FLOODS IN AUSTRIA

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Abstract- This paper examines an extreme flood at a tributary of the Danube. This is then put into the context of flood processes in medium sized and small catchments in all of Austria. The paper concludes with two applications of the flood process analyses in Austria.

Keywords: flood processes; extreme events; storms

1. Introduction

Floods in Austria are a major issue both economically and politically. There has been a continuing research interest in the hydrology of floods, both in small catchments (Gutknecht, 1984) as well as along the Danube and other large rivers in Austria (Kresser, 1957). To illustrate flood processes in Austria, this paper first examines an extreme flood at a tributary of the Danube. This is then put into the context of flood processes in medium sized and small catchments in all of Austria. The paper concludes with two applications of the flood process analyses in Austria.

2. Analysis of the August 2002 Flood of the Kamp

The flood in August 2002 has been an extreme one in northern Austria, the Czech Republic and parts of Germany. On August 6, a low pressure system moved over Austria which caused heavy precipitation. Radar images indicate that the precipitation fields moved quickly in most of

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Austria but in the Kamp region, in the north of Austria, they remained stationary for more than a day. There were two main rainfall bursts in the evening of August 6 and on August 7 for which a total of more than 250 mm point rainfall was recorded. The Kamp river had average discharges prior to the event. On August 6 at 20h the Kamp started to rise and at 2h on the next day water levels were 2 m above average at Zwettl. Water levels peaked on August 7 at midnight. Water levels were 4m above average. The water level at Stiefern, down stream of Zwettl, started to rise 4hrs later than those at the Zwettl gauge. Peak flows at Zwettl and Stiefern were 460 m³/s and 800 m³/s respectively. The catchment areas for these two gauges are 622 km² and 1493 km² respectively. A second event occurred only a few days later during August 12 and 13. Precipitation and peak discharges at the Kamp where somewhat lower than during the first event but major flooding occurred at the Danube.

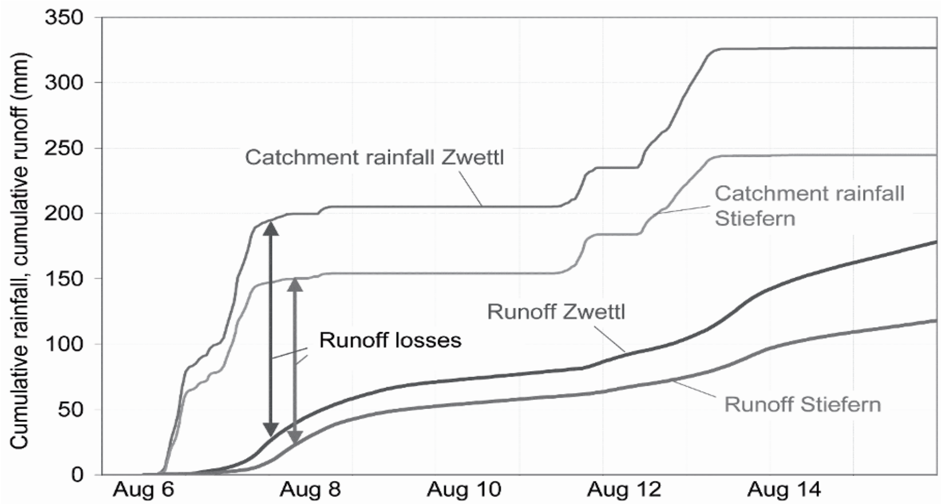

Figure 1. Cumulative catchment rainfall and cumulative runoff depth for two catchments of the Kamp (Zwettl, 622 km²; Stiefern, 1493 km²)

