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RECONSTRUCTION AND ANALYSIS OF 19TH CENTURY FLOODS IN SW GERMANY

P Dostal[1], K Buerger[2], F Imbery[1], and J Seidel[3]
1. Meteorological Institute, Albert-Ludwigs-University, Freiburg, Germany
2. Department of Physical Geography, Albert-Ludwigs-University, Freiburg, Germany
3. Department of Hydrology and Geohydrology, University Stuttgart, Germany

ABSTRACT: The analysis of historical flood disasters as well as their regional consequences within long-term climate variability provide a useful understanding of past, present and future relationships between climate and extreme floods (Bardossy *et al.*, 2005). Therefore, historical floods receive greater interest in flood management and in applied flood protection (Benito *et al.*, 2005). The integration of extreme historical floods in contemporary flood protection contributes towards improved risk management and safer handling of floods in the future.

In the context of the “Xfloods” project at the University of Freiburg (Germany), the discharges of the extreme floods in 1824 and 1882 in the Neckar River Basin (Baden-Württemberg/southwest Germany) were reconstructed using historical data. Quantitative and qualitative historical sources were applied to model the regional atmospheric circulation pattern, the weather conditions and the precipitation distribution associated with the event. Based on the reconstructed area precipitation the discharges were simulated using the water-balance model LARSIM. The developed methodology shows potential for wider use in assessing extreme historical floods and for application to contemporary flood management.

Key Words: historical flood events; atmospheric circulation pattern; area precipitation; flood discharge

1. INTRODUCTION

Climate variability, floods and their impacts in Central Europe have received increasing attention in Central Europe in recent years (IPCC, 2007). In particular, the Elbe flood in 2002 showed that changes in the frequency and characteristics of floods may reflect climatic transitions. This led to an initiative by the German Federal Ministry of Education and Research (BMBF) for a ”Risk Management of Extreme Flood Events“ to avoid or limit the adverse impact of floods in Germany (Merz *et al.*, 2005). The research group Xfloods is part of this initiative with a special focus on past extreme floods in the Federal State of Baden-Württemberg, Southwest Germany (Bürger *et al.*, 2006). The research project integrates the information of historical data to identify and quantify extreme flood events of the past 500 years as a basis for flood risk management as well as for the calculation of maximum area precipitation.

The data from historical records such as local annuals and chronicles from 1500-1900, supplemented by instrumental observations available since the middle of the 18th century, were extracted to simulate the regional atmospheric circulation pattern and the area precipitation for the floods in 1824 and 1882 of the

Neckar catchment. Afterwards the discharges of these events were calculated by a rainfall-runoff simulation with the water-balance model LARSIM (Large Area Runoff Simulation Model), the operational flood forecasting model in Baden-Württemberg (Ludwig *et al.* 2007).

The project can contribute to a safer handling of extreme floods in the future. This applies in particular to the analysis and modelling of millenarian flood events, which have been little considered previously. In such a way, the knowledge of the past can be integrated in the flood protection for tomorrow.

2. METHOD, DATA AND STUDY SIDE

2.1 Methodological concept and data overview

First step in analysing extreme hydrometeorological events is to detect them. Important is to know, at what time the extreme flood occurred, regarding the longest possible time scale. Concerning extreme floods this will be done for example with flood marks. Flood marks show several extreme events on a long time scale. This kind of detection was made in the case of the Neckar flood in October 1824, which was the highest flood during the last 300 years induced solely by heavy precipitation. Second step is to proof the meteorological circumstances which led to such an extreme flood event. The main information about the weather situations in 1824 and 1882 was derived from documentary sources. Third step is to quantify the amount of the area precipitation which induced the extreme runoff like in the case of October 1824. This was done by consulting historical meteorological and hydrological data from the regarded river catchment and from whole Europe, to reconstruct the flood triggering weather situation. Fourth step is to interpolate the spatial rainfall on the basis of recent reference data. The last step is to integrate the modelled precipitation into the water-balance model LARSIM to calculate the discharges that occurred due to the extreme spatial rainfall.

