Effects of Climate Change on Water Resources and Runoff in an Alpine Basin

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ABSTRACT

The combined influence of increased temperatures and changed precipitation on the seasonal snow cover and runoff is evaluated for the upper Rhine basin at Felsberg (3250 km^2, 560-3614 m a.s.l.). The runoff regime reflects the snow accumulation in the winter half year and snowmelt in the summer half year. The method of predicting future runoff regimes is based on high resolution periodical snow cover mapping by satellites in order to evaluate the climate-effected snow cover and runoff by the SRM-ETH model. Conditions of the present climate are represented by a *normalised year.* Snow conditions and yearly hydrographs are evaluated for the years 2030 and 2100 according to the given climate scenarios for this region. Quantitative results indicate the decrease of the snow accumulation on 1 April as well as the seasonal redistribution and changes of runoff.

1. Introduction

Hydrological models are increasingly used for predicting the climate effected runoff. At the same time, opinions are gathering weight that the calibration models are not suitable for this purpose because the model parameters cannot be meaningfully adjusted to a changed climate (Klemevs}, 1985, Becker and Serban, 1990, Nash and Gleick, 1991). Therefore the non-calibration model SRM-ETH was used in this study which was carried out in the framework of the *Swiss National Program on Climate Changes and Natural Disasters.*

2. Characteristics of the test basin

The Rhine-Felsberg basin (3250 km^2, 560-3614 m a.s.l.) is situated in the eastern Swiss Alps as illustrated in Fig. 1. For modelling purposes, the basin was divided into 5 elevation zones which are listed in Table 1.

The SRM model, which is described elsewhere (Martinec et al., 1994), uses depletion curves of the snow coverage as a main input variable for evaluating snow reserves and computing runoff. A runoff simulation in the hydrological year 1994 may serve as an example of the runoff regime. Due to snow accumulation in the winter months, the major proportion of runoff occurs in the summer half year as shown in Fig. 2. In order to improve the river flows in the winter for water power generation, the summer runoff is partially stored in artificial reservoirs. This manipulation is corrected for a comparison with computed runoff so that Fig. 2 shows the reconstructed natural runoff.

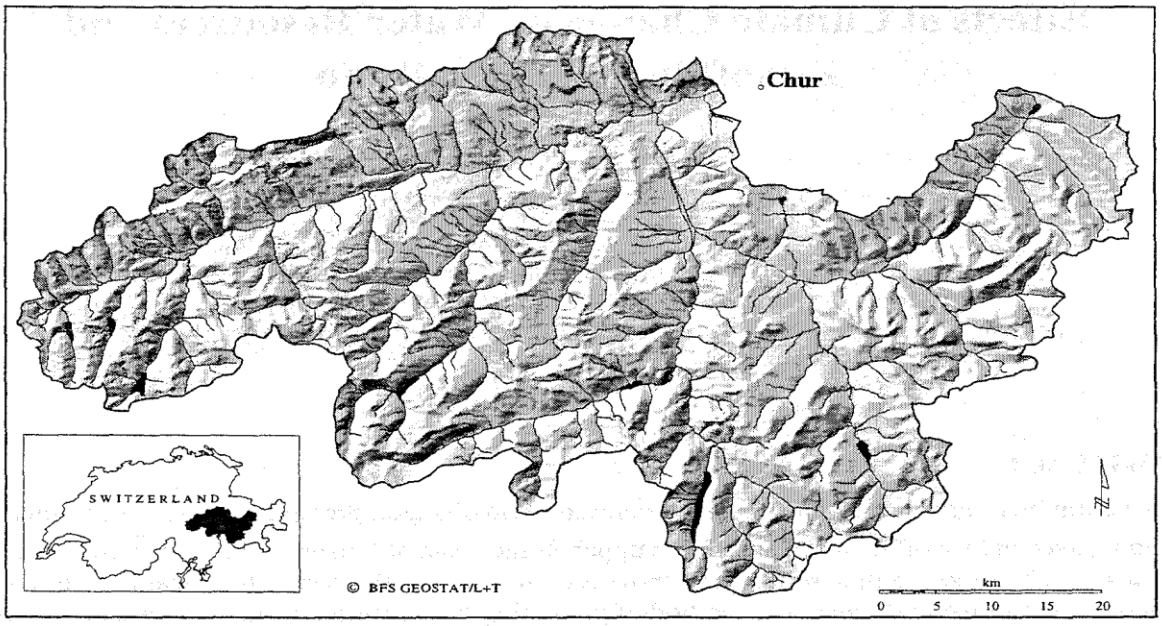

Fig. 1: Situation of the Rhine-Felsberg basin

Table 1: Elevation zones of the Rhine-Felsberg basin

Zone	Elevation [m a.s.l.]	Area [km^2]
A	575 - 1100	257
B	1100 - 1600	520
C	1600 - 2100	890
D	2100 - 2600	1165
E	2600 - 3614	409
Basin	575 - 3614	3241