It is interesting to examine the rainfall depths and runoff depths of the event in the Kamp (Figure 1). The catchment rainfall depth of the two events were 200 mm and 130 mm respectively in the Zwettl catchment, i.e. a total of 330 mm of rainfall. This is enormous given that the mean annual precipitation of the area is 700 mm. The total runoff depth was more than 200 mm vis a vis a mean annual runoff depth of 300 mm in the catchment. Figure 1 indicates that during the first event the catchment has stored more than 150 mm of rainfall of which 120 mm of rainfall infiltrated into the groundwater and did not contribute to event runoff. About 60% of the precipitation became runoff during the second event, i.e., a runoff coefficient of 0.6. For smaller floods in the catchment, typically, the runoff coefficient is only 0.3 or less. As rainfall persists, the soils saturate up and contributing areas form which are not activated during smaller floods. This is a threshold process that has very important practical implications. In some climates, such as in the Kamp region, the threshold may occur at rainfall depths that are rarely observed. It is therefore difficult to extrapolate from medium sized events to extreme events such as the 2002 flood at the Kamp. Extrapolation is important, though, for a range of purposes including design flood estimation. In fact, at a reservoir in the region the spillway discharge was close to design capacity during the 2002 flood.

To provide context for the extreme event in the Kamp catchment, extreme precipitation data starting from 1896 were compiled. Most maximum annual values are around 40mm/day. The second largest rainfall in the period 1896 to 2002 occurred in 1903 (92 mm/day). In contrast, the maximum daily precipitation of the 2002 event was 158 mm, i.e., it was 70% larger than the second largest daily rainfall on record. A comparison of rainfall of various durations indicates that for durations of a few hours, the rainfall intensity of the 2002 event was not particularly extreme. However, for a duration of 48 hours the rainfall of the 2002 event was far larger than any of the observed values. On August 12, 1959 a rainstorm with much higher intensities but much shorter duration and smaller space scale occurred in the region. The flood produced by the 1959 storm was large (140 m^3/s for the Kamp at Zwettl) but this was only one third of the peak discharge of the 2002 event. Figure 2 shows the maximum annual flood peaks observed in the Kamp catchment from 1895 to 2002. The second largest event (160 m^3/s) occurred in 1911. This means that the peak discharge of the 2002 event was three times that of the second largest flood in the past 100 years. It is difficult to assess the return period of such an extraordinary flood. A flood frequency analysis with the data in Figure 2 suggests that the 100 year flood is on the order of 200 m^3/s. A peak flow of 460 m^3/s would be associated with return periods in excess of 1000 years. Applying the probability concept to outliers, however, is not necessarily consistent with the unique nature of such events. The local archives report on extreme historic floods in the area. On March 4, 1655 a similar water level occurred in the city of Zwettl. However, the flooding was due to ice jams, and the associated discharges were likely smaller than those during to 2002 flood.

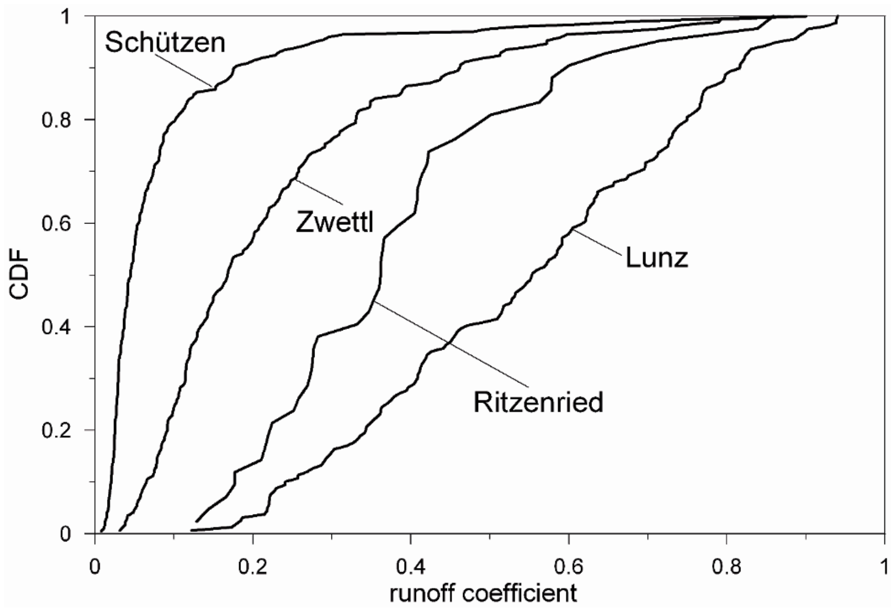

Figure 2. Maximum annual flood peaks observed in the Kamp catchment, Austria (Zwettl, 622km² catchment area). Redrawn from Gutknecht et al. (2002)