For the reconstruction of the historical heavy precipitation events of 1824 and 1882 a model with various regression tools and geostatistical methods was developed. An overview of the used data and the different steps of processing the rainfall patterns and discharges of the Neckar is given in figure 1. Sources such as chronicles, official records, newspapers and weather descriptions, as well as meteorological and hydrological observations, were gathered from more than 100 archives and libraries in Baden-Württemberg. The descriptive data contain qualitative and quantitative information. In particular, observations of the flood and weather situation were of great value. The qualitative data allow to assess the overall process of developing weather patterns and the course of the flood event. To calculate the area precipitation, sets of historical meteorological data, like precipitation (N), sea level pressure (SLP), wind speed (u) and wind direction (d) were used. With a European wide dataset of historical meteorological data (Barriendos *et al.*, 2003) synoptic weather charts were developed for October 1824 and December 1882. With the synoptic weather charts it is possible to find similar weather situations in the reference dataset (Bardossy *et al.*, 2003). The weather charts help to understand the superior weather situation for hydrometeorological extreme events and improves the results of the Kriging calculation for the spatial rainfall (Hinterding *et al.*, 2001; Isaaks *et al.*, 1989). In addition there is a need of reference data to calculate the spatial precipitation. The reference data are measured data from 1900 - 2006 provided from the German Meteorological Service (DWD). As a reference basis the whole meteorological data set of South Germany was used with a total of more than 1000 meteorological stations.

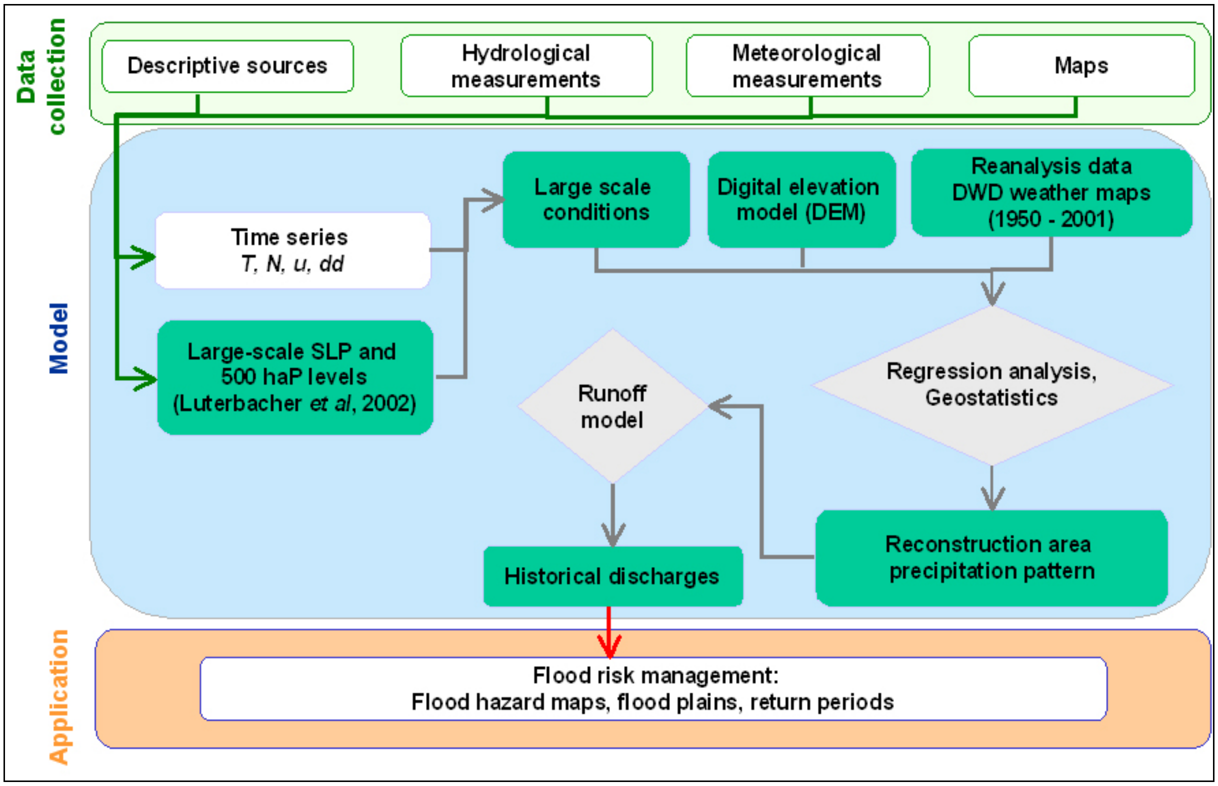

Figure 1: Flowchart of processings for the reconstruction of the 1824 and 1882 flood events in the Neckar catchment (T=temperature, N=precipitation, u= wind speed, dd=wind direction, SLP= sea level pressure)

