Historical floods: changes in floods since the 13th Century

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3. Historical floods: changes in floods since the 13th Century

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3.1. Introduction

Historical hydrology is based on data derived from historical written, pictorial and epigraphic documentary evidence (e.g. BRÁZDIL et al. 2006a, PFISTER et al. 2006). It is situated at the interface between hydrology and environmental history, using methodologies from both disciplines (BRÁZDIL et al. 2006b, 2012; BENITO et al. 2015) to significantly extend the measurement period (WETTER 2017) with flood experience from the pre-measurement past, especially within the period of human activity in the landscape affecting rivers. Quantitative hydrological, meteorological and climatological information is paramount for the analysis of possible changes in the magnitude and frequency of floods. Such information can support not only flood hazard assessment, but also enables the identification of interconnections between flood frequency and severity with climate, land use and river morphology (MACDONALD and BLACK 2010; BENITO et al. 2015). For example, the EXAR project attempted to acquire data on analogues to the 10^3 to 10^7 years flood in the catchment area of the Aare River. Such extreme events cannot be adequately assessed by using standard statistical methods as the extrapolation from short reference series causes high level of uncertainties. In this section, we present how the inclusion of documentary flood information significantly expands the assessment of flood changes in Switzerland from instrumental records in the recent past (**Box 3.1**).

Box 3.1: Documentary evidence on floods in Switzerland

Documentary evidence on floods, droughts and other extreme events are found in chronicles, annals, memorial books, memoirs, diaries, travel reports, newspapers, journals, early scientific expert reports, municipal accounts, accountings, paintings, photographs, maps, flood marks, hunger stones or river profiles (WETTER 2017). According to PFISTER (1999), historical documentary evidence can be "direct" (DD) and "indirect" (ID). DD describe the course of events per se, while ID refer to (bio)physically based phenomena associated with such events. DD in continuous chronologies often contain sufficient information for identifying and characterizing floods (BARRIENDOS AND RODRIGO 2006), as they usually provide flood date, magnitude and socio-economic impacts (BRÁZDIL et al. 2006b; 2012; GLASER et al. 2010; BENITO et al. 2015). With respect to the generation of historical documentary evidence, PFISTER (2018) differentiates between individual (IS) and institutional sources (IN). IS are shaped by the social background, motivations and preferences of their authors (BENITO et al. 2015), and their temporal scope is limited. IN on the other hand are produced by institutions (i.e., bodies in charge of performing official functions including taxation, law, etc.). IN generally involve a good level of standardization, which is a good prerequisite for creating long-term homogeneous series of climate and flood parameters. Swiss IN, for example like the books of weekly expenditures of the city of Basel, do have a very good potential for hydrological and climatological analysis, as shown by SPYCHER (2017), who found 70 high water and flood episodes for the river Rhine and 218 events for the brook Birsig which is a local tributary of the Rhine for the period between 1600 to 1650, while chroniclers only reported 3 Rhine and 5 Birsig floods. The significantly “sharper observation skills” towards minor events by IN is explained by the fact that infrastructure may already be endangered by relatively small events, whereas IS (e.g. chroniclers) only focus on spectacular extreme events. IN like the weekly expenditures are at hand for almost every other Swiss town.

3.2. High Rhine River flood occurrences since the 13th Century

The River Rhine at Basel drains two thirds of the Swiss territory (approximately 36’000 km²), and as such reflects the major flood occurrences in Switzerland (e.g., BELZ et al. 2007). The drainage area of the main tributary, the Aare River (17 779 km²) is entirely situated in Switzerland. Its runoff was affected by an artificial diversion of one of its tributaries, the Kander River, to Lake Thun in 1714, and since 1868 and 1891 it is controlled by the First Jura-Waters Corrections (FJWC), which diverted the Aare into Lake Biel in 1878. These regulations considerably reduced the peak discharges of the River Aare and, thus, those of the Rhine at Basel (see **Figure 3.1**).

