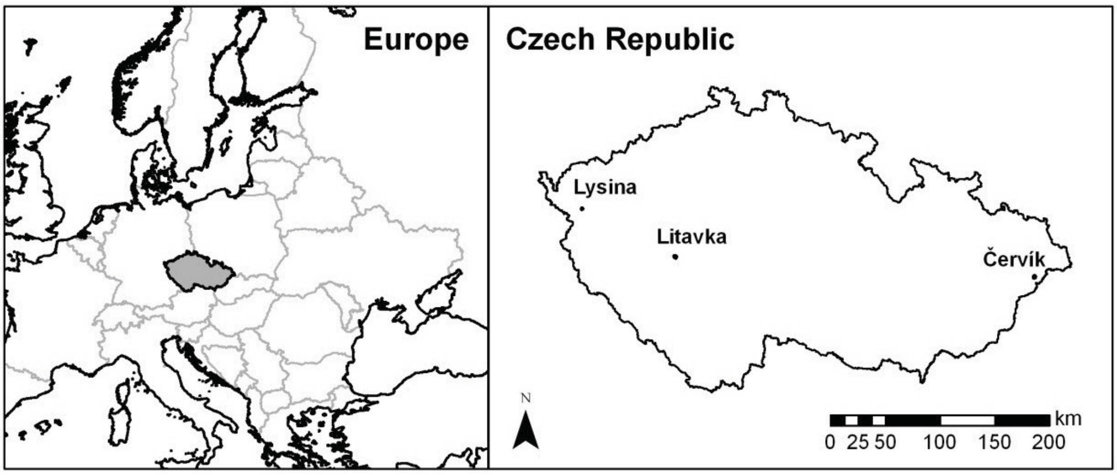

Figure 1: Map of the Czech Republic showing the location of three catchments whose hydrological patterns were investigated Lysina, Litavka and Červík

Abbildung 1: Karte der Tschechischen Republik mit der Lage der Untersuchunsgebiete Lysina, Litavka and Červík