2.2 Study site

The Neckar River Basin (area 14 000 km^2) is located in the southwest part of Germany and is a tributary of the Upper Rhine (figure 2). The elevation in the Neckar catchment ranges from 1020 m a.s.l. in the Black Forest to 78 m a.s.l. at Mannheim; the mean value is 435 m a.s.l. The precipitation in the region is strongly modified by the local orography. The highest mean annual precipitation values of 2000 mm are recorded in the mountain ranges of the northern Black Forest. Towards the eastern part of the study site, the mean annual precipitation decreases to values of approximately 800–1000 mm (Röckel, 1995). The Neckar is the principal tributary of the Upper Rhine, rises in the eastern Black Forest and is 367 km long. It is the river with the largest catchment in the Federal State of Baden-Württemberg, southwest Germany. The Neckar is navigable from Plochingen at the inflow of the Fils (km 202.5) to Mannheim (at the river mouth) and beside the rivers Rhine and Main, it is one of the three main waterways in Baden-Württemberg. Several industrial centres are situated in the Neckar Basin around Stuttgart and Mannheim. These areas, therefore, constitute a high flood damage-potential.

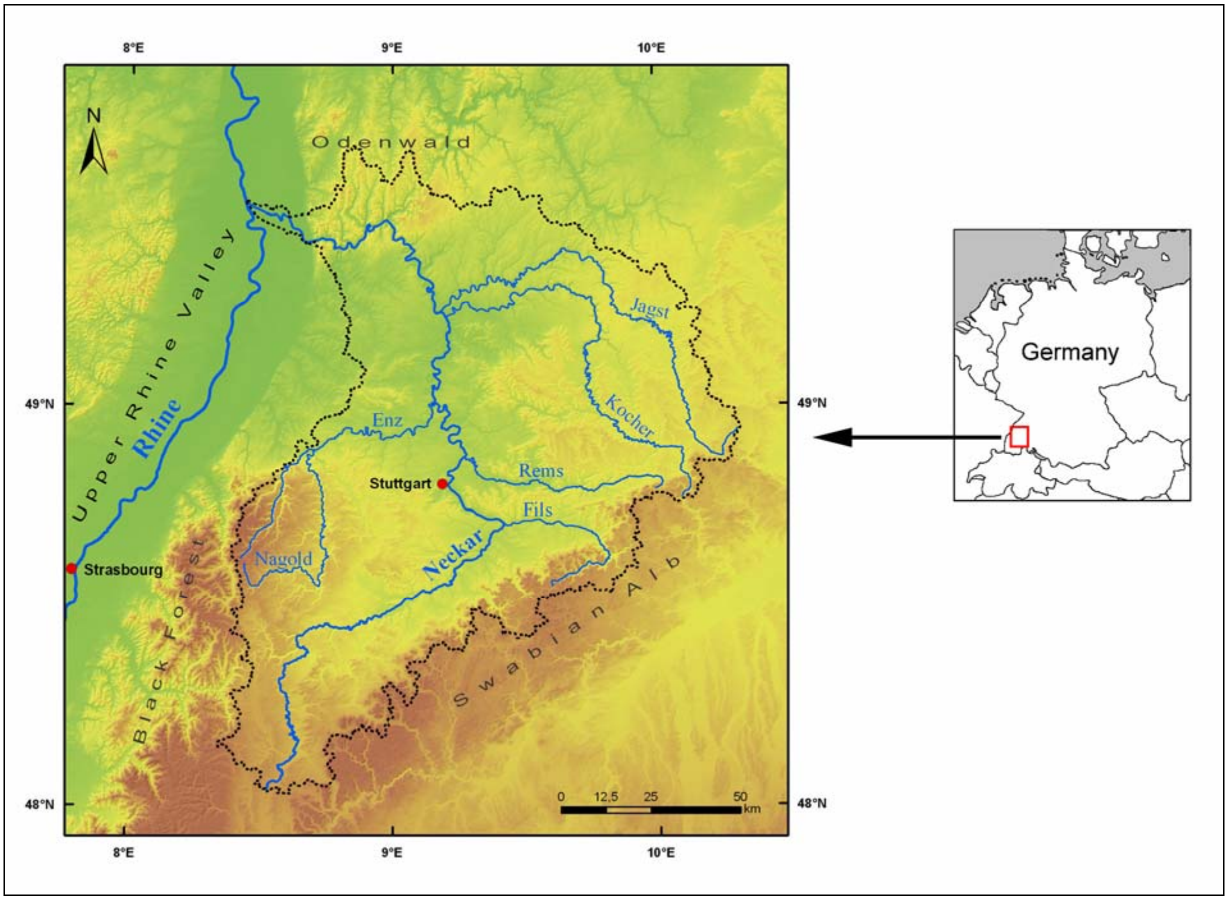

Figure 2: Overview map of the study area

3. SIMULATION OF AREA PRECIPITATION

For a detailed reconstruction and visualization of the local rainfall for the historic flood events, the weather conditions by the end of October 1824 and December 1882 were compared qualitatively with all major weather conditions of the years 1934 to 2006. Based on the monthly weather reports from the German Meteorological Service and a heavy rainfall analysis for southwest Germany, the period 26-28. October 1998 was determined as analog weather course for the event in October 1824. As analog weather course for the precipitation event 25.-27. December 1882 the period of 29.