3. Flood Processes and Flood Risk

The Kamp example has been an extreme event in the north of Austria. It is now of interest to contrast this extreme event to other flood events in Austria. To this end, about 500 gauged catchments in Austria were examined (Merz et al., 2005). Flood events were isolated from the continuous records and for each event the event precipitation was estimated from a total of 1100 raingauges in Austria. The event runoff coefficient for each flood event and each catchment was then calculated as the ratio of event runoff to event rainfall. From this, the distribution function of runoff coefficients was derived to illustrate the range of runoff coefficients that can be expected in the various climatic regions of Austria. Figure 3 shows the distributions of the runoff coefficients for four example catchments.

The Pitze catchment is a high alpine catchment with mean annual precipitation of more than 1000 mm/year. The runoff is controlled by snow processes during most of the year. The runoff coefficients are nearly uniformly distributed with a median of 0.36. The Ois at Lunz am See catchment is a forested catchment at the northern rim of the Alps with rainfall that is both high and persistent with mean annual precipitation of more than 1600 mm/year. Figure 3 indicates that the runoff coefficients are the largest of the catchments examined here. The distribution is approximately uniform with a median of 0.55. The Kamp at Zwettl catchment is located in a dryer region in the north of Austria where mean annual precipitation is about 700 mm/year. The catchment is mainly forested and the direct runoff depths are much smaller than in the Lunz catchment. The distribution of the runoff coefficient is right skewed with a median of 0.17. The skewness implies that large runoff coefficients are rare but do occur occasionally. The Wulka at Schützen am Gebirge catchment is the driest catchment of this set and is located in the east of Austria close to the Hungarian border. Most of the catchment is flat. Land use is mainly agriculture and mean annual precipitation is less than 600 mm/year. It exhibits the smallest direct runoff depths of the four catchments. Most of the runoff coefficients are less than 0.1 and the median is 0.04. It is clear that the runoff coefficients of the four catchments differ vastly. The wettest catchment has the largest runoff coefficients while the driest catchment has the smallest runoff coefficients but the distribution is highly skewed. This indicates that in this hydrological regime, extreme floods can be much bigger than average floods. This is clearly illustrated by the August 2002 event at the Kamp.

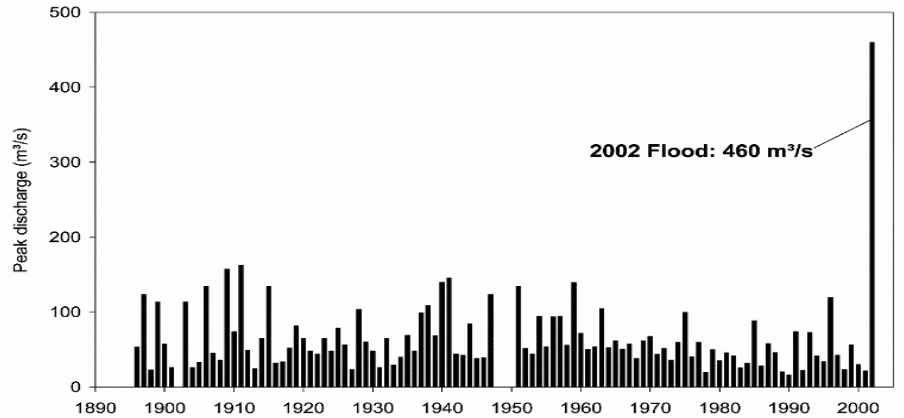

Figure 3. Distribution function of the event runoff coefficients of four catchments in Austria: Ritzenried / Pitze (220 km²); Lunz am See / Ois (117 km²); Zwettl / Kamp (622 km²); Schützen am Gebirge / Wulka (384 km²). Redrawn from Merz et al. (2005)

