The contribution of hydropower reservoirs to flood control in the Austrian Alps

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ABSTRACT A considerable improvement to flood control is a significant - and free - additional utility accruing to the general public from the construction of hydropower storage reservoirs. By way of illustration, the author presents a comparative study on the basis of a number of flood events in valleys influenced by storage power plants.

INTRODUCTION

Austria has approximately thirty major storage reservoirs built by hydropower companies and operated on a seasonal basis. Since they tend to be located at high altitudes, total stored energy from a combined active storage of 1.300 hm$^3$ is over 3.500 GWh for winter and peak power generation, and this forms the backbone of electricity generation in Austria. Taking into account also the smaller reservoirs for daily and weekly storage, approximately 31% of the country's present annual total hydroelectric generation of 34,000 GWh is controlled by reservoir storage, with the high degree of control and flexibility this offers.

The primary goal in the construction of all storage power schemes in Austria, and the only source of subsequent earnings for the hydropower companies, is of course electricity generation, but such schemes also involve a whole series of additional utilities that accrue to the general public free of charge. As a rule, significant improvements in flood control are the most important of these spin-offs, although benefits to the local infrastructure and tourism as well as a markable increase of flow during the winter period are not to be underestimated, either.

SOME BASIC CONSIDERATIONS AND STATISTICAL DATA

The fact that the retention capacity of a reservoir is a significant flood-risk reducing factor for downstream areas is obvious enough and is appreciated by the people who directly benefit there, but this function has not yet been given due recognition by a wider public in their frequently unfavourable judgment on further hydropower development schemes. At any station along a river downstream of a dam, the degree of improvement in flood control is determined by two parameters:

a) the ratio between the storage volume available for retention at the time of a flood and that part of the flood which contributes to peak outflow, and

b) the percentage of total catchment area which is controlled by the reservoir (decrease in flood control capacity with increa-
Criticism is frequently made of the apparently contradictory strategies of providing either for a full energy reservoir or for empty flood storage. Theoretical studies and long-term operating records, however, show that for conditions common with seasonal storage reservoirs in the Austrian Alps, firstly, even a relatively small retention volume can drastically reduce a flood, and secondly, such a retention volume will in all probability be available at the time of extreme floods.

Available retention volume is determined by the volume between actual and retention water level, plus an additional flood surcharge above the latter, i.e. above the crest of the usual free overflow spillway. This flood surcharge volume would also be available in the case of flood discharge into a full reservoir, but that is an extremely unlikely event given the normal filling cycles of Austria's seasonal storage reservoirs. Extreme flood events, and especially the biggest occurring in July and August, in all probability do not coincide with maximum storage in the reservoirs, whose filling, as a rule, is not completed until September or October, so that only heavy rains in September can still pose a hazard to a certain extent. In any case, statistics show that maximum reservoir level is only reached once every five years on average, and that this condition is maintained for only a few days so as to avoid seepage losses (Lauffer 1975).

Given the considerable size of Austria's seasonal storage reservoirs relative to the runoff from their catchment areas, even an available retention capacity of only a few percent of reservoir capacity is sufficient to effectively reduce peak discharge. For example, with only 5% of its active storage capacity of 138 hm³ left, i.e. only 2.80 m below retention level, the Gepatsch reservoir (fig. 4) could completely impound a more than 100-year flood with peak inflow of 232 m³ s⁻¹. An analysis of data taken from decades of operating experience with over thirty Austrian reservoirs (Widmann 1974 and 1988, Ganahl & Widmann 1980) leads to the prediction that the spillways of reservoirs with an active storage equal to at least 40% (60%) of annual inflow will be activated only by floods with return periods of more than 10 (25) years. No side valley in Austria that is controlled by a seasonal storage reservoir upstream has ever suffered flood damage since the construction of the reservoir, and peak flows in the main valleys have been significantly reduced since then as well.

The following two sections give a number of specific examples of the flood protection function of reservoirs in Austria.

FLOOD CONTROL EXPERIENCE IN THE VICINITY OF STORAGE POWER PLANTS

In the Kaprun Valley (fig. 1) the Wasserfallboden and Mooserboden seasonal reservoirs, with total active storage of 168 hm³, control 57% of the catchment area at the Kaprun gauge. The construction of the power plants has artificially increased floods with short return periods because the 36 m³ s⁻¹ design discharge of the Kaprun power house in itself corresponds to a natural two-year flood, while the increase in discharge capacity of the Kapruner Ache to 70 m³ s⁻¹, achieved by some river bed regulation, permits plant operation to continue unrestricted even under minor flood discharge conditions. On the other hand, there has been a significant decrease in major flood events,
and the peak discharge of a natural ten-year flood (before construction) corresponds to a 75-year flood under present operating conditions, while the peak discharge of a natural fifty-year flood (before construction) corresponds now to a 2,500-year flood, which means that the Kaprun area now has practically total flood protection (Ganahl & Widmann 1980, Widmann 1988).