-31. January 1983 were identified. The precipitation has been interpolated using historical measurement series and the spatial distribution of rainfall during the recent weather courses. Using regression models, the historical data in the examination periods were linked with measured data from 220 rainfall stations of the German Meteorological Service. Thus, the spatial distribution of the historical precipitation events of 1824 and 1882 for southwest Germany could be simulated on a daily basis with a resolution of a 1 km grid (figure 3).

From the modelled 36-h precipitation pattern of the 1824 flood event for the Neckar catchment and its neighbouring areas it may be seen that the highest precipitation – with values up to 230 mm in 36 h – occurred in the western crest of the northern parts of the Black Forest. The lowest precipitation was determined for the area in the Upper Neckar Valley. This pattern corresponds very well to the descriptive information and the historical water levels from historical sources. The upper areas of the Neckar catchment were not so severely affected by the flood in 1824 as the areas in the Black Forest and in the northern and eastern part of the Neckar catchment.

Concerning the 1882 flood event, the highest precipitation amounts occurred in Black Forest and in the eastern and northern parts of the Neckar catchment. The daily precipitation amounts for December 25 range from 30 mm in the eastern parts of the Neckar catchment up to 50 mm in the Black forest. Most of this precipitation was still snowfall. December 26 marks the transition from snowfall to rainfall. During this day the precipitation amounts sum up to 60 mm in the Black Forest. December 27 shows a similar precipitation pattern with local maxima in the Black Forest (60mm) and the north-eastern parts of the Neckar catchment (40mm). The total precipitation from December 25 to 27 1882 summed up to 180 mm in the Black Forest. During these three days, the central parts of the Neckar catchment received relatively small precipitation since this area is situated on the leeward side of the Black Forest and thus in the precipitation shadow during westerly circulation patterns. The combination of snow melt and the heavy precipitation led to this extreme flood at the end of December 1882.