The runoff coefficient as related to antecedent soil moisture is one of the important flood process characteristics. To gain more insight into the causes of flooding in Austrian catchments the flood events were classified into one of five flood process types - long-rain floods; short-rain floods; flash floods; rain-on-snow floods; and snow-melt floods (Merz and Blöschl, 2003). The classification was performed manually based on maps of process indicators for each event. The process indicators included antecedent soil moisture, snow water equivalent, snow melt, the spatial extent of the flooding and rainfall duration. The analysis indicated that 35% of the events were long-rain floods, 26% short-rain floods, 13% flash floods, 19% rain-on-snow floods and only 7% snow-melt floods. It is interesting that the frequency of the process types changed with the magnitude of the event. In the case of the short-rain type, 12.5% of the peaks of this type were larger than the 10 year flood in each catchment. In contrast, for the rain-on-snow type, only 3.3% were larger than the 10 year flood and for the snow-melt type only 1.4% were larger than the 10 year flood. This means that large floods are quite frequently caused by short-rain events, large floods are rarely caused by rain-on-snow events and they are almost never caused by snow-melt events. These differences would be expected because of the limited energy available for melt water release.

In Figure 4 all flood peaks have been plotted against the day of occurrence within the year, stratified by the process type. Long-rain floods occur throughout the year but there is a tendency for more events and more extreme events to occur in summer, particularly in June and July. This is because heavy rainfall events occur more frequently in the summer months than in the rest of the year. Short-rain floods also mainly occur in the summer and there is a tendency for some of the major events to also occur in autumn. These are events that have occurred in southern Austria. Flash-floods only occur in summer when enough energy is available for convective storms. Rain-on-snow floods occur throughout the year with the exception of late summer and early autumn. The largest rain-on-snow floods occur in late December. Similarly, snow-melt floods occur throughout the year with the exception of late summer and autumn when all of the catchments are snow free. There are pronounced spatial patterns in the frequency of flood type occurrence (Merz and Blöschl, 2003). For example, rain-on-snow floods most commonly occur in northern Austria.

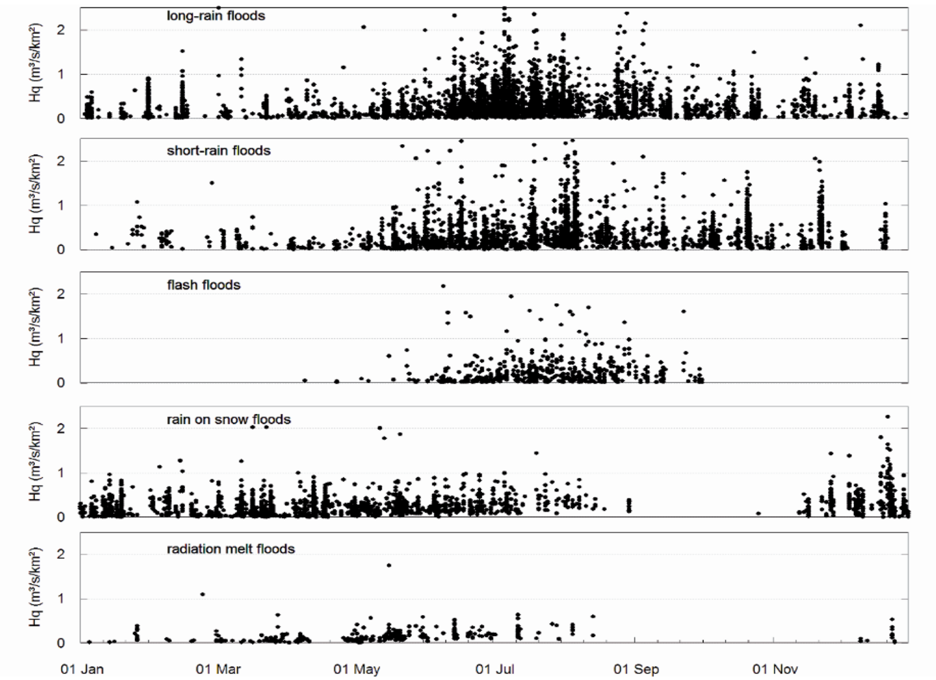

Figure 4. Specific flood peaks of maximum annual floods plotted versus the date of occurrence within the year, stratified by process type. From Merz and Blöschl (2003)