In the second example (fig.2), extremely heavy precipitation centred on the Malta Valley led to extremely high runoff, which - as subsequent calculations showed - would have reached the level of a hundred-year flood at Gmünd and would have led to greater damage throughout the valley than that caused by the catastrophic 1965 September flood or the 1966 August flood. Through the appropriate use of the hydropower plant facilities, however, i.e. pumping at the upper stage and turbining into the Möll river at the main stage, plus utilization of available retention capacity in the Samerboden-Kölnbrein seasonal storage reservoir and the Galgenbichl and Gösskar compensation basins, it was possible to reduce peak discharge at the Sandriesen gauge near Gmünd, upstream of the confluence with the Lieser, from a theoretical figure without the Malta hydropower plant of 300 m$^3$ s$^{-1}$ (i.e. a hundred-year flood, as derived from subsequent calculations) by no less than 45% to a recorded figure of 165 m$^3$ s$^{-1}$, i.e. the equivalent of only a fifty-year flood prior to the construction of the scheme (Kugi & Weissel 1986).
Prior to construction of the seasonal storage schemes in the Ziller Valley (fig.3), adjoining fields and meadows used to be flooded every two to three years, and major flood events would inundate the local communities with up to a metre of water, as on 21 August 1956, when
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peak discharge reached 750 m$^3$ s$^{-1}$. With today's hydropower plants (fig. 3a), this figure could have been reduced to 426 m$^3$ s$^{-1}$ (Gmeinhart 1988).

Since first filling of the seasonal storage reservoir at Durlas-boden (1966), Schlegeis (1971) and Zillergründl (1987), and also of the weekly storage reservoirs at Gmünd (rebuilt in 1964) and Stillup (1969), inundation from the Ziller has been greatly reduced or altogether prevented.

Peak discharge of the major flood events of the last 15 years has been reduced by 25-40% compared with the theoretical figures calculated for the same flood conditions without storage reservoirs. Peak discharge for the 300-year flood on 25 August 1987, for example, would have been 852 m$^3$ s$^{-1}$ and the damage correspondingly great - instead of the recorded figure of only 507 m$^3$ s$^{-1}$, which involved only some isolated overflow (fig. 3b).

These data relate to the Ziller gauge at Hart near Fügen, with a 1095 km$^2$ catchment area which is 12% directly controlled by seasonal storage and 12% indirectly controlled via diversions, while the hydropower plants influence a total of 53% catchment. Not only was power generation discontinued pursuant to regulations at a predetermined high-water mark on the Hart gauge (340 cm, fig. 3b), but also standby procedures within the Austrian and south German grids permitted power to be made available to pump water from diversions back into the Schlegeis and Zillergründl reservoirs. As a result, water retention during this flood totalled 14 million m$^3$ (Gmeinhart 1988).

Also on 25 August 1987, the Ötztal Valley was heavily damaged by floodwater, while the Stubai Valley suffered its worst damage on 19 July 1987. On these two days the Kauner Valley (fig. 4), which is located only 10-12 miles to the west of the Ötztal Valley and also runs parallel to it, suffered no damage at all - thanks to the effects of the Gepatsch reservoir. The gauge at Platz near Feichten, with a 189 km$^2$ catchment area which is 54% directly controlled by the Gepatsch reservoir and 25% indirectly via diversions, recorded peak discharge of only 5 m$^3$ s$^{-1}$ on both days, which is a normal figure for summer discharge. Without the reservoir, peak discharge would have been 62 and 50 m$^3$ s$^{-1}$ respectively for 19 July and 25 August 1987 (fig. 6), figures that correspond to a more than hundred-year flood and would certainly have been higher than peak discharge for the 1960 flood, whose devastating effects have not yet been forgotten by the people of the Kauner Valley. At all events, the result would have been flooding across the full width of the valley in the flatter sections where most people live. In fact, however, the Pazna river has not once burst its banks during any flood event since the opening of the Kauner Valley hydropower plant in 1964 (Tschada & Moschen 1988).

The Montafon in Vorarlberg similarly enjoys almost total flood protection from the hydropower plants built by the Illwerke company. For the Gaschurn gauge, for example, with a 145 km$^2$ catchment area which is 44% controlled by reservoirs, the theoretical greatest flood discharge peaks calculated without storage reservoirs for the last 33 years have been reduced by 26 - 82%.

In addition, a marked reduction of flood flows has been observed also downstream of mere water intakes. Depending on their design capacity, this effect relates above all to minor and medium floods. Thus, the diversion from the upper Pitz Valley to the Gepatsch reservoir reduced the peak discharge at the gauge in St. Leonhard during the 1965 flood from 54 to 36 m$^3$ s$^{-1}$ (fig.4), with the result that the Pitz Valley
- unlike neighbouring valleys without hydropower structures - suffered no flooding at all (Lauffer 1975). On 19 July 1987 the same diversion reduced peak discharge from 67 to 54 m$^3$ s$^{-1}$ (fig.5), thereby reducing an approximately eighty-year flood to the magnitude of a thirty-year event.