The model parameters in this simulation were predetermined with regard to hydrological and climatic conditions for a present summer as follows:

Degree-day factor a = 0.25 - 0.65 cm $^{\circ}C^{-1}d^{-1}$ (evaluated from snow density)

Runoff coefficient for snow $c_S = 0.8 - 0.9$

Runoff coefficient for rain $c_R = 0.6 - 0.9$

Critical temperature $T_{crit} = 0.5 - 1.0$ (distinguishing snow and rain)

Temperature lapse rate $\gamma = 0.65$ °C per 100 m

Time lag = 9 hrs

Recession coefficient $k_n = x \cdot Q_{n-1}^{y}$ with x = 1.32 and y = 0.09 in summer and x = 1.28 and y = 0.065 in winter, varying according to the current discharge, derived from historical discharge data and the basin size as explained elsewhere (Martinec et al., 1994).

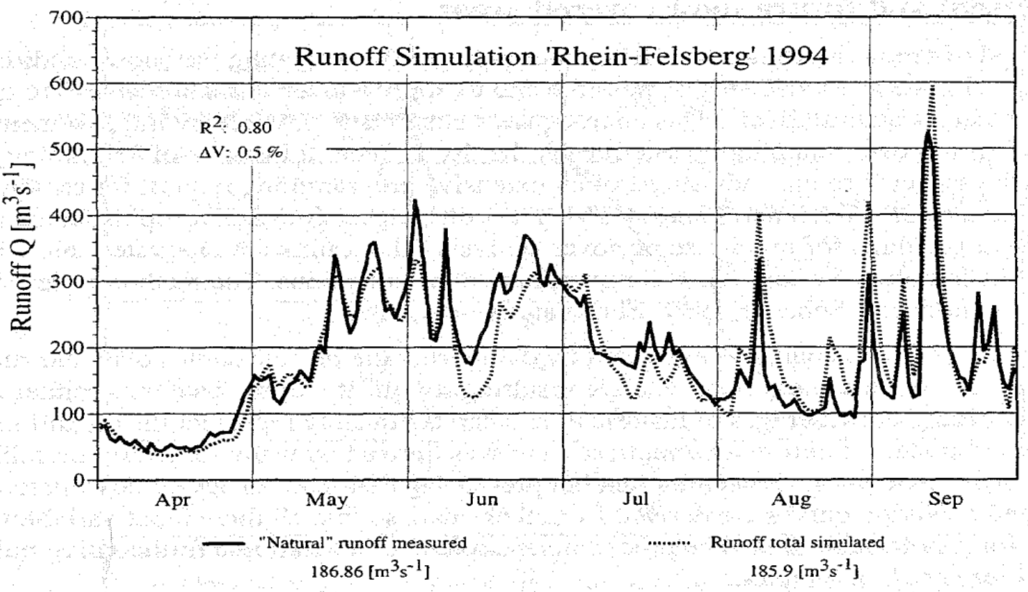

Fig. 2: Runoff in the Rhine-Felsberg basin in the hydrological year 1994

3. Climate scenarios

There is a general consensus that temperature is already on the rise and that it will continue to increase in the next century due to the greenhouse effect.

Precipitation is also expected to change but quantitative indications are less certain and vary in different locations of the globe. The climate scenarios for the Rhine-Felsberg area are listed in Table 2.

Table 2: Climate scenarios for the area Rhine-Felsberg

Year		Temperature		Precipitation	
		Winter	Summer	Winter	Summer
--2030	C	+1.4°	+1.5°	0%	-5%
	A	+1.8°	+1.9°	+5%	-10%
2100	C	+2.1°	+2.4°	+5%	-10%
	A	+3.8°	+4.1°	+10%	-12.5%

The present scenarios do not indicate whether, for example, evapotranspiration will increase in a warmer climate or whether the increase of CO_2 will offset this effect. Also, it should be noted that the scenarios were derived for the Alpine region from global models. Therefore the results of the study should be considered with regard to these uncertainties.