It is also of interest to calculate the distribution of runoff coefficients stratified by the flood process type. There are very large differences between the flood types. The smallest runoff coefficients are associated with flash floods with a median of 0.15. The second smallest runoff coefficients are associated with short-rain floods with a median of 0.36. These are events that mainly occur in the south of Austria as a result of short storms that have significant spatial extent. Slightly larger runoff coefficients (median of 0.38) are produced by long-rain floods which result from synoptic or frontal type storms that often cover an area up to several thousands of square kilometres and can last over a few days. In these types of events, much of the catchment seems to wet up, so saturation excess overland flow may be an important runoff generation mechanism. Rain-on-snow events are associated with still larger runoff coefficients with a median of 0.48. This type of floods often occurs in the winter and it is apparently the increase of antecedent soil moisture due to snowmelt and rain falling on wet soils that causes the large runoff coefficients. The largest runoff coefficients are associated with snowmelt floods with a median of 0.63. Snowmelt usually wets up the catchment over a period of days or weeks which tends to enhance runoff coefficients. The differences between the flood types are also apparent in the extremes. Snowmelt floods almost never have small runoff coefficients and flash floods are almost never associated with large runoff coefficients.

4. Example Applications

The process analyses presented in this paper are currently used in a number of flood related applications in Austria. Two of them, probabilistic flood estimation and flood forecasting, will be briefly discussed here. In the flood estimation application, the 30, 100, and 200 yr floods are estimated for 26000 km of Austrian streams. The goal is to map the hazard zones in a project known as HORA. The strategy is to start with flood frequency statistics for gauged catchments. In small catchments, often, the records are short and there are outliers of the kind of the Kamp as illustrated above. The process analysis shown here assists in fitting the flood frequency curve to the sample. The focus is not on statistical goodness of fit criteria but on an understanding of the flood hydrology of the particular catchment. For example, if the runoff coefficients are small and increase with flood magnitude it is likely that the flood frequency curve bends up, i.e. has a large skew. In contrast, if snow is the main control, the flood frequency curve tends to be flatter because of the limited energy available for snow melt. The process analyses are also used for regionalising the T-year floods to ungauged catchments along with a geostatistical approach and manual judgement. The results are compared with the assessment of local authorities. Derived flood frequency, where flood statistics are derived from rainfall statistics can also be used to assist in the interpretation of flood probabilities (Sivapalan et al., 2005).

In the forecasting application, a real time flood warning system is implemented for the Kamp catchment. Again, the process information assists in the development and parameterisation of the hydrological model (Reszler et al., 2005). A spatially distributed conceptual water balance model based on a 1 x 1 km^2 grid is used for a total catchment size of 1550 km^2. The response time of the catchments and sub-catchments ranges from 1 to 4 hours so a time step of 15 minutes was chosen. The model has 20 parameters that need to be specified for each grid cell. To reduce the number of parameters to be specified 8 zones of uniform model parameters were identified for each subcatchment. This procedure was guided (in decreasing importance) by the understanding of runoff processes from field surveys, geologic maps, soil maps and sensitivity analyses. It is important to note that these zones differ from traditional hydrologic response units in that in assigning each pixel to one of the eight zones the relative role of runoff processes was carefully assessed by expert judgement. One of the zones, for example, is a groundwater recharge area which was identified by analysing the dynamics of piezometric heads in the area. Runoff routing in the catchments and in the streams is represented by non-linear transfer functions. In the latter case, the transfer function is calibrated to the results of a detailed hydraulic model to represent the flood plain effects on the hydrograph for very large flows. Another particularity of the Kamp catchment is that half the catchment drains into a reservoir. Future reservoir operation was therefore represented by a simulation routine that captures typical operation strategies of the plant operators. Developments of the forecasting system in progress include ensemble forecasts and a real time updating procedure based on ensemble Kalman filtering.

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