HYDROLOGICAL SCENARIOS OF FUTURE SEASONAL RUNOFF DISTRIBUTION IN CENTRAL SLOVAKIA

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Abstract

The hydrological scenarios of future seasonal distributions of runoff in the upper Hron River basin, which was chosen as a representative mountainous region in Central Slovakia, were evaluated. Changes in the future climate were expressed by three different climate change scenarios developed within the framework of the Central and Eastern Europe Climate Change Impact and Vulnerability Assessment Project (CECILIA). The climate change scenarios were constructed using the pattern scaling method from the outputs of transient simulations made by 3 GCMs - ECHAM4/OPYC3, HadCM2 and NCAR DOE-PCM. A conceptual hydrological balance model calibrated with data from the period 1971-2000 was used for modelling changes in runoff with monthly time steps. The runoff change scenarios for the selected basin in the future time horizons of 2025, 2050 and 2100 show changes in the seasonal runoff distribution.

Keywords: *Hydrological balance model, Climate change scenarios, Changes in runoff.*

1 INTRODUCTION

The impacts of climate change on hydrological processes are often estimated by defining scenarios of changes in climatic inputs to a hydrological model from the output of general circulation models (GCMs). Two approaches are often used to construct weather series representing a changed climate (Dubrovsky, et al., 2000): an observed weather series is modified by the scenario's parameters (Maytín, et al., 1995), or a weather series is produced by a weather generator whose parameters have been modified according to the scenario (Dubrovsky, et al., 2000).
Monthly conceptual water balance models are intended to simulate selected hydrological processes, usually by conceptualising a catchment as an assemblage of interconnected storage systems through which water passes from input as rainfall to output as streamflow at the catchment outlet; the controlling equations usually satisfy the requirements of the hydrological balance. In impact studies, the model's parameter values from the representative periods are usually considered to be representative of runoff generation in the future.
Several climate change impact studies have been conducted in recent years on the territory of Slovakia. Usually, three types of climate change scenarios have been used in previous impact studies: analogue scenarios based on an analogy with warmer periods and periods with a specified variability in the climate in the past; regionally downscaled GCMs scenarios with typical time horizons of 2010, 2030 and

2075; and incremental climate change scenarios. Modified model input time series have usually been constructed from the baseline data by adding the differences in mean air temperature and precipitation prescribed by the scenarios for the given time step. Observed runoff series from 1931 – 1980 or 1951−1980 have usually been considered as baseline periods. Additional details can also be found in the following studies on Slovak rivers: Danihlík, et al. (2004); Fendeková (1999); Fendeková and Némethy (2001); Halmová (2004a,b, 2005, 2006); Halmová and Melo (2006); Hlavčová, et al. (1999, 2000, 2002, 2005, 2006a,b); Kostka and Holko (2000, 2001); Kostka (2003); Majerčáková (2000); Majerčáková and Takáčová, (2001); Pekárová, et al. (1996, 2001); Pekárová (2000); Pekárová and Miklánek (2001); Pekárová and Szolgay, eds. (2005); Petrovič (1998, 2000); Szolgay, et al. (1997, 2002, 2003, 2007a,b) and Takáč (2001).

In this study the potential impact of climate change on river runoff in the upper Hron River basin was evaluated using a conceptual spatially-lumped water balance model. The conceptual water balance model was calibrated with data from the 1971-2000 period. The period of 1971-2000 was assumed to be the reference for impact simulations in the Central and Eastern Europe Climate Change Impact and Vulnerability Assessment project (CECILIA). Changes in climate variables in the future were expressed by three different climate change scenarios developed within the framework of the CECILIA project. The climate change scenarios were constructed using the pattern scaling method from the outputs of transient simulations made by the ECHAM4/OPYC3, HadCM2 and NCAR DOE-PCM global circulation models (Dubrovský, et al., 2005).

2 SCENARIOS OF CLIMATE CHANGE

In this study three climate change scenarios developed for the Hron basin within the framework of the 6 FP CECILIA (CECILIA, 2007) were applied. The scenarios were based on transient simulations with three GCMs, i.e., ECHAM (ECHAM4/OPYC3), HadCM (HadCM2) and NCAR (NCAR DOE-PCM), were constructed using pattern scaling techniques from the outputs of these GCMs and representative scenarios for the development of emissions of greenhouse gases and aerosols, and the intermediate climatic sensitivity to the emissions. The climate change scenarios were constructed for three future time horizons, i.e., 2025, 2050, and 2100.

