# Plate 5.9 Attenuation of Flood Peaks in Rivers

## Introduction

Floods are impressive natural events. The fact that our century-long battle against this natural hazard has not yet been won can be seen from the large-scale inundations which often occur when there are serious floods (fig. 3). Over the past 200 years many rivers have been banked and straightened. Areas which used to be flooded regularly are now protected and have been developed into valuable residential and industrial zones. Every major flood raises the question, however, as to the extent to which flooding has been aggravated by the elimination of these floodplains. Large-scale flooding is so impressive that it is believed to have an important attenuating effect on floods. The volume of water which remains on inundated land, however, should always be seen in proportion to the volume of runoff during a flood. This volume, which as a product of runoff and time cannot be directly appreciated, is normally underestimated. When the River Aare in Berne flooded in May 1999 the runoff volume over 14 days was around 600 million $m^3$ [1]. Such an amount of water would cover the whole of the canton of Zug (240 $km^2$) to a depth of 2.5 m. In order to reduce the maximum runoff in Berne in May 1999, for example, from 620 $m^3$/s to 400 $m^3$/s it would have been necessary to retain around 106 million $m^3$ of water between Thun and Berne. This would have meant flooding an area of 40 $km^2$ to a depth of 2.5 m. Since in such a flood zone the water generally flows slowly downstream, the actual area needed to achieve the above mentioned reduction in runoff would in fact have been even greater.

It is not easy to estimate the effect of retention on flood discharge. Retention is influenced by flow processes within the channel and from the floodplain (hydraulics) as well as by the way the flood develops and thus by its origins (hydrology) (fig. 1). This plate includes examples which show the various possible effects of retention; an overview indicates in which rivers substantial attenuation of floods can be expected.

A distinction is made between the effects of retention within the channel, flowing retention on the floodplain and standing retention on the floodplain.

## Retention within the channel

In steep channels, water flows so fast that no attenuation occurs. On the contrary, after a sufficient distance the flowing water may even build up into a vertical flood wave which can have disastrous consequences for people caught in its path.

In contrast, in less steep channels flood waves flatten out even if there is no flooding. The drop in peak runoff is influenced by the characteristics of the channel and the form of the flood wave [2,3]. An effect of retention can be perceived where the gradient of the river-bed is less than 1 % (fig. 8). Retention will be increased in a rough channel (fig. 9). The most important factor influencing attenuation, however, is the time it takes for a flood to reach its peak (fig. 10). The faster the runoff increases, the more the runoff peak will be attenuated in the channel. If the flood exceeds a certain duration retention effects cease altogether.

Therefore retention in the channel is of importance only if the gradient of the river-bed is under 1 % and has an effect only on floods of short duration with high peak runoff rates. The first map shows the gradients of the rivers; it is noticeable that streams and rivers in the Alps and the Alpine foothills develop very little retention effect.

## Standing and flowing retention

Inundation of the floodplains of a river attenuates floods more efficiently than retention within the channel. Standing retention occurs when water from the channel inundates the floodplain and is trapped in natural hollows or man-made basins as well as for example behind road embankments, and is thus separated from the body of the flood (fig. 3) [6]. An important factor is the timing of the inundation. If it occurs at the beginning of the flood owing to a small channel capacity, the natural or man-made retention basins will be full before the flood reaches its peak, and there will be little attenuation of flood peaks.

The most decisive factor influencing retention, however, is the ratio between the capacity of the retention basin and the volume of the flood. If the volume of flood water which could inundate the floodplain is much greater than the retention volume, no retention effect can be expected.

A much more common occurrence, which is less effective however, is flowing retention. In this case the water is not retained on the floodplain but slowly flows downstream. The floodplain does not act as a retention basin but as an extension of the channel (fig. 2). With this kind of retention the difference in flow velocity in the main channel and on the floodplain is the main factor responsible for attenuating flood peaks [2,3]. Owing to shallowness and increased friction, the water flows more slowly on the floodplain than in the main channel. The entire flood wave is considerably attenuated if the velocity of the water on the floodplain is so reduced that the runoff peaks from the floodplain and from the main channel do not overlap (fig. 11). The degree of attenuation is therefore determined by the difference in flow velocity in the main channel and on the floodplain, the duration of the flood and the length of the section of river.