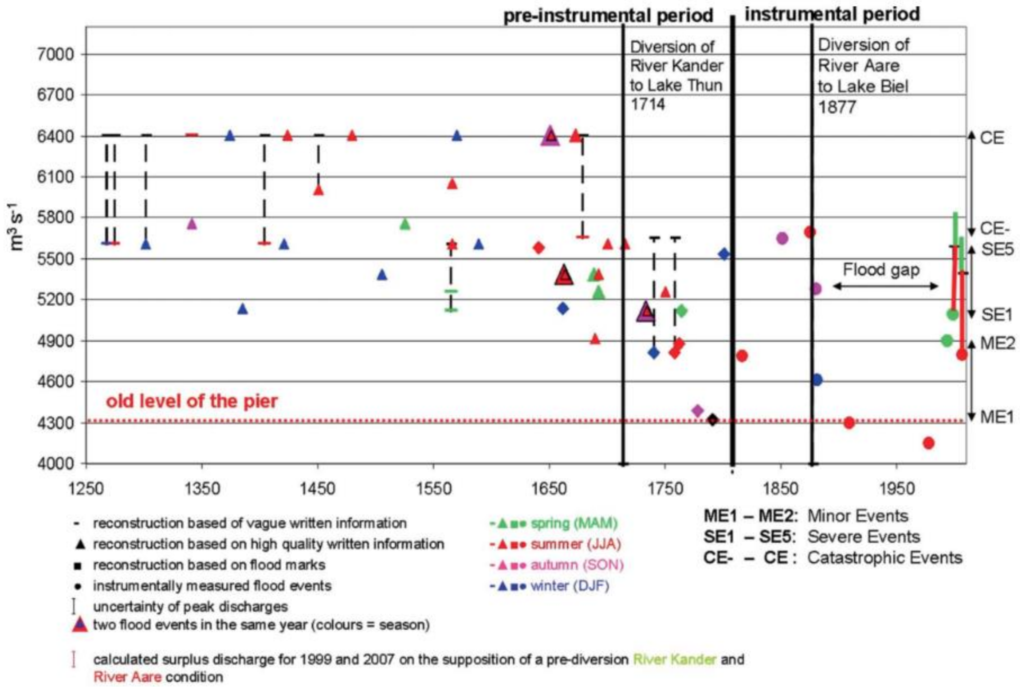

*Figure 3.1: Rhine River discharges between 1250 and 2010 based on documentary and instrumental evidence assessed by reconstructed peak water levels based on IS and unsteady 1D flood routing modelling (*WETTER et al. 2011*).*

All severe events except two floods (1999 and 2007) occurred before 1877, with no single severe event documented between 1877 and 1998 (**Figure 3.1**). This intermediate 121-year-long “flood disaster gap” is unique in the period from 1268. Chroniclers repeatedly mentioned that the Lakes of Neuchâtel, Biel and Murten including their adjacent shore and swamp areas merged into a huge lake for several days, suggesting that the peak floods on the lower course of the Aare were considerably dampened. However, the above-mentioned river engineering measures (Kander and FJWC) may not be the only reason for the observed peak discharge reductions but additional climatological explanations should be considered as well (WETTER et al.

2011). Some of the pre-instrumental flood events were described in such detail, that the triggering meteorological conditions could be reconstructed in sufficient detail. For example, the flood event of 1480 was described in great detail by the Bernese chronicler Diebold Schilling the Older (1446-c 1486) as the “Deluge of the Rhine”. He writes: “On Maria Magdalena Day it began to pour down in the form of driving rain persisting three days and nights without cessation.” The preceding days were very hot, melting the snow at higher altitudes. Indeed, due to a cold spring and early summer the snowmelt was delayed. Assuming an average rainfall intensity of 10 mm/h for the 72 hours between 29th and 31th July we get an estimated precipitation amount of 720 mm for this storm.

