Plate 6.6 Water Balance of River Basins in the 20th Century

Introduction

The water balance of a catchment area is affected by regional climatic factors. Additional influence is exerted by the type of land cover, land-use and various hydro-engineering modifications of the water balance by man. Examples of this are large-scale irrigation systems, water reservoirs or water-level management in lakes. Changes in climatic conditions or land-use are reflected in the water balance: the climatic changes observed since the middle of the 19th century include a rise in temperature which has led to greater melting of glaciers and higher levels of evaporation (evapotranspiration). Precipitation patterns can also change. Changes in land-use such as more intensive farming or increased afforestation also result in increased evaporation. Long measurement series for the elements that make up the water balance thus show on the one hand the water resources available in a catchment and, on the other, how the water balance has possibly changed owing to the influences mentioned above. The simplified water-balance equation, which is valid for a closed catchment with no artificial withdrawal and return of water or subterranean or surface in-flow or out-flow can be expressed as follows:

$$P - R - E - \delta S = 0$$

where P is precipitation, R is runoff, E is evapotranspiration and δS is change in storage (e.g. glaciers, snow-cover, lakes, artificial reservoirs, groundwater). Taken over a longer period changes in the volume of water retained, with the exception of glaciers, can be disregarded. Accordingly, for the present plate, evaporation can be calculated as the remainder of the water-balance equation.

Data and methods

The present plate is an update and extension of plate 6.1, which included data only up to 1980. The period since 1980 is remarkable for a considerable increase in temperature and the corresponding melting of glaciers, however. The new plate provides information about individual water-balance components for larger catchments for the whole of the 20th century. Runoff in the larger river basins examined is based largely on measurements obtained by federal runoff measuring stations (see plate 5.1[2]). Compared with plate 6.1 another new feature is the results of calculations concerning the water balance of two sections of the Aare catchment, namely Berne to Brügg and Brügg to Brugg. The data for the two sections of the Aare catchment Aare–Berne (measurement series from 1917 on) and Aare–Brügg (measurement series from 1904 on) have been partly reconstructed using regression models. Subsequently it was possible to weight the intermediate Aare catchments Berne to Brügg and Brügg to Brugg according to their surface area.

The “old” precipitation data for 1901–1980 shown in plate 6.1 have been adapted to include the “new” precipitation data for 1961–2007 [3] and combined to give a homogenous data series for 1901–2007. Subsequently, the whole measurement series was standardised with the precipitation data from plate 6.3 [7]. This ensures that the results are consistent with the data given in plates 4.1 (evaporation), 2.6 and 2.7 (precipitation). The “new” precipitation data were obtained by high-resolution interpolation (2 km • 2 km grid) of pluviometer station data using the PRISM climate mapping procedure (see plates 2.6 and 2.7, and [1]).

A number of important new scientific papers have been published on determining the volume of glaciers [2,4]. For this reason, for this plate changes in glacier volume (water reserves) in individual catchments have been recalculated for 1901–2007 using a new method, annual volume changes for the Aletsch Glacier being taken as a basis [4]. In order to determine changes in the surface area of the glacier in each catchment during the whole of the 20th century, reference values for 1901, 1930 and 1973 were calculated from the 1973 glacier inventory [5] and for 2007 using the digital Swiss-landscape model “VECTOR25” devised by the Federal Office of Topography. Values between the reference values were obtained by interpolation. The use of data on changes in volume of the Aletsch Glacier for the purposes of determining the annual change in glacier volume in all the larger catchments examined is based on the much simplified assumption that the relative change in volume of the Aletsch Glacier is representative of changes in glacier volume throughout Switzerland.

Data on changes in volume of natural lakes are based on water-level information provided by federal measuring stations. In this connection, only larger lakes that cause a monthly fluctuation of at least 1 mm in the catchment water reserve were taken into account. Monthly data for 1901–1980 on changes in volume of artificial lakes (reservoirs) and withdrawal and return of water [6] were shown in plate 6.1. With the exception of the Spöl withdrawal (Inn/En–Martina catchment) and the return from the Unteralpreuss to Lake Ritom (Ticino–Bellinzona catchment), no measurements were available anymore for volumes of water withdrawn and returned. For this reason, the missing data had to be estimated on the basis of the most recent available figures.

Evaporation was calculated as the remainder of the water balance. The figures for evaporation for the period 1901–1980 shown in the present plate vary slightly from those shown in plate 6.1 because, as already mentioned, different methods of calculation were used for obtaining the data on changes in glacier reserves. Overall, however, the figures for evaporation from larger catchments correspond quite closely to those given in plate 4.1.