If there is only a slight difference in the flow velocity, either the section of river must be long or the duration of the flood must be short in order for the flood hydrograph to show a significant change. For example, over a distance of 10 km and with a difference in flow velocity of 1 m/s, a flood will be attenuated only if it lasts less than 3 hours.

## Hydrology

Plate 5.7 uses six catchments to illustrate that each catchment has its own flood reaction characteristics. Owing to specific hydraulic conditions, only floods that develop rapidly may be affected by retention. Short, rapidly developing floods occur in areas where the soil has a low storage capacity, such as in the Allenbach catchment (Adelboden). Such conditions are found mainly in the Alps and the Alpine foothills. In these areas, however, the gradient of the river-beds is generally steeper than 1 %, with the result that retention cannot have much effect. In flatter areas where the gradient of the river-beds is less than 1 % the soil generally has a higher storage capacity. This means that floods develop gradually which are consequently not influenced by retention. These arguments show that retention occurs only in the case of certain floods and in certain types of catchments, such as the Langeten [4]. The upper reaches of the Langeten are steep so that rapidly developing floods are often observed; the lower course of the river is flat and has broad floodplains. Major floods which are attenuated by retention thus often occur in this catchment. In the Luthern catchment too certain flood events are attenuated. There are other floods, however, which remain virtually unaffected. Although the lower reaches of the Dünnern are very flat there is no attenuation of flood peaks through retention since the floods build up very slowly (fig. 4).

The second map highlights those catchments where major floods are attenuated by the gradient and the flood discharge pattern. The map was drawn up by determining the development time of major floods from water-level measurements or, in the case of rivers where the level is not measured, by estimating it from hydrological characteristics.

## A case study: the River Thur

The lower reaches of the River Thur have been canalised and have extensive floodplains which are inundated when the water rises above a certain level. Extensive hydraulic calculations have shown how floods of varying duration and volume are attenuated in the stretch between Halden and Andelfingen (fig. 5). In the case of floods which develop over a period of more than 10 hours, no attenuating effect can be expected from the channel itself or the inundation of the floodplains. The development times and peak levels of the major floods which have occurred over the past 35 years, however, considerably exceeded this period during which attenuation effects can develop. It can therefore be concluded that major floods are not affected by retention in this section of the river.

## A case study: the River Gürbe

In the case of the River Gürbe, retention can develop a considerable effect. On 29 July 1990, 240 mm of rainfall was measured over a period of a few hours in the upper part of the catchment. The rapidly rising flood had dire consequences in the upper reaches of the river. The Gürbe enters the plain above the Burgistein water-gauge and from here to the point where it flows into the River Aare below Belp the gradient is small. This section is therefore ideal for retention. During the flooding in 1990 the river inundated the plain in various places [5]. Tree-trunks which had been brought down were jammed against a bridge in Toffen, which led to additional flooding. The diagram in figure 6 shows the effect of this flooding on runoff in Belp. Inflow at Burgistein is shown and was used for calculating discharge at Belp, involving a numerical model. It was assumed that there was some attenuation due solely to retention in the channel itself on the one hand and additional attenuation through the inundation of the floodplain on the other. These hydrographs are compared with the actual discharge measured in Belp, which was further reduced by the blocking of the bridge in Toffen. While the flood in the upper reaches of the Gürbe was quite extreme, in Belp the population was hardly aware of anything unusual, owing to the attenuation of the flood level through retention. Retention in the channel itself accounted for a reduction in discharge of 5 $m^3/s$. The fact that around 160 000 $m^3$ of water inundated the floodplain in various places led to a further reduction of 34 $m^3/s$. The blockage at the bridge in Toffen diverted an additional 290 000 $m^3$ of water, although the peak discharge rate was reduced by only 12 $m^3/s$, since this occurred long before the flood reached its peak, i.e. at a less favourable time.

## Conclusions

Overall the plate shows that major flooding is effectively attenuated through natural retention in only a surprisingly small number of catchments. In most rivers the duration of floods is so long that, owing to hydraulic conditions, the effect of retention becomes negligible before the flood reaches its peak.

## References


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