Plate 6.4 The Hydrological Significance of the European Alps

Introduction

Mountains and highlands are typically areas that provide considerable quantities of water. The basic reason for this is that higher land causes air to rise and subsequently cool; it then releases the humidity it contains in the form of precipitation (orographic precipitation). In addition, there is less evaporation (cf. plate 4.1) owing to a lower rate of net radiation (cf. plate 4.2), lower temperatures, more frequent snow cover (cf. plate 3.6) and a shorter period of vegetation. In the European Alps, as compared with the surrounding lowlands, these factors result in considerably higher annual discharge (table 2), which is why the Alps are often referred to as the water tower of Europe.

Since the Alps are exposed to the influence of three different seas (the Atlantic, the Mediterranean and the North Sea) and lie in a zone of predominantly westerly winds, the amount of humidity that reaches them is considerable. Another decisive factor contributing towards the importance of the Alps as a water tower for Europe is the fact that they store winter precipitation – temporarily or over a longer period – in the form of snow and ice that melt only in spring and summer, i.e. precisely when the water supply in the lowlands is at a minimum and the agricultural demand for water is high. In the summer months in particular, the lower catchments of the Rhine, the Rhone, the Po and the Danube profit from the highly dependable summer runoff from the Alps, whose variation coefficient is negligible.

The climatic differences between the Alps and the surrounding lowlands are also clearly evident in their respective discharge regimes. The discharge regime for the rivers that rise in the Alpine region is influenced mainly by glaciers and snow (cf. plate 5.2), while the regime in the lowlands to the north is principally dependent on rain (maritime climate); to the south the regime is predominantly Mediterranean with a summer minimum. To the east, the discharge regime is mainly subalpine, i.e. influenced by snow and rain, owing to the proximity of other mountain ranges (the Carpathians, the Dinaric Alps and the Balkans). The classification of discharge regimes used in the present plate (fig. 1) is based on a former study [2] and takes into account the mean seasonal runoff pattern of maxima and minima. Each discharge regime of a tributary is classified according to its discharge characteristics before it flows into the main river.

The definition of the Alpine region as used here is based on a slightly modified version of the criteria applied in a recent report [3]. The primary criterion is altitude. Areas above 1000 m are termed mountains if they also meet other criteria concerning slope and local range of elevation.

Inclusion in the «mountain» category is based on a digital elevation model with a resolution of around 1 km (0.5'). A smoothing algorithm was applied to avoid having small isolated areas of «mountains».

In order to quantify the hydrological influence of the Alps at a greater distance the proportion of discharge originating in the Alpine region was determined every month. Consequently, the figure for the principal rivers when they leave the Alps is 100 %. This proportion is then reduced as tributaries flow into the main river further downstream; the proportion may increase, however, if other rivers that rise in the Alps join the main river. This applies in particular to the Rhone, the Po and the Danube. The latter is a special case in that it does not rise in the Alpine region. For this reason, its proportion of Alpine discharge can never be 100 % (see below).

Since the hydrological data were obtained from a variety of archives (cf. table 1) and therefore cover different periods it was not possible to select a common period of reference. Long-term series from between 1961 and 1990 were used wherever possible, however.

The River Rhine

In the case of the Rhine, the distinction between the Alpine section and the lower reaches is most marked from a geographical and a hydrological point of view: together, the Alpine stretch of the Rhine (Diepoldsau) and the River Aare are responsible for the Alpine proportion of discharge, which is enhanced by the subalpine River Thur. The Alpine-type discharge regime of the High Rhine at Rheinfelden is gradually modified by tributaries in the Upper and Middle Rhine, which, with the exception of the River Main, show a more maritime regime. Finally, in its lowest reaches (Rees) the Rhine discharge regime shows little seasonal fluctuation, although there is a slight winter maximum and autumn minimum.

It is in the summer months (June to September) that the Alps play a clearly supportive role with regard to overall discharge. The mean Alpine proportion of discharge at Rees in June is thus 52 %, despite the fact that the Alps represent only 15 % of the total catchment of the Rhine. The specific discharge pattern of the Rhine also illustrates the increased supply of water from the Alps during the summer half-year (May to October); it is only downstream from Mainz that winter-specific discharge begins to exceed summer-specific discharge, indicating that the maritime influence gradually becomes predominant. In the case of the Rhine, the seasonal character of the hydrological significance of the Alps can be illustrated by comparing mean monthly discharge at Rheinfelden and Rees (fig. 4): the correlation between the two discharge values for the whole year is relatively weak, but is much stronger if one considers the winter half-year and the summer half-year separately. Thanks to the closer correlation of the summer figures and the similar gradient of the regression lines for summer and annual values, it becomes clear that the Alps exert a long-distance influence in particular in the summer half-year.