3.3. Low and high flood frequency periods since the 16th century in Swiss river basins

Documentary sources are also key to reconstruct flood frequencies over longer periods of time and to identify cycles of high and low flood activity. One recent period without significant floods was identified by the flood reconstruction for the High Rhine River in Basel. However, it would be interesting to know if the same low flood frequency period affected other river basins in Switzerland and Europe or if other periods of high or low flood frequencies can be identified and explained.

To answer these questions SCHMOCKER-FACKEL et al. (2010a) collected historical flood data for 14 Swiss catchments dating back to 1500 AC (**Figure 3.2**). These catchments were all situated in northern Switzerland, either in the Alps or in the Swiss Plateau. The largest catchment is the Rhine River catchment up to Basel and the smallest is the Renggbach in central Switzerland (12 km^2). In this study, a flood event was counted if the name of a river and flood damage caused by the river were mentioned explicitly in documentary records. The use of different catchments, sources and definitions of flood events lead to differences in the final reconstruction, and this should be taken into account when comparing different historical flood series.

The obtained data series resulted in 400 historical flood events in the 14 catchments. More than 100 events affected more than one catchment and 48 events were classified as large-scale flood events (i.e., a flood occurred in more than three catchments at the same time and caused extensive damage). Flood-rich periods alternate with lower flood frequency periods in all catchments, independently of catchment size. The recent increase in flood frequencies, starting in the 1970s is still in the range of observed natural variability. In a further step, SCHMOCKER-FACKEL et al. (2010a) tried to explain the changes in flood frequencies using generalized parameters like climate periods, solar activity, the north Atlantic oscillation (NAO) index, mean air temperatures, or length variations of glaciers.

The results in **Figure 3.2** show that the periods characterized with reduced flooding correspond to the end of the Spörer Minima (1420–1550), the Maunder Minima (1645–1715) and the Dalton Minima (1790–1820) of solar activity. However, solar activity alone does not explain flood frequency, as in the 20th century period characterized with low flood frequency, solar activity was high (see following and previous chapters). The authors did not find a clear relation between the flood data and the reconstructed summer and winter NAO indices, meaning that the forcing of the NAO in the Alpine region might be weak and NAO phases do not correlate well with Alpine precipitation. No clear relationships could be identified between mean air temperatures (winter or summer) and flood frequency. However, high flood frequency periods correspond to periods of rapid climatic change in the Alpine region. According to these observations, it was not possible to explain the detected flood frequency changes with single generalized climatic parameters, as the reasons for these changes are likely due to a combination of several factors.