Even short-term storage reservoirs, in spite of their limited active storage relative to flood discharge, can significantly reduce discharge peaks. A case in point is the Klaus reservoir on the Steyr...
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river, which is normally kept at maximum storage level so as to ensure maximum head for the run-off-river power plant. However, when the transmitted figures for precipitation in the 539 km² catchment area exceed a given threshold, a flood forecast is calculated and continuously updated with the help of the flow figures transmitted from the feeder waterways, and if necessary generating is stepped up to achieve deliberate drawdown and thus create a flexible retention capacity of up to 7.8 million m³. This permitted the two floods experienced since the plant opened in 1975 to be reduced by 30 and 42% respectively (Widmann 1988).

In general, bed load management and the related effects of hydropower plant construction is a highly complex subject. In this context, suffice it to say that decades of continuous monitoring of the desilting chambers of numerous water intakes has made the biggest contribution to date to our knowledge of bed load yield, and that the torrent control measures financed in whole or in part by power companies as part of all hydropower generating projects in mountain locations in Austria do not merely prevent any exacerbation of bed load problems but in most cases represent a clear improvement (Lauffer 1975, Sommer 1980, Tschada 1975).

REMOTE RESERVOIR EFFECTS ON FLOOD DISCHARGE IN THE MAIN RIVER

In the Alpine region there are many examples showing how seasonal storage reservoirs located on the side streams have a beneficial effect on winter runoff in the main river, which in turn benefits its biology and purity and improves the operating efficiency of run-of-river power plant.

The 5794.3 km² catchment area of the River Inn at the Innsbruck gauge, for example, is influenced by three seasonal storage reservoirs, whose total active storage of 362 hm³ accounts for approximately 32% of natural winter runoff volume. 68 km further downstream, the 9313.3 km² catchment area at the Kirchbichl gauge is influenced by eight reservoirs, whose total active storage of 717 hm³ again accounts for about 31% of natural winter runoff volume. Hence, the resulting increase in flow in winter is almost one third, and over half in the coldest months, while the 10% average retention in summer is hardly even noticed (Moschen & Lauffer 1977).

Such significant changes to natural flow patterns and the fact that more than 10% of total catchment is directly controlled by seasonal storage reservoirs for both gauging stations, would lead one to expect significant reductions in flood discharge too, and this aspect was therefore analysed in an actual case at the Innsbruck gauge (fig. 7).

Of the two 1987 flood events discussed in the previous section, it was the flood on 19 July that led to highest peak discharge in the Inn. Backanalysis of the retention effect of the hydropower reservoirs and the natural peak discharge in the Inn that would have occurred without them must carefully take due account of the timing of peak discharges from the side valleys and their superimposition in the Inn, because such factors as overflow and the activation of retention capacities are influenced by relatively slight changes in flow and water level. Careful calibration of the mathematical flow model on the basis of numerous gauge records is therefore essential. An analysis of the flood on 19 July 1987, conducted with such care and precision, showed that peak discharge at the Innsbruck gauge decreased from 1250 to 1130 m³s⁻¹, with 70
m³s⁻¹ of this reduction deriving from the Gepatsch reservoir alone. During this flood, a total of 13,4 m³ was retained in the reservoirs of Livigno (Switzerland/Italy), Gepatsch, Finstertal and Längental or diverted to the reservoirs of the Vorarlberger Illwerke company. Consequently, a 2oo-year flood was reduced to the magnitude of a natural forty-year flood (without storage reservoirs), and the Innsbruck city precincts were saved from partial flooding (fig. 7). It was sufficient to restrict generating for just the few critical hours of peak discharge (Tschada & Moschen 1988).

On the basis of these encouraging results, the decision was taken to institutionalise contacts which had hitherto been ad hoc and sometimes improvised - but successful for all that - between the meteorological and hydrographic services, civil defence organizations, waterway authorities and power companies, in the form of a fully coordinated flood management system with the backing of mathematical flow models and forecasts.

**CONCLUSION**

Storage hydropower plants not only meet 23% of Austria's electric power generation requirements but also make a major contribution to flood control. The considerable significance of this protective function today is the result of developments that go back over a number of decades. And it has been achieved without imposing direct charges on either the beneficiaries or public funds. To that extent it is a low-profile function, and that explains the regrettable inability of the general public to recognize its importance. The time has therefore come to focus more attention on the flood control function of hydropower plants in public discussions of both existing installations and new projects so as to attain a greater degree of objectivity.

**REFERENCES**