The methodology for constructing the scenarios is described in Dubrovsky, et al. (2005). In this method, the standardized scenario, which relates the climate's variable responses to a 1°C rise in the global mean temperature (TG), is multiplied by the predicted change (ΔTG). The standardized scenarios were determined from GCM runs and ΔTG values, which were calculated by the simple MAGICC climate model (Harvey, et al., 1997; Hulme, et al., 2000) for 3 combinations of conditions that were selected from representative emission scenarios and climatic sensitivities.

The SRES A1, A2, B1, and B2 emission scenarios from the IPCC Third Assessment Report (IPCC 2001) were used in the estimation of future increases in global temperature together with the most likely range of the values for the climate sensitivity factor, i.e., an increase in global temperature by 1.5-4.5°C per doubling of the atmospheric CO_2 concentration (IPCC, 2001). The values of the increases in global temperature for the emission scenarios used were compared for the low (LO), medium (MI), and high (HI) estimates of the climate sensitivity factor, i.e., the most optimistic, the mid-range, and the most pessimistic.

Changes in the mean monthly air temperature for the time horizon 2050 in the Hron basin are illustrated in Table 1.

Table 1. Scenarios of changes in the mean monthly air temperature in the Hron River basin for the horizon 2050 in °C as compared to the 1971−2000 reference period.

Scenario	Months											
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
ECHAM												
High (HI)	2.6	2.7	2.4	2.9	1.6	2.9	3.2	3.7	3.4	2.7	2.7	2.7
Low (LO|	0.9	0.9	0.8	1.0	0.6	1.0	1.1	1.3	1.2	0.9	0.9	0.9
Medium (MI)	1.7	1.7	1.6	1.9	1.0	1.8	2.1	2.4	2.2	1.7	1.7	1.7
HadCM												
High (HI)	2.3	2.8	2.2	2.3	2.5	2.6	3.6	4.3	3.7	2.7	2.2	3.1
Low (LO|	0.8	1.0	0.7	0.8	0.9	0.9	1.3	1.5	1.3	0.9	0.8	1.1
Medium (MI)	1.5	1.8	1.4	1.5	1.6	1.7	2.3	2.8	2.3	1.7	1.4	2.0
NCAR												
High (HI)	2.3	2.6	1.5	1.3	1.3	1.4	2.9	3.2	2.6	3.0	2.6	2.1
Low (LO|	0.8	0.9	0.5	0.5	0.5	0.5	1.0	1.1	0.9	1.0	0.9	0.7
Medium (MI)	1.5	1.7	1.0	0.8	0.8	0.9	1.8	2.0	1.7	1.9	1.7	1.4

3 HYDROLOGICAL SCENARIOS OF CHANGES IN SEASONAL RUNOFF DISTRIBUTION

The scenarios of the changes in the seasonal runoff distribution were constructed using the following methodology:

1. calibration of the conceptual hydrological balance model for the selected pilot basins,
2. simulation of the reference mean monthly runoff series using input climate data from the reference period of 1971−2000,
3. modification of the climate input data from the reference period (precipitation and air temperature) according to the climate change scenarios for the time horizons of 2025, 2050 and 2100,
4. simulation of the monthly runoff series using a hydrological balance model based on the changed input data and parameters of the model from the calibration,
5. comparison of the differences between the seasonal runoff distribution for the individual scenarios and the time horizons considered.

Description of the pilot area and input data

The upper Hron River basin to Banská Bystrica profile was selected as the pilot basin for the impact study. The basin has an area of 1766 km^2; the minimum elevation of the basin is 340 ma.s.l.; the maximum elevation is 2004 m a.s.l.; and the mean elevation is 850 m a.s.l. Seventy percent of the basin's area is covered by forest, 10 % by grasslands, 17 % by agricultural land and 3 % by urban areas. The location of the basin within the territory of Slovakia is shown in Fig. 1.

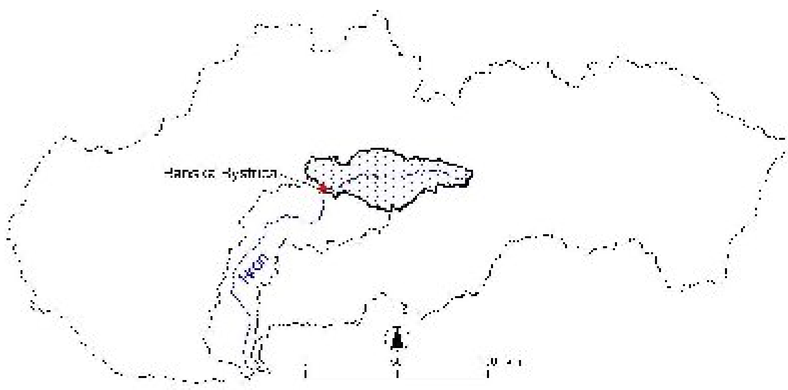

Figure 1. Location of the upper Hron River basin in Slovakia.