As a comparison of a model-based water balance at various points along the Rhine valley shows (fig. 3), greater discharge originates in the Alps.

The River Rhone

Like the Rhine, the Rhone has a clearly Alpine discharge regime with a summer maximum when it leaves Switzerland (Geneva). In this connection, the Alpine River Arve, which rises in the Savoie and flows into the Rhone in Geneva, plays a decisive role by accentuating the Alpine discharge regime that is attenuated by Lake Geneva. Further downstream, tributaries with a subalpine (Fier), a maritime (Ain, Saône) and a Mediterranean character (Ardèche, Durance) modify the discharge regime. Owing to their proximity to almost the whole length of the Rhone, the Alps continually influence runoff, in particular through another tributary, the Isère. While the regime of the Rhone downstream from the confluence of the Saône shows a clear minimum in summer or autumn, the proportion of Alpine discharge is at its highest during the summer, thus presumably preventing the river from drying up. As far as concerns specific discharge, the pattern is again similar to that of the Rhine, being marked by the large volume of water supplied by the Alps in summer. Winter-specific discharge is low in the upper reaches owing to the reduced runoff during the accumulation of snow and ice. While in the case of the Rhine the transition from a predominantly summer to a predominantly winter discharge is gradual over more or less the whole length of the river, for the Rhone the confluence of the Saône is a clear point at which this transition can be observed.

The River Po

The discharge of the River Po is characterised by a combination of influences: the Alps, the Appenines and the Mediterranean climate, which is more marked towards the south. The clearly Alpine regime of the Po (Crissolo) gradually becomes a Mediterranean regime with typical spring and autumn maxima. Important tributaries from the Alpine region (Dora Baltea, Ticino, Adda, Oglio and Mincio) continue to provide large volumes of water during the summer months, however, without which the late-summer minimum of the Po would be greater and the discharge regime less balanced. This becomes even more evident in the pattern of specific discharge. The figure illustrates the fact that the direct influence of the Alps in summer decreases relatively quickly. The large volumes of water flowing down in the Alpine tributaries are extremely important for the lowlands, however, and once again underline the importance of the Alps as a water tower.

The River Danube

The long-term mean discharge of the Danube in its upper reaches (Ingolstadt) is typical of the balanced discharge regime of a river that rises in lower mountains, showing no marked minima or maxima. In this section of the river the influence of the Alps comes into play solely through Alpine tributaries (Iller, Lech and Isar). Subalpine tributaries (Naab, Regen) have only a minor influence. The Danube takes on an Alpine character only downstream from the confluence of the River Inn (Passau-Ilzstadt), which gives the Danube a marked summer maximum discharge. The River Drava is a further Alpine tributary; otherwise the Danube’s maximum discharge tends to shift from summer to spring through subalpine confluents. The proportion of Alpine discharge is at its highest in late summer when the volume of water brought in by the subalpine tributaries decreases and snow and ice have not yet begun to accumulate in the Alps.

The significance of the Alps and other mountain ranges

A comparison between the proportion of discharge that can be expected on the basis of catchment size and the actual discharge measured demonstrates the marked hydrological significance of the Alps (table 3).

With a mean contribution of 34 % of the total discharge, the Alpine regions of the Rhine river system supply 2.3 times more water than might be expected on the basis of surface area alone (disproportional influence). In the summer months of July and August this proportion is considerably higher for all four river systems, ranging from 36 % (Danube) to 80 % (Po).

The hydrological significance of the Alps as documented in this plate also applies to other mountain ranges. This role of mountains as water towers is particularly marked in arid and semi-arid areas, where over 90 % of total discharge may be provided by mountain ranges [4].

References

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[3] **Kapos, V. et al. (2000):** Developing a map of the world's mountain forests. In: Price, M.F., Butt, N. (Eds.): Forests in Sustainable Mountain Development: a State of Knowledge Report for 2000. IUFRO research series 5:4–9, Wallingford.

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Tab. 2 **Mean annual water balance 1961–1990**

	Canton of Uri	Switzerland	Europe
Precipitation [mm]	2088	1458	780
Evapotranspiration [mm]	382	469	510
Change in stored water [mm]	-5	-2	0
Discharge [mm]	1711	991	270

(cf. plate 6.3 and [1])

Tab. 3 **Contribution of the Alps to total discharge**

River	Mean contribution of Alps to total discharge [%]	Proportion of total Alpine region [%]	Disproportional influence of the Alpine region
Rhine	34	15	2.3
Rhone	41	23	1.8
Po	53	35	1.5
Danube	26	10	2.6