The SRM-ETH model is being adapted to handle more sophisticated climate scenarios which may be available in the future.

4. Present and future snow covered areas

The method of predicting future runoff regimes is based on evaluating the snow conditions in the present climate as realistically as possible and to apply a given climate scenario to determine the changes quantitatively. This approach has been made possible by improvements of periodical snow cover mapping by satellites at the Swiss Federal Institute of Technology in Zurich. One aspect is to take advantage of an extensive programming request for remote sensing sata, such as SPOT-XS and Landsat-TM. The other aspect consists in sophisticated image processing algorithms for precise snow cover analysis. The results are integrated into a Geographical Information System (GIS) for quantitative investigations. The method is described elsewhere (Ehrler and Schaper, 1997, Ehrler and Seidel, 1995).

The effect of a climate change is evaluated by comparing the present snow cover and runoff with a climate-affected snow cover and the resulting runoff. It was realized that neither a single year nor long term averages of historical data can adequately represent the conditions of the present climate. Therefore a *normalized year* was derived by using long term monthly averages of temperature and precipitation, but preserving their natural day-to-day fluctuations. Normalized depletion curves are derived from these data so that all three input variables are available for runoff modelling. The procedure is explained in detail in a forthcoming publication (Martinec et al., in preparation).

Fig. 3 shows runoff simulations for actual years (1982/83 in the winter and 1985 in the summer) compared with the runoff simulation using normalized precipitation, temperatures and snow covered areas. This *normalized* hydrograph serves for comparison with the climate-affected hydrograph. Data from two different years have been used in the winter and in the summer, respectively, (both of them as *normal* as possible), in order to minimize the adjustments.

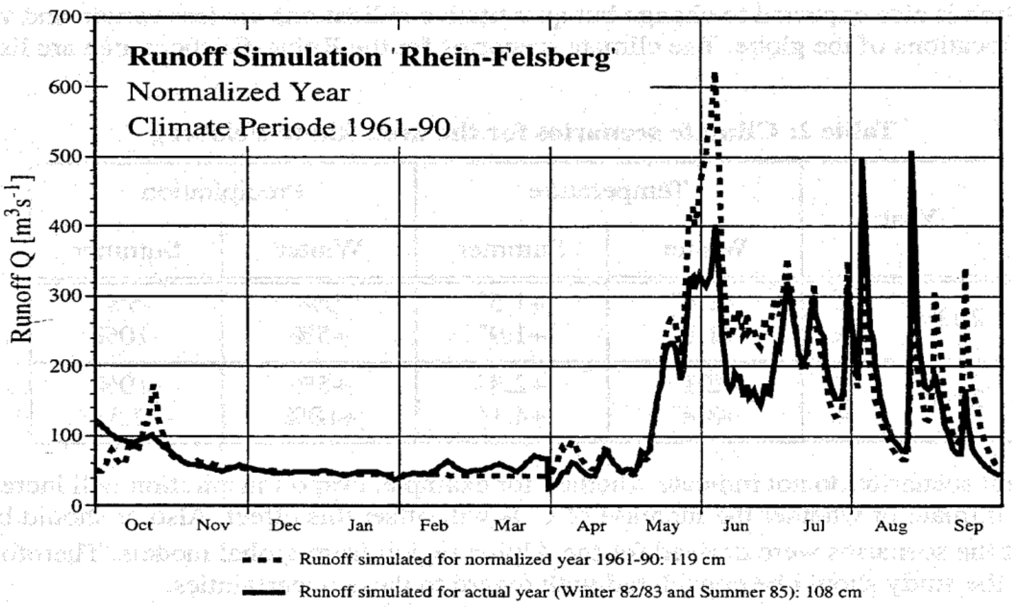

Fig. 3: Runoff simulation in the winter of 1982/83 and in the summer of 1985 compared with the computed runoff of a normalized hydrological year