The hydrological and climate input data for the hydrological modelling were collected in monthly time steps during the period of 1971-2000. Monthly precipitation totals were available from 23 precipitation stations; the data of the mean monthly air temperature, mean monthly water vapour, cloudiness and snow cover were collected from 5 climate stations in the basin. The values of the mean monthly potential evapotranspiration were calculated by the Tomlain method, based on energy balance equations (Tomlain and Damborská, 1999). The mean monthly discharges were available from the Banská Bystrica gauging station.
The lumped input data for modelling the basin were prepared using the nearest neighbour interpolation method and the elevation gradient method.

The monthly water balance model
For estimating the changes in the seasonal runoff distribution, a conceptual water balance model developed at the Slovak University of Technology was used. This model, which simplifies a river basin into 2 nonlinear reservoirs, simulates water accumulation in the basin, snowmelt, evapotranspiration, runoff from impermeable areas in the basin, surface and subsurface runoff and baseflow. The inputs required for modelling the water balance in a monthly time step are: the mean monthly precipitation for the basin, the mean monthly discharges in the outlet of the basin and the mean monthly potential evapotranspiration (*PET*). For calculating the potential evapotranspiration, various methods can be used (the Tomlain, Thornthwaite, Ivanov and FAO methods), and additional climate data (the long-term mean monthly hours of the duration of sunshine, the long-term mean monthly values of the relative air humidity, and the mean monthly air temperature values) are required.
The basic mass balance equation in the model is written as:

$$S_i - S_{i-1} = \left(P_i\left(1-drc\right)\right) - Rs_i - Rss_i - Ev_i - Rb \tag{1}$$

where:

S_i, S_{i-1} - current water storage in the basin in months i and i -1 [mm],
i - time step [month],
P_i - basin's average precipitation in the month i [mm],
drc - direct runoff coefficient ($0 \leq drc \leq 1$) [–],
Rs_i - surface runoff in the month i [mm],
Rss_i - subsurface runoff in the month i [mm],
Ev_i - basin's average actual evapotranspiration in the month i [mm],

Rb - baseflow [mm].

In the calibration procedure of the hydrological balance model, 11 model parameters are optimized (*Smax*, *α*, *γ*, *ε*, *PeffPar*, T_s, T_l, *Rb*, *ActEpar*, *drc* and *Zinitial*). The *Zinitial* parameter is the initial value of the ratio between S_i and S_{max}. In the model a genetic algorithm (GA) is built in to calibrate the model parameters for the at site data, and several criteria (or their combinations) are used as an objective function. The basic optimization criteria are the Nash-Sutcliffe criterion, the sum of the squared differences between the measured and simulated values, the sum of the squared differences between the logarithms of the measured and simulated values, and the Nash-Sutcliffe criterion for the long-term mean monthly values.

The hydrological model was calibrated using monthly data from the period 1971-2000 and validated using data from the period 1961-1970. The values of the Nash – Sutcliffe criterion for the calibration and validation period are listed in Table 2.

Table 2. Values of the Nash –Sutcliffe criterion for the calibration and validation period.

Nash – Sutcliffe	
Calibration 1971-2000	Validation 1961-1970
0.826	0.819

4 RESULTS

The values of the long-term mean monthly discharges in the reference period 1971-2000 and the 2050 time horizon calculated for the ECHAM, HadCM and NCAR climate change scenarios are shown in Fig. 2; the differences in percentages between the long-term mean monthly discharges in the reference period and the future time horizons are compared in Table 3.