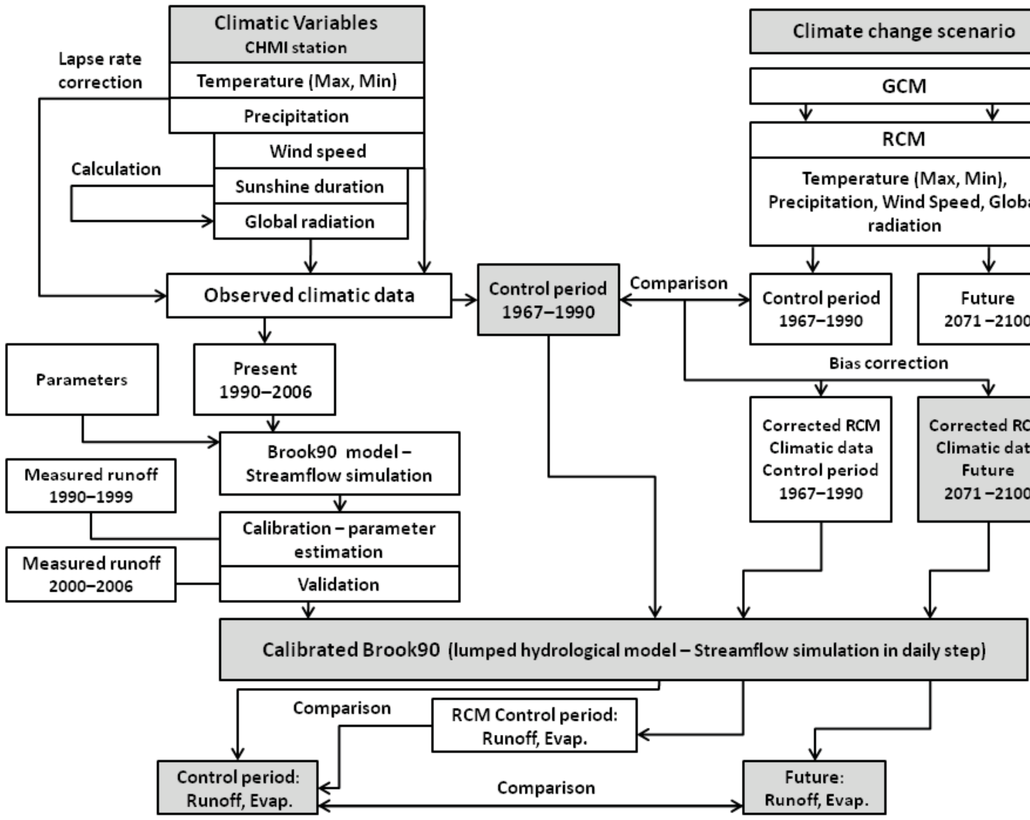

Figure 2: Scheme of the experimental design
Abbildung 2: Flussdiagramm des Beobachtungs- und Simulationskonzeptes

Regional climate model data

The climate model data used were obtained as a result of dynamic downscaling by the regional climate model RCAO (the Rossby Centre regional Atmosphere-Ocean model; DÖSCHER et al., 2002). The RCAO model uses large-scale lateral boundary conditions from two GCMs: HadAM3H (Hadley Centre, United Kingdom; hereafter RCAO-H) and ECHAM4/OPYC3 (European Centre Hamburg Model, developed at Max Planck Institute for Meteorology, Germany, hereafter RCAO-E), each run with A2 and B2 emission scenarios. The A2 scenario, the more severe case, corresponds to a change in equivalent CO_2 content (CO_2 plus other greenhouse gases) from 353 ppm, corresponding to 1990 levels, to 1143 ppm in the future (2071–2100). The equivalent CO_2 content for the B2 future climate scenario is 822 ppm. These future climate scenarios are based on the IPCC (Intergovernmental Panel on Climate Change) A2 and B2 SRES (Special Report on Emissions Scenarios) anthropogenic CO_2 emissions scenarios (NAKIĆENOVIĆ ET al., 2000).

Simulated daily maximum and minimum temperatures, daily amounts of precipitation, global radiation, and average daily wind speed were downloaded from the PRUDENCE project (Prediction of Regional scenarios and Uncertainties for Defining EuropeaN Climate change risks and Effects) (CHRISTENSEN et al., 2007). These datasets are available for 0.44° grids (~50 km resolution) for a control period from 1961–1990 and a projected period from 2071–2100.

Simulated RCAO atmospheric data for the control period (1961–1990) differed notably from measured data, and therefore had to be transformed for hydrological modelling purposes. We applied the method of bias correction (e.g. Fowler and Kilsby, 2007). Daily minimum and maximum temperature, precipitation, wind speed, and global radiation data series were 'bias-corrected' by monthly factors, so that the downscaled monthly average of the present climate matched the observed monthly average over the period 1961–1990. The future temperature and rainfall time series were adjusted by the same factors as for the control climate.

Results

In general, Brook90 reproduced quite well the flow conditions in the study catchments, including both individual flood events and long-term runoff. For the validation period (2000–2006) at the Lysina catchment, the correlation coefficient was 0.93 (r_{crit} = 0.2199, n = 84, p = 0.05) for monthly data and 0.67 (r_{crit} = 0.1966, n = 2557, p = 0.05) for daily data. In the case of Červík, the correlation coefficient was 0.92 (r_{crit} = 0.2542, n = 84, p = 0.05) for monthly data and 0.86 (r_{crit} = 0.1966, n = 2557, p = 0.05) for daily data during this same period 2000–2006.

The bias-corrected RCAO data were used for runoff modelling in the calibrated Brook90 model for the control period (1961–1990). The seasonal runoff distribution calculated from the bias-corrected RCAO model input data show similar patterns as the simulation based on observed data (Figure 3).