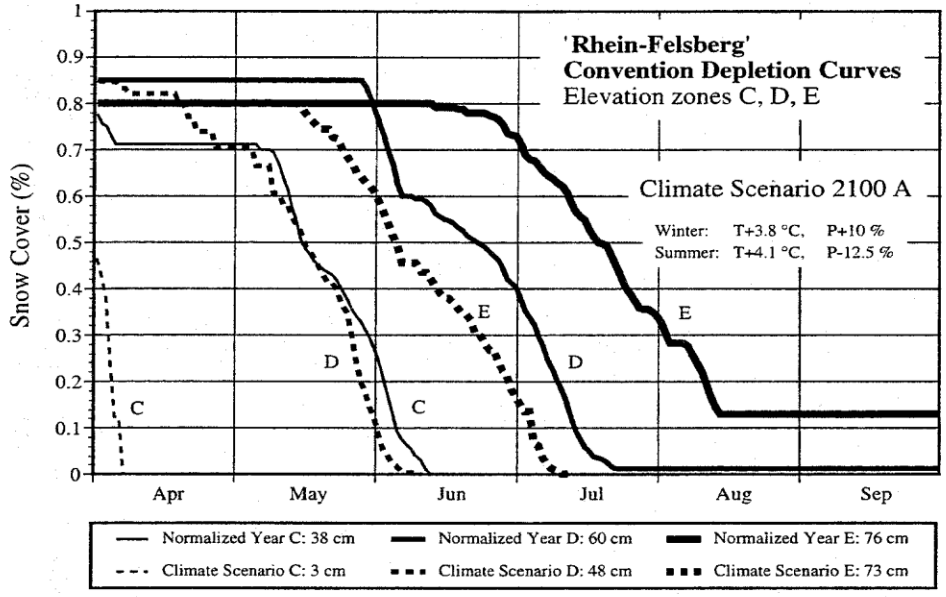

Fig. 4: Conventional depletion curves (elevation zones C, D, E) of the normalized year and climate-effected curves for the climate scenario 2100A

Fig. 4 shows the depletion curves of the snow coverage representing the present climate compared with curves for the climate scenario 2100A. These are derived as follows: from the original curves of the present climate, modified curves are derived which relate the cumulative snowmelt depth to the decrease of the snow coverage. In a warmer climate, computed cumulative snowmelt depths occur at earlier dates. Consequently the depletion curves as input variables for the snowmelt runoff model are shifted in time. The effect of precipitation change is also taken into account by the computer program. As has been explained earlier (Martinec and Rango, 1987) the modified depletion curves indicate the initial areal water equivalent of the snow cover (on 1 April in this year). The decrease of snow reserves after a warmer winter is an additional reason for the time shift of the climate-effected curves.

5. Present and climate-effected runoff

The effect of the scenario 2100A on runoff is shown in Fig. 5. The winter runoff is measured while the summer runoff is considerably decreased. Even the yearly runoff volume is reduced by as much as 13%. The river flows during the snowmelt period (April - July) are particularly diminished. The climate-effected snow conditions have little effect on the magnitude of flood peaks because these events are mainly caused by heavy rainfall. However, the risk of floods is extended by 1 - 2 months (June - October) because some of the present summer snowfalls are converted to rainfalls.

The runoff decrease can be expected because there is less yearly precipitation. However, a runoff decrease was also evaluated for a temperature increase only with unchanged precipitation. Apart from precipitation, the following factors are responsible: 1. In a warmer climate there are more rainfall events with lower runoff coefficients (= more losses) and less snowfall events with a higher runoff coefficients. 2. The model parameters were adjusted to a changed climate. For runoff coefficients, that means extending the low values of mid-summer to additional