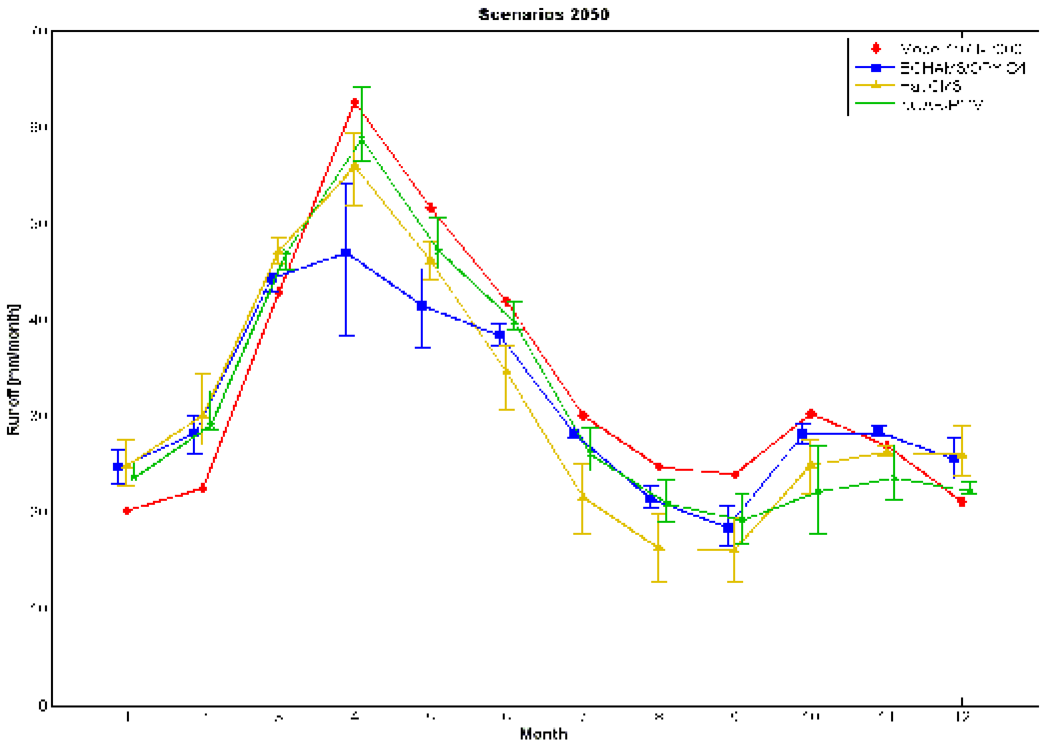

Figure 2. Long-term mean monthly runoff in the reference period 1971-2000 and in the time horizon of 2050 for all considered climate change scenarios.

Table 3. Percentage changes in the long-term mean monthly runoff for all the considered climate change scenarios in comparison with the reference period of 1971-2000.

Scenario/ Horizon	Month											
	1	2	3	4	5	6	7	8	9	10	11	12
ECHAM												
2025_HI	21	24	6	-18	-15	-6	-4	-9	-17	-4	5	18
2025_LO	8	9	3	-8	-8	-3	-2	-4	-7	-1	3	7
2025_MI	13	16	3	-13	-12	-5	-4	-6	-11	-3	4	11
2050_HI	32	34	0	-39	-28	-11	-8	-17	-31	-10	8	31
2050_LO	13	16	4	-13	-12	-6	-4	-8	-13	-4	4	11
2050_MI	23	25	4	-25	-20	-9	-7	-14	-23	-7	5	21
2100_HI	54	39	-17	-63	-47	-23	-16	-32	-55	-28	8	63
2100_LO	25	24	6	-30	-22	2	8	-12	-38	-8	7	25
2100_MI	32	34	0	-39	-29	-12	-9	-18	-32	-11	8	32
HadCM												
2025_HI	21	30	10	-8	-8	-14	-22	-28	-26	-14	-1	20
2025_LO	8	12	5	-3	-5	-7	-10	-13	-12	-6	0	7
2025_MI	13	19	7	-5	-7	-11	-17	-20	-19	-9	0	12
2050_HI	36	53	13	-17	-15	-27	-41	-49	-47	-28	-4	37
2050_LO	13	20	7	-5	-7	-11	-17	-20	-19	-9	0	12
2050_MI	23	34	10	-11	-11	-18	-28	-34	-32	-18	-2	23
2100_HI	74	93	9	-29	-21	-47	-68	-75	-74	-54	-11	77
2100_LO	28	39	16	-5	-6	-14	-24	-29	-27	-13	3	27

2100_MI	37	54	13	-18	-14	-27	-42	-50	-48	-28	-4	38
NCAR												
2025_HI	14	25	9	-5	-7	-5	-12	-13	-17	-22	-10	5
2025_LO	5	10	4	-2	-3	-1	-5	-6	-7	-9	-3	2
2025_MI	9	16	6	-3	-5	-3	-7	-9	-10	-14	-6	3
2050_HI	26	45	14	-10	-12	-7	-19	-23	-30	-42	-21	7
2050_LO	18	27	15	2	-2	0	-5	-6	-8	-11	0	11
2050_MI	17	29	10	-6	-9	-5	-13	-15	-19	-27	-12	6
2100_HI	53	85	25	-18	-19	-11	-35	-42	-52	-73	-53	6
2100_LO	15	26	9	-5	-8	-4	-11	-14	-18	-24	-10	5
2025_HI	26	46	15	-10	-12	-7	-19	-23	-30	-42	-22	7