The RCAO models estimated an increase in mean annual 2 m air temperatures of between 2.5 and 5.8 °C and the change of annual precipitation amounts within ±10% compared to the control period. Annual runoff is predicted to decline by 11–28% (LYS), respective 2–23% (CER). Impacts on the distribution of monthly flow are predicted to be significant (see Figure 4), with summer-autumn decreases up to 94% (LYS), 97% (CER) and winter increases of up to ~69% (LYS), ~176% (CER) compared to mean flow from the control period. These changes would have serious ecological consequences (Horecký et al., 2006), with the possibility of streams becoming dry regularly for short periods.

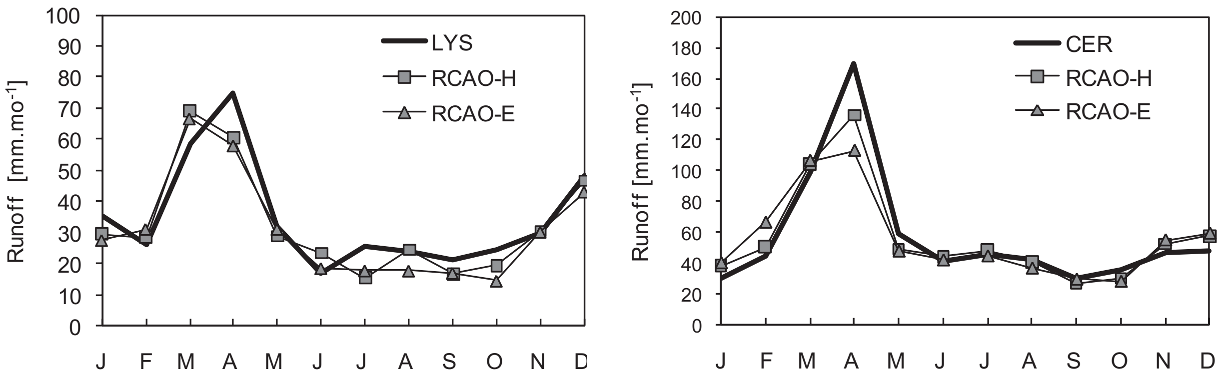

Figure 3: Runoff monthly means modelled by Brook90 using observed climatic data (LYS = Lysina, CER = Červík) and RCAO bias corrected simulated data in the control period (1967–1990, respective 1961–1990 Regional climate model RCAO uses lateral boundary conditions from general circulation models HadAM3H (RCAO-H) and ECHAM4/OPYC3 (RCAO-E)

Abbildung 3: Berechnete mittlere monatliche Abflussspenden mittels Brook90 unter Verwendung beobachteter Klimadaten (LYS = Lysina, CER = Červík) und simulierter bias-korrigierter RCAO Daten für die Periode 1967–1990 bzw. 1961–1990