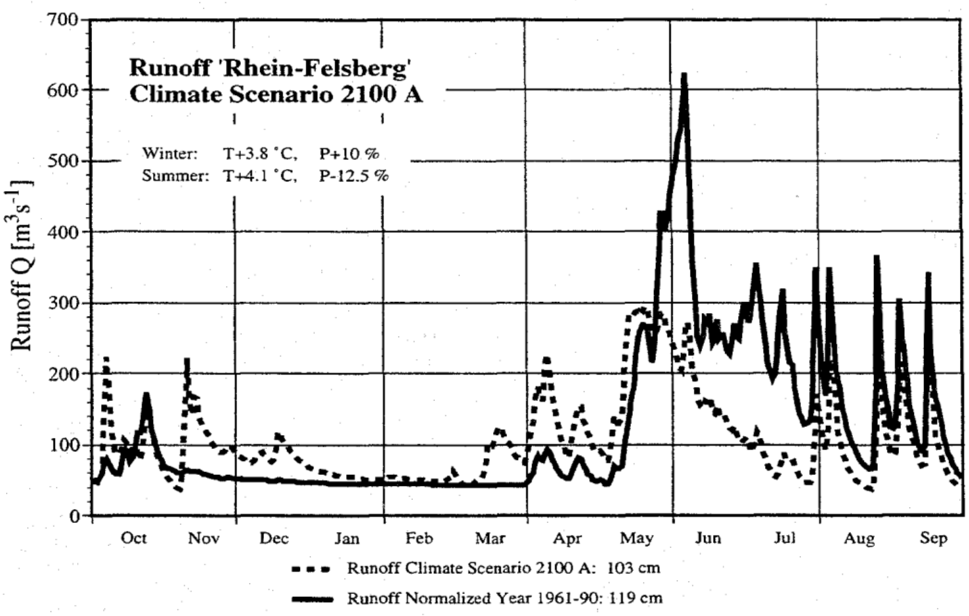

Fig. 5: Runoff computed for the normalized year (representing present climate) and for the climate scenario 2100A

months and increasing the losses. This part of runoff reduction is uncertain. The respective runoff volumes evaluated for all scenarios (Table 2) are indicated in Table 3.

Table 3: Redistribution and changes of runoff for the given climate scenarios

Year	Winter		Summer		Year		Year
	10^6 m^3	%	10^6 m^3	%	10^6 m^3	%	% of present
Present	872	22	3010	78	3882	100	100
2030 C	939	26	2636	74	3572	100	92
A	952	28	2503	72	3455	100	89
2100 C	970	28	2491	72	3461	100	89
A	1236	37	2127	63	3363	100	87

It should be noted that the computed normalized yearly runoff is by 5% higher than the measured long term average. The other runoff volumes in Table 3 are probably affected similarly.

6. Effect of temperature and precipitation on snow accumulation and runoff

Apart from the prescribed climate scenarios listed in Table 2, the combined effect of hypothetical combinations of temperature and precipitation changes were evaluated. Fig. 6 illustrates the changes of the average areal water equivalent of snow on 1 April in the Rhine- Felsberg basin. With temperature unchanged, the water equivalent naturally increases according to the increase of precipitation. With precipitation unchanged, the water equivalent decreases with increasing temperature because more snow is melted during the winter. With various combina-

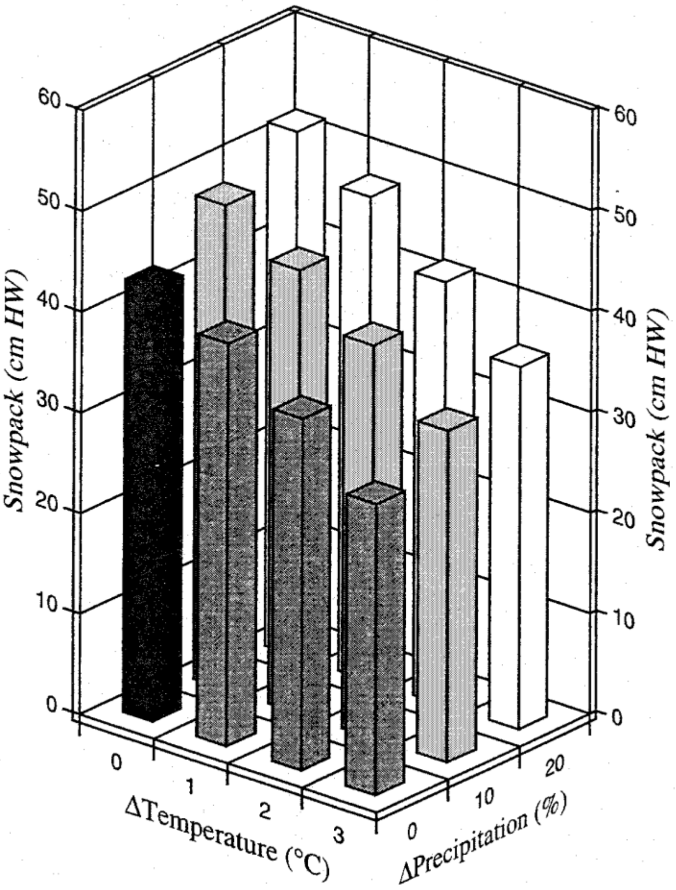

Fig. 6: Snow accumulation in terms of the average water equivalent in the basin Rhine-Felsberg on 1 April for various hypothetical temperatures and precipitations

tions of temperature and precipitation increases, the result depends on which of these contradictory effects prevails. Fig. 6 shows, for example, that a temperature increase of +2°C is nearly compensated by a precipitation increase of 20%. With no changes of temperature and precipitation, Fig. 6 indicates the water equivalent of the snow cover normalized for the present climate.

