Plate 6.5 Water Balance in Selected Medium-Sized Catchments 1961–2007

Introduction

Knowledge of the characteristics of the elements that make up the water cycle (precipitation, runoff, evaporation and changes in the volume of water retained) in medium-sized catchments that are not affected by anthropological factors is extremely important, since their water balance is a direct reflection of the climatic conditions and thus clear indicator of any possible changes in these conditions. Owing to the many man-made modifications of rivers and lakes (hydroelectric power stations, withdrawal for drinking water and other purposes, regulation of the water-level in lakes) there are few catchments in Switzerland whose runoff is not affected by man and where the elements that make up the water balance can be reliably determined. The forerunner of the Hydrology Division of the Federal Office for the Environment (FOEN) started setting up a network of hydrological study areas in 1957. The principal aim was to be able to determine natural changes in the water cycle through long measurement series. In order to ensure that information about the water cycle could be obtained for as many different types of landscape and climate as possible throughout the country, care was taken to include catchments with varying regimes, altitude, etc. in the network of study areas.

Trends in precipitation and runoff

Long-term data and seasonal variation for precipitation and runoff – basic elements governing water-balance – are shown for twelve catchments in various parts of Switzerland. Precipitation for each catchment has been estimated from spatial precipitation analyses carried out by MeteoSchweiz, the Swiss meteorological service. These pan-Swiss analyses have a spatial resolution of around 2 km and are based on data received from some 430 measuring stations. The data are evaluated using a modified version of the SYMAP algorithm [4,6], the relative deviation from the long-term mean and not figures for precipitation itself being used as a basis. This method reduces the systematic error due to the non-representative altitude distribution of the various measuring stations. The precipitation data were applied to a grid and the mean for the catchment was calculated. The resulting figures for precipitation in that catchment do not always correspond to true precipitation, since it was considerably underestimated in a number of catchments that are very exposed. The results obtained are ideal for representing relative precipitation patterns, however.

The diagrams showing the pattern of the 10-year moving mean for precipitation and runoff show firstly the increase or decrease in the mean for the periods from 1961–1970 to 1998–2007 (x axis) and secondly the change in the variability for the same period (standard deviation; y axis). For reasons of clarity, the individual points have been joined up and selected periods have been indicated. Before standard deviation was estimated the time period was detrended in order to eliminate trend-based variability (cf. [2,5]). Finally, in order to make the different catchments more easily comparable, the figures have been standardised in relation to the earliest or reference period (1961–1970). A bootstrap approach [3] was used for calculating the 95 % significance zone (shaded area): firstly, 1000 artificial time series, including detrending, were obtained from the reference period by sampling and replacing, from which the means and standard deviation were again calculated. Subsequently, a two-dimensional Gaussian kernel density estimator was used to calculate the significance zone around these artificial figures.

The diagrams in the lower left-hand side show seasonal variation in the form of the mean Pardé coefficients for precipitation and runoff for three different periods (whole period 1961–2007; early: 1961–1970; late: 1998–2007). With the help of these diagrams we can estimate the effect of a change in the precipitation pattern on the runoff regime.

A comparison of patterns for precipitation and runoff of various catchments reveals marked differences. For example, variability and in particular mean annual runoff in the Massa catchment have considerably increased over the past 40 years or more. In contrast, however, conditions in the Allenbach and the Hinterrhein have remained much more stable. Moreover, whereas there has been little variation in the runoff regime in the Massa catchment between the early and the late period, runoff in the Allenbach in high summer has decreased, although it has risen somewhat in the winter months. Catchments at lower altitudes, such as the Sense or the Sitter, show a different picture again. Here the starting and finishing points in the trend graphs are relatively close, while the regime graphs reveal clearer differences between the early and the late period. More significant changes can be seen here in spring, during the snow melt. On average, precipitation has produced runoff earlier (March) during recent years, which has resulted in a lower mean runoff in April and May. These shifts cannot be explained solely by changes in the precipitation regime, however, since temperature – and thus the snow-line – also plays an important role in catchments at higher altitudes. In a catchment at a higher mean altitude, precipitation will fall in the form of snow in winter even if temperatures are not so low, and when a large part of the catchment is under ice (a glacier), the highest runoff rates are seen in high summer when the glacier is melting. This means that in such a case there is very little variation in the regime. At lower altitudes with milder temperatures precipitation tends to fall more in the form of rain, even in winter, and runoff is immediate. The storage effect of the snow cover is less noticeable and the regime tends to shift.