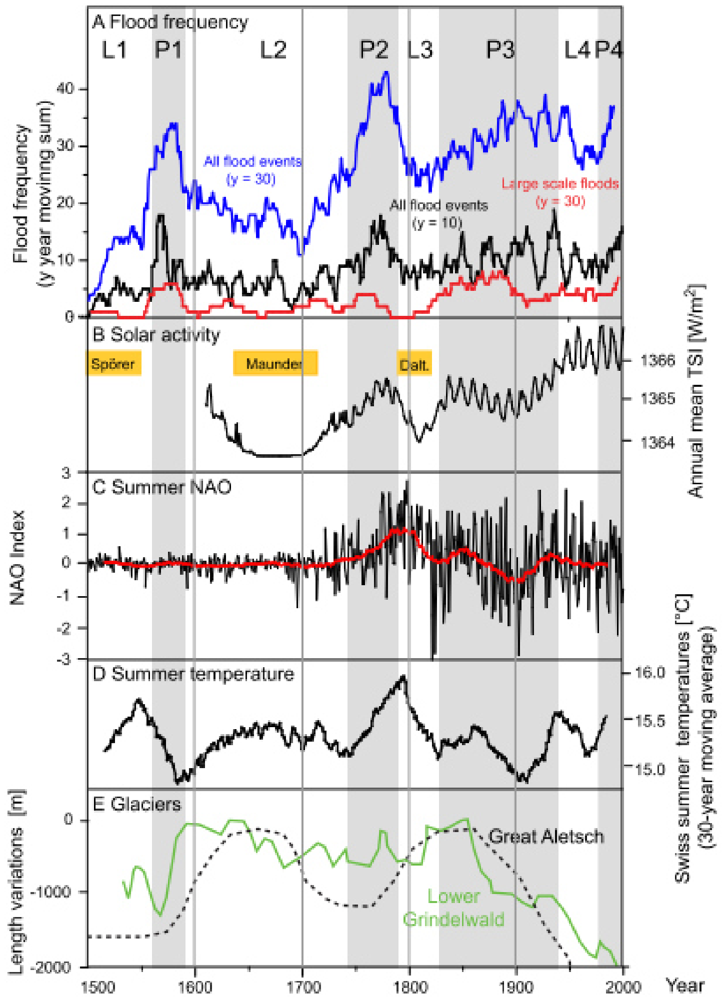

Figure 3.2: (A) Frequency of flood events in 14 Swiss catchments and catastrophic events throughout Switzerland. P1-P4 are periods with many floods and L1-L4 with few floods in northern Switzerland. (B) Spörer, Maunder and Dalton periods of low solar activity and the total solar irradiance TSI. (C) Annual summer NAO values (black) and the 30-year moving average (red). (D) Reconstructed Swiss summer temperatures. (E) Advances and retreats of the Lower Grindelwald and the Great Aletsch glacier (from SCHMOCKER-FACKEL et al., 2010a).

Other authors also found that flood frequencies in Europe have changed at intervals of 30-100 years during the last 500 years (e.g. BÖHM and WETZEL 2006; BRÁZDIL et al. 2006b; GLASER 1998; HALL et al. 2014) or even within the past millennium (GLASER and STANGL 2004). A comparison with the flood patterns of other European rivers suggests that flood frequencies are not in-phase over Europe but reoccurring spatial patterns of flood frequency do seem to occur (SCHMOCKER-FACKEL et al. 2010a). This seems to be the case also on a global scale (e.g. BERGHUIJS et al. 2017). The flood frequencies in northern Switzerland are often in phase with those of rivers in Spain, Italy and the Czech Republic, but less with those in Germany. Although it seems likely that changes in atmospheric circulation patterns on decadal time scales may be responsible for these spatially heterogeneous changes in flood frequency (JACOBEIT et al. 2003, MUDELSEE et al. 2004; WANNER et al. 2004), there are also other factors at play.

Similar patterns can be observed at the Limmat river in Zurich (**Figure 3.3**) for the interval from 1300 to 2015. A local increase in flooding occurred at around 1567 (0.12 events per year). The subsequent 17th and early 18th centuries saw significantly reduced flood risk, in agreement with findings for other regions in central Europe

(LUTERBACHER et al. 2001; MUDELSEE et al. 2003; 2006). A second peak in flood occurrence was reached at around 1867 (0.14 events per year), from this time on the flood occurrence rate steadily decreased. Such a downward trend during the recent decades has also been observed for the rivers Elbe and Oder during winter (MUDELSEE et al. 2003).