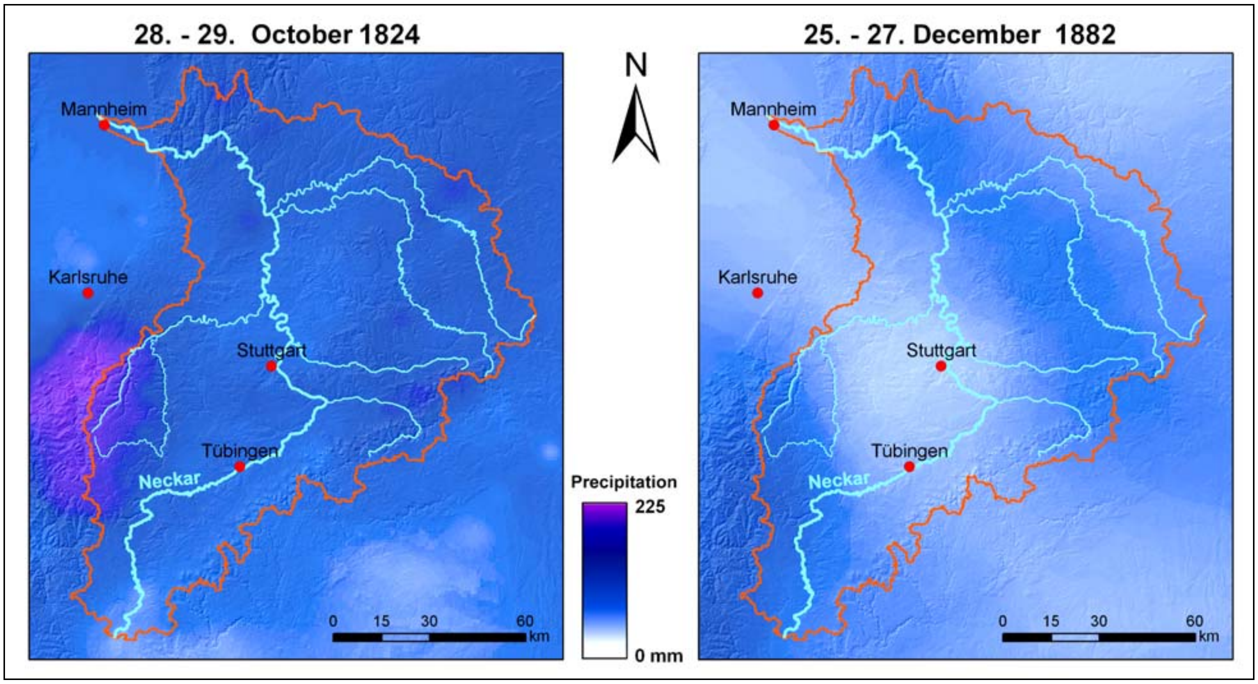

Figure 3: Totalized area precipitation for 29.-30. October 1824 and 25.-27. December 1882

4. RUNOFF SIMULATION

The reconstructed area precipitation were integrated in the water-balance model LARSIM to simulate the discharges. The LARSIM model is also based on a 1-km grid and incorporates different meteorological parameters (e.g. air temperature, precipitation, air pressure, wind direction, wind velocity). Some hydrometeorological parameters such as air humidity and evapotranspiration were not considered because of their minor influence on discharges during such extreme events.

The runoff simulation for the Neckar during the flood events of 1824 and 1882 are compared in figure 4 with the values for a 100-year flood (HQ_{100}) and an extreme flood ($HQ_{extreme}$). The discharge values of 1824 in the Lower Neckar exceed clearly the values for HQ_{100} and $HQ_{extreme}$. A flood event with the dimension of 1824 would have devastating consequences for the riparian owners. Particularly for industries settled in the flood plains, e.g. Stuttgart, a flood event of 1824 would have enormous damages and costs. The flood of 1882 is comparable with a 100-year flood.