A similar illustration concerning the yearly runoff depth is shown in Fig. 7. As already mentioned, there are reservations about the decrease of runoff in response to a temperature increase. The assumption that a conversion of snowfall to rainfall by higher temperatures increases the losses (runoff coefficient lower for meltwater then for rain) is acceptable. However, a major part of the runoff decrease in Fig. 7 depends on whether higher temperatures justify low runoff coefficients in additional months which is uncertain (Carlson and Bunce, 1991).

7. Conclusion

The effect of increased temperatures and changed precipitation on the runoff regime in mountainous basins is preferably based on a realistic seasonal snow cover from satellite monitoring

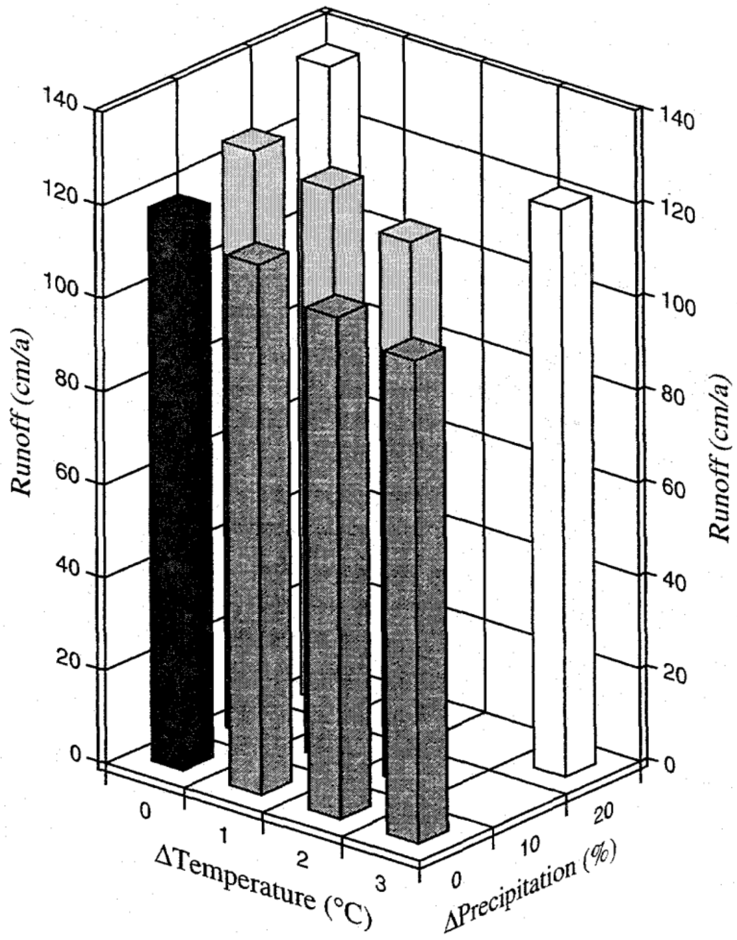

Fig. 7: Yearly runoff depths in the Rhine-Felsberg basin for various hypothetical temperatures and precipitations

rather than on a fictitious snow cover reconstructed from precipitation and temperature data.

Non-calibration models with a determinsitic approach (like SRM) are suitable for these studies because the parameters can be meaningfully adjusted for a new climate.

It is recommended that the representativity of the present snow and runoff conditions are improved by normalizing temperature and precipitation data of selected years with the use of long term monthly averages.

Even with these precautions, quantitative assessments of the climate effect on runoff contain an uncertainty with regard to future losses by evapotranspiration.

An advantage of the presented procedure is also the possibility to evaluate not only the future runoff, but, as an intermediate result, the future snow accumulation and duration of the seasonal snow cover.

8. References

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