Finally, the diagrams on the lower right-hand side complete the picture by showing the deviation in the annual means for precipitation and runoff from the long-term means for the entire period 1961–2007.

Characterisation of the catchments

The two maps and the table in the right-hand column on the map page provide some useful information for interpreting the graphs for precipitation and runoff. The top map provides a partial solution to the problem concerning the uncertain absolute precipitation level mentioned above in that the blue part of the columns represents mean runoff while the red part represents mean evaporation (evapotranspiration, modelled mean for the period 1973–1992, see plate 4.1). The overall height of the column therefore represents an estimation of mean precipitation; the catchment is indicated accordingly on the map. Runoff rates have been obtained from Federal Office for the Environment’s measuring network and have been corrected for human influences (withdrawal and return of water) where necessary.

The bottom map is a visualisation of table 1. The parameters have been taken from [1] and are available for all hydrological study areas.

Water-balance models

In order to gain a detailed insight into the water balance of a catchment, hydrological models can be used. The models simulate the relevant components of the water cycle, with a varying degree of detail depending on the complexity of the model (fig. 1), and are normally calibrated to the runoff measured. The example of a hydrological model system used here is the PREVAH (Precipitation-Runoff-EVApotranspiration HRU model) [7], which consists of individual linear water stocks that denote snow dynamics (SSNO), interception (SI), soil humidity dynamics (SSM) and runoff formation (SUZ, $SLZ_{1–3}$) (fig. 2). In the case of areas under ice-cover the glacier module is also available. The storage modules in turn represent the starting point for the runoff modelled, namely snow melt (SM), evapotranspiration (ESM, EI), infiltration (IF) and percolation (PERC), as well as the individual runoff components (R_0, R_1, R_2) and total runoff (R_{TOT}). Hourly readings of precipitation, temperature, air humidity, wind speed, hours of sunshine and global radiation are fed into the model.

Figure 3 shows on the left the monthly pattern of the principal input and output values for the water balance for six selected catchments as means for the years 1984 to 2003.

Precipitation is the primary input factor, providing the system with water. Depending on the lie of the catchment, the long-term mean will show a marked or less obvious seasonal pattern. In winter the accumulation of snow (SSNO) is the main output factor while it represents an input factor from spring to summer, when the snow melts. In the nival to glacial catchments of the Allenbach (nival alpin), the Dischmabach (b-glacio-nival) and Minster (nival de transition) the dynamics of the snow have a considerable influence on the seasonal water balance. The groundwater stocks ($SLZ_{1–3}$) are also subject to seasonal influences; during the months when water is collecting in the aquifer it acts as an output factor, while the rest of the time it feeds water into the system and the level gradually drops. Whereas water retention in the aquifer in Alpine catchments is linked to snow melt (e.g. the Dischmabach), this happens in winter in catchments in the Central Lowlands and the Jura Mountains, when evaporation is low (e.g. Mentue). Evaporation itself is an output factor; it comprises both interception (EI) and ground evaporation (ESM) and shows a clear seasonal pattern in all areas with a maximum rate in the summer. Finally, runoff is principally a function of the input and output processes mentioned above and represents the output element which characterises the hydrological pattern of the catchment as a whole. The model simulates separate values for surface (R_0), intermediate (R_1) and base flow (R_2), which together make up total runoff (R_{TOT}). For reasons of legibility we have not shown the changes in soil humidity (SSM) and the upper runoff storage (SUZ) according to the model. Consequently the figures for input and output in individual months do not correspond exactly. The simulated water balance is accurate over the whole year, however.

Since the PREVAH model is basically intended for zones that react in a hydrologically similar manner (hydrotopes), spatially differentiated analyses of all factors in the model are possible in addition to gaining information about discharge at given points within the catchment. The results concerning total annual runoff obtained using the model are shown in the 2nd and 4th columns in figure 3 with a resolution of 500 m • 500 m chosen for the model. One feature that can clearly be seen in all catchments is the relationship between the altitude of the catchment and total runoff, which is largely due to the increase in precipitation at higher altitudes and is enhanced by the simultaneous drop in actual evaporation. Owing to the considerable differences in altitude, the dependence of runoff on altitude is especially visible in catchments within the Alps and the Alpine foothills (Allenbach, Dischmabach, Minster), while in catchments located in the Central Lowlands (Murg, Mentue, Scheulte) it is less obvious.

References

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