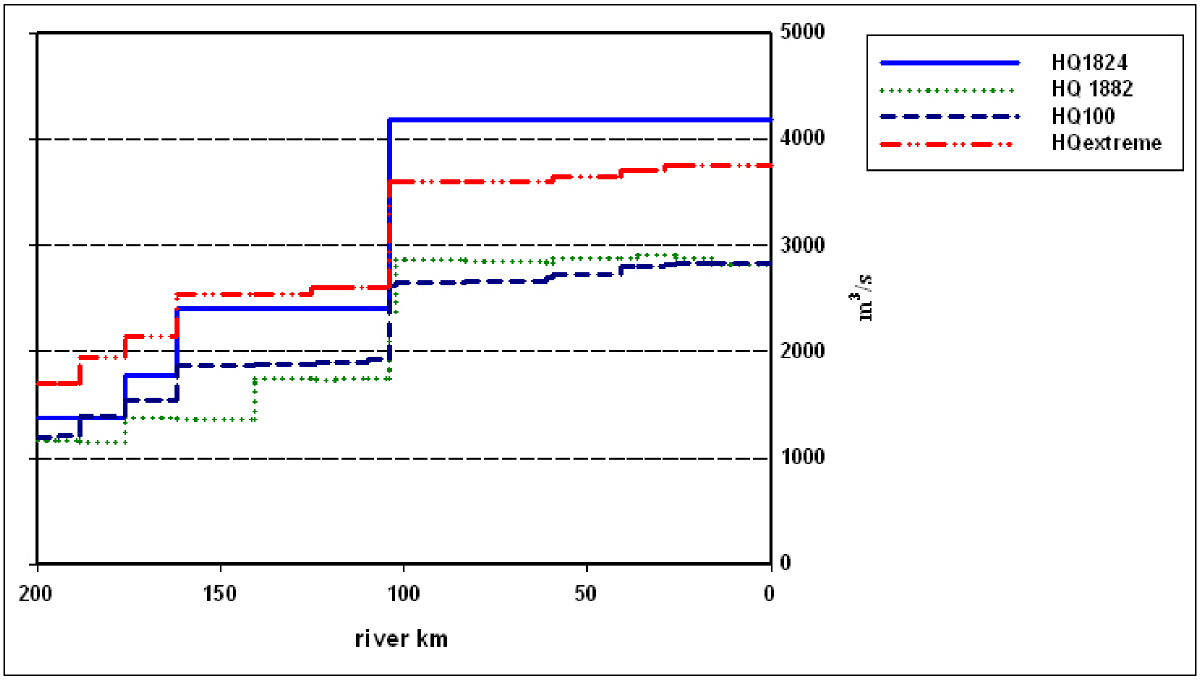

Figure 4: Discharges for the Neckar during the floods of 1824 and 1882 and the values for HQ_{100} and $HQ_{extreme}$ (LFU, 2000; LFU, 2005)

The discharge simulation provides an indication of the effects which such extreme flood events as witnessed in October 1824 and December 1882 would have on the contemporary Neckar catchment nowadays.

5. DISCUSSION

The analyzed historical floods with their cyclonic west situation (Wz) are caused by a weather condition, which is considered as major condition triggering heavy precipitation in the last 500 years for southwest Germany (Jacobeit *et al.,* 2003). Their occurrence is to expect more frequently in the future as a result of the increase from westerly wind streams in consequence of the regional climate change (KLIWA, 2005; IPPC, 2007).

The results show that the design base for a $HQ_{extreme}$ in the Lower Neckar has been severely underestimated and the runoff values has already been surpassed in the last 200 years. As presented, it is possible to reconstruct the area precipitation of extreme historical events and to use the data for runoff and rainfall models to calculate discharges. The results can be used as a basis for the calculation and modeling of extreme design floods and for the preparation of flood hazard maps. The flood of 1882 has a frequency of occurrence of 100 years and can thus be involved in the calculation of 100-year floods. The results of this study prove how the reconstruction of historical flood events can contribute to an improvement in flood prevention. The historical discharge values can be integrated in the calculation of return times and will therefore reduce existing uncertainties.

6. CONCLUSION

These results show the potential of historical flood analysis for flood-risk management. Better understanding of extreme flood events and better protection of endangered areas, goods and humans are the tangible outcomes. The importance of analysing historical floods is that it can be used to demonstrate the consequences of such extreme events in a selected river catchment, such as the Neckar. This knowledge can be incorporated into flood-risk management. By combining the historical precipitation and flood data with contemporary river channel morphology, current hazards and impacts can be predicted. This will lead to a better understanding of flood processes, as well as their characteristics. Improvements in the analysis of historical extreme events should be extended to other river catchments in order to mitigate the consequences of catastrophes such as the Elbe flood in 2002.

7. ACKNOWLEDGEMENT

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