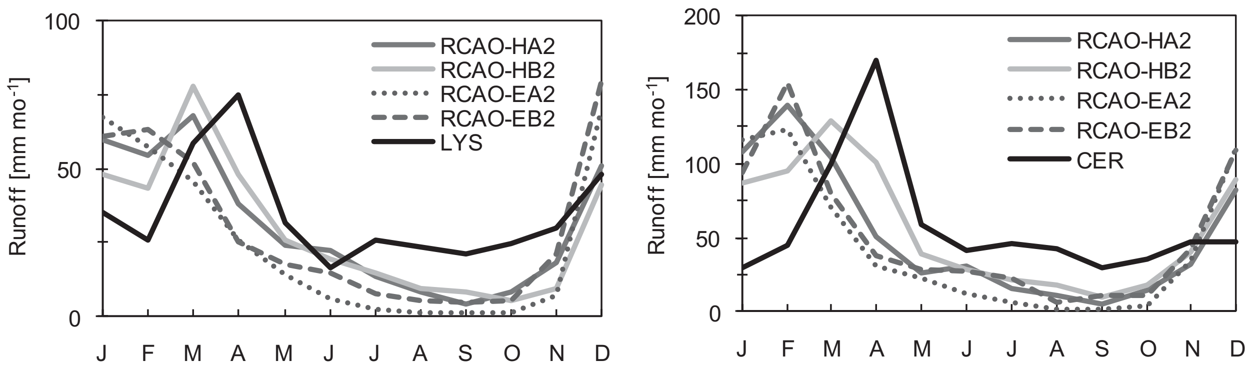

Figure 4: Mean annual cycle of runoff for a) Lysina (LYS) and b) Červík (CER) in the control period (1967–1990, respective 1961–1990) and future runoff in 2071–2100 simulated based on bias-corrected RCAO outputs. Regional climate model RCAO uses lateral boundary conditions from general circulation models HadAM3H (RCAO-H) and ECHAM4/OPYC3 (RCAO-E) with SRES A2, B2 scenarios)

Abbildung 4: Berechneter, jährlicher Verlauf der mittleren monatlichen Abflussspenden für die Gebiete a) Lysina (LYS) and b) Červík (CER) für die Referenzperiode 1967–1990 (bzw. 1961–1990) und den Prognosezeitraum 2071–2100 mittels bias-korrigierter RCAO-Daten

The low summer flow and no flow periods projected for the Lysina and Červík can be seen recently in the Litavka catchment. With an annual precipitation of 764–1057 mm (1961–1990 average was 750 mm in this area), the annual runoff was only 87–227 mm in hydrological years 2007–2009. The stream was dry from July-September 2007, from the end of June to the beginning of December 2008 and from September-October 2009 (Figure 5). Short drought spells have historically occurred in the Litavka catchment. The catchment is highly sensitive to changes in the seasonal precipitation distribution and temperature increase. Several factors contribute to this situation, including the underlying crystalline bedrock and less precipitation compared to Czech mountains located around the borderline. This causes relatively low groundwater storage in the region.

With the anticipated increase of temperature and change in seasonal precipitation distribution, we estimate that other small catchments in the Czech Republic could become vulnerable to extreme drought spells. similar to the situation observed recently in the Litavka catchment.

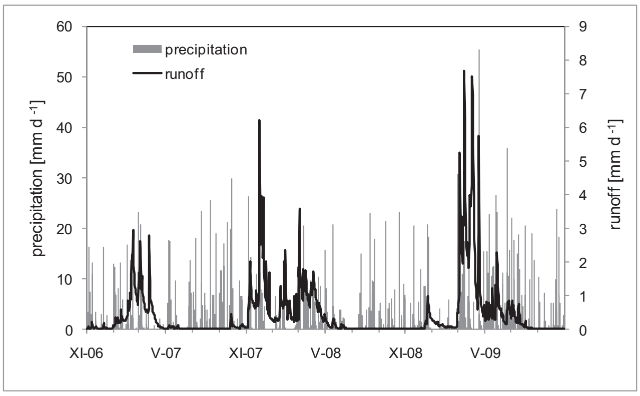

Figure 5: Daily values of runoff and precipitation from the Litavka catchment for the hydrological period 2007–2009

Abbildung 5: Tageswerte der Abflussspenden und der Niederschläge des Einzugsgebiets Litavka für den Zeitraum 2007–2009

Conclusions

The calibrated hydrological model Brook90 provides a suitable tool for the modelling of future changes in hydrological patterns in small-forested catchments.

The response to the anticipated climate change shows a similar pattern for both western and eastern parts of the Czech Republic. The annual runoff is expected to decrease and the annual cycle will change significantly. Winter runoff is expected to increase, the runoff maxima will shift and runoff in summer and autumn will decrease notably. The estimated declines in mean daily flows indicate that studied streams might regularly dry up for short periods in the summer and autumn. A similar scenario could also be expected in other small catchments in the Czech Republic.

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