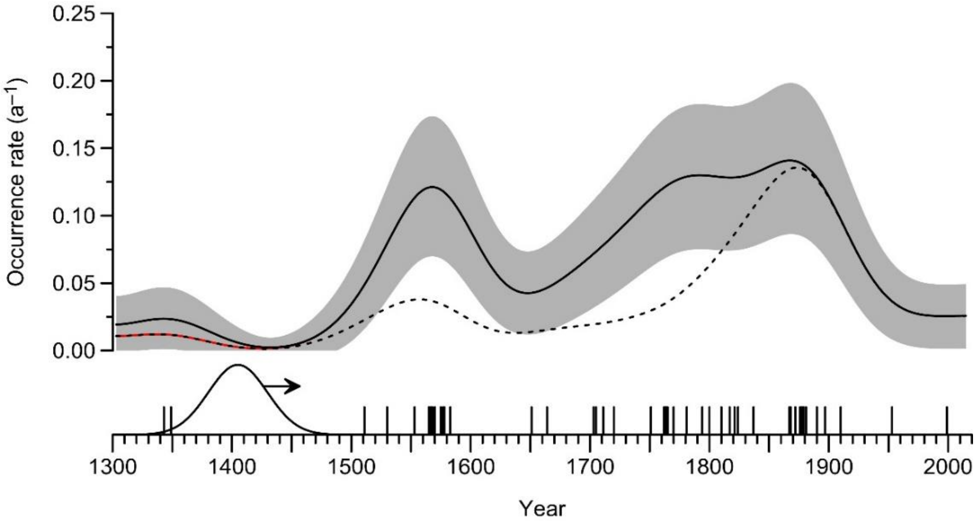

Figure 3.3: Estimated flood occurrence rate (number of floods per year, solid line; 90% confidence band, grey) analysed using a Gaussian kernel function (shown with an arrow in the bottom part) for the river Limmat in Zurich for the interval 1300-2015. The estimation is performed on all m = 47 historical events (shown as bar chart in the bottom part). Omission of the uncertain event in AD 1349 (m = 46) leads to an indistinguishable estimation (red line). Utilization of only the historically critically examined events (m = 26) leads to a lower occurrence rate (dashed line). See MUDELSEE et al. (2003), (2004) and (2014) for further methodological details.

An important limitation of historical flood data series analysis is that man-made or natural morphological changes in the river channel geomorphology, river flow capacity, or the anthropogenic construction of dams and channelization works over centuries (**Box 3.2**), may lead to homogeneity problems (CAMUFFO and ENZI, 1996; SCHULTE et al. 2009; SCHMOCKER-FACKEL et al. 2010, HALL et al. 2014a). Methods have been developed to quantify the changes due to anthropogenic river engineering measures on the overall in- and outflow runoff conditions of a location of interest (e.g. WETTER and SPECKER 2014; WETTER et al. 2016; NÄF-HUBER et al., 2016; WETTER 2017). Once the relevant anthropogenic changes to the overall runoff conditions are known and quantified, two things become possible. First is the identification of hot spots, i.e. locations where failure in river engineering measures could dramatically change floods, and second is that correction can be applied to flood events that took place in the pre-anthropogenic conditions, to homogenise them to the contemporary runoff conditions.

For example, at the Limmat River, five periods were identified as having homogenous runoff conditions and then homogenised to the current runoff conditions. According to the homogenised flood series we are now able to see that in the last 718 years there were at least three flood events (1876, 1817 and 1720) that most probably would have been more extreme than the 1999 flood event if they had taken place under current runoff conditions in Zürich. Flood risk analysis may thus now be based on long term homogenised flood evidence which simulates the risk under current runoff conditions (see **Fig. 3.3.**).

Box 3.2: Floods and anthropogenic changes

Rivers are dynamic systems, which adjust their geometry, morphology, grain size to the dominant discharges and sediment supply, thereby affecting flooding. All of these processes may have experienced important variations due to environmental and anthropogenic changes during the last centuries. The human action produced not only land cover and land use changes, but includes also direct alterations due to river regulation, deviation and the construction of embankments. The identification of such long-term spatial changes requires a complex approach (e.g. SCHULTE et al. 2009; 2015) that integrates multiple archives and methods (e.g., geomorphological mapping, systematic coring of floodplain sediments, location of historical buildings and archaeological sites, the study of historical maps, sources and aerial photographs. This spatial integration contributes to the understanding of current as well as historic flooding, channel shifts and aggradation of sediments which effected settlements and local communities. For example, the repeated flooding of the Lütschine fan delta and the changes of drainage to Lake Brienz and/or the Bödeli-Aare River are shown by the reconstruction of the paleo drainage systems in 2003 (see **Figure**; SCHULTE et al. 