The results presented of the modelling of the long-term mean monthly discharges indicate future changes in the seasonal runoff distribution in the upper Hron river basin. According to the pessimistic version of the ECHAM runs, the highest relative increase in runoff in comparison with the reference period can be expected in February, i.e., +24 % in 2025, +34 in 2050; and in December/January, i.e. +63 % in 2100. This increase could be caused by an increase in air temperature during the winter and a shift in the snow melting period from the spring months to the winter period. The most extreme relative decrease in runoff can occur in April, i.e. -18 % in 2025, -39 % in 2050, -63 % in 2100; and in September, i.e., -17 % in 2025, -31 % in 2050 and -55 % in 2100. The decrease in April is caused by an increase in air temperature (+1.5 ºC in 2025, +2.9 ºC in 2050 and +6.2 ºC in 2100) and by a decrease in precipitation (about -7 % in 2025, -13 % in 2050 and -29 % in 2100). The decrease in September is caused by the increase in air temperature (+1.8 ºC in 2025, +3.4 ºC in 2050 and +7.2 ºC in 2100) and by the decrease in precipitation (-10 % in 2025, -18 % in 2050 and -39 % in 2100) if compared to the reference period.
According to the pessimistic version of the HadCM runs, the highest relative increase in runoff in comparison with the reference period can be expected in February, i.e. +30 % in 2025, +53 % in 2050; and in December, i.e., +77 % in 2100. The most extreme relative decrease in runoff can occur from July to September, i.e., -28 % in 2025, -49 % in 2050 and -75 % in 2100. The lower runoff is caused by the increase in air temperature (in August: +2.3 ºC in 2025, +4.3 ºC in 2050 and +9 ºC in 2075), as well as by the decrease in precipitation (in August: -15 % in 2025, -29 % in 2050 and -62% in 2100).
For the pessimistic version of the NCAR scenario, the highest relative increase in runoff can again be expected in February, i.e., +25 % in 2025, +45 % in 2050 and in December, i.e. +85 % in 2100. The most extreme relative decrease in runoff can occur from September to October/November, i.e., -22 % in 2025, -42 % in 2050 and -73 % in 2100. This decrease is caused mainly by the considerable decrease in precipitation (in October: -19 % in 2025, - 35 % in 2050 and -76 % in 2100).
It could generally be concluded for both of the investigated scenarios, that during the winter and early spring periods, an increase in the long-term mean monthly runoff could be assumed. The period of an increase in runoff could occur from November/December to March. This increase could be caused by the increase in air temperature and a shift of the snow melting period from the spring months to the winter period. The period of the decrease in runoff could occur from April to October/November. The most extreme decrease could be expected in April-May and

July-September. The increase in winter runoff and the decrease in summer runoff are expected to be more extreme for later time horizons.

5 CONCLUSIONS

According to the anticipated changes in the seasonal distribution of the mean monthly runoff, the Hron river basin could become vulnerable to drought in the summer and early autumn. In months with increased water demands for irrigation, domestic and industrial use and tourism, the monthly flows could exhibit a decrease under conditions of climate change. The intensity of the changes could increase towards the time horizon of 2100. A continual general decrease in the utilizable potential of the surface and subsurface water resources is likely to occur, which will have to be taken account of in the planning and management of water resources in the near future.

However, due to several uncertainties, it is rather difficult to present quantitative adaptation guidelines and estimate their cost. Uncertainties in the boundary conditions for the long-term development and management of water resources in Slovakia include: the not-quite-clear priorities for Slovakia's economic transformation, its energy policy, and the gradually changing water legislation in the near future; the changing, but unsettled, priorities for institutional, industrial, agricultural and urban developments; and the possibility of the privatisation of the water supply, water power and irrigation sectors.

A "no regret" policy based on environmental protection priorities, which would incorporate adaptive measures for the mitigation of the effects of climate changes, is therefore seen here as a solution for the near future. In order to eliminate the effects of the possible negative trends in the hydrological cycle and development of water resources in Slovakia, the adaptation strategies addressed on the national level will have to incorporate a number of legislative, organisational and technical actions aimed at protecting the country's water resources and their source areas.

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