Analyses

The map of regional precipitation gives a clear picture of the different climatic zones of Switzerland: the figures for the Tessin are high and the northern slopes of the Alps also receive above-average precipitation. In contrast, the northern Jura mountains and the Central Lowlands, as well as the Engadin (as a dry valley within the Alps) are drier, with precipitation well below average. The map of regional runoff reveals a similar spatial distribution, although it is more pronounced since evaporation is above average in the lower-lying parts of the Central Lowlands. Since evaporation in areas with higher precipitation is determined principally by temperature, the relevance of the altitude of the areas with higher regional evaporation is clear. The long-term changes in water reserves are dominated by the melting of the glaciers; accordingly, the greatest changes can be seen in the Rhone catchment, where the volume of the glaciers is the greatest (see table 1). For Switzerland as a whole, and taking the entire 20th century (fig. 2), almost exactly a third of precipitation is lost through evaporation. Correspondingly, two-thirds leaves Switzerland in the form of runoff via the main river systems. And although the glaciers have lost around 40 % of their volume over the 100-year period, they contribute on average only 1.4 % of this runoff.

It should also be noted in connection with the map of changes in water reserves, figures 2 and 3 and table 1, that figures for 2007 concerning changes in the glaciers in individual catchments as well as for water reserves in the form of ice are extremely uncertain [2]. As far as concerns volume, a variation of ± 12 % must be allowed for, and for temporal changes the level of accuracy is even lower.

It is astonishing to note the continuing level of stability of water-balance components over the long term. A similar pattern can be seen in Switzerland as a whole as well as in the individual catchments (fig. 4): there are marked fluctuations in both individual annual rates of precipitation and consequently individual annual runoff. The precipitation figures for extremely wet years can be as much as double those for extremely dry years and one may follow closely after the other. In addition, wet and dry periods seem to occur in regular intervals of 7 to 12 years. In contrast, with the exception of evaporation, there are few significant long-term trends. Precipitation has risen significantly in northern Switzerland, from the R. Birs to the R. Thur, as well as in the western section of the Aare river basin and, to a slightly lesser extent, in the Valais. There has been a general decrease in precipitation in the Tresa basin, however. Increased evaporation has compensated for this rise in precipitation to such an extent that runoff has hardly been affected.

Special aspects

Figure 5 is linked to plate 6.5 in that the question has been addressed as to whether the investigation of small catchments can provide information about the hydrological characteristics of the larger catchments of which they are part. A comparison of runoff regimes shows that the smallest catchments, located in mountain areas, have nival (Rotenbach) or glacial (Massa) runoff regimes, in contrast to the more balanced regimes of lower-lying areas. A comparison of mean annual runoff clearly shows the high figures for catchments at higher altitudes; in the Rotenbach catchment, which does not have any glaciers, figures have remained relatively constant over the years, while in the Massa catchment with its many glaciers there has been a marked fluctuation in runoff from one year to the next due to the varying contribution from melting ice. The figures for runoff in January and July reveal even more clearly the difference in regimes. It is interesting to note that in the Valais the influence of artificial lakes (reservoirs), which retain meltwaters in the summer and release them only in the winter, has dramatically changed these relative figures since around 1950. This change can be observed even where the R. Rhone flows out of Lake Geneva! There are clear similarities in the precipitation ratios for January and July between the different areas: monthly precipitation within one climatic region is extremely constant.

Figure 6 illustrates the spatial distribution of seasonal precipitation, showing the ratio of precipitation in the summer half-year (April to September) to that in the winter half-year (October to March). The map reveals clear regional differences in the ratio of summer to winter precipitation. The ratios increase from west to east and in particular to the south, i.e. there is considerably more precipitation in the summer in comparison to the winter. Over the entire 20th century there have not been any marked changes in the seasonal precipitation pattern, as shown in the four case studies.

Figure 7 is a summary of the hydrograph analyses referred to in figures 1 and 4. Evaporation in particular has increased in all areas, in some cases by over 20 %. To a lesser extent and not throughout the country, precipitation has also increased, while runoff has remained more or less unchanged.

References

[1] **Daly, C. et al. (2002):** A knowledge-based approach to the statistical mapping of climate. In: Climate Research 22:99–113, Oldendorf/Luhe.

[2] **Farinotti, D. et al. (2009):** An estimate of the glacier ice volume in the Swiss Alps. In: Global and Planetary Change 68 (3):225–231, Amsterdam.

[3] **Frei, C., Schär, C. (1998):** A precipitation climatology of the Alps from high-resolution rain-gauge observations. In: Int. J. Climatol. 18 (8):873–900, Chichester.

[4] **Huss, M. et al. (2008):** Determination of the seasonal mass balance of four Alpine glaciers since 1865. In: J. Geophys. Res., Vol. 113(F01015), Washington.

[5] **Müller, F., Caflisch, T., Müller, G. (1976):** Firn und Eis der Schweizer Alpen – Gletscher-inventar. ETH Zürich, Publ. Nrn. 57 und 57a, Zürich.

[6] **Schädler, B. (1985):** Der Wasserhaushalt der Schweiz. Mitteilung der Landeshydrologie und -geologie, Nr.6, Bern.

[7] **Schädler, B., Weingartner, R. (2002):** Ein detaillierter hydrologischer Blick auf die Wasserressourcen der Schweiz – Niederschlagskartierung im Gebirge als Heraus-forderung. In: Wasser–Energie–Luft 94. Jg., Heft 7/8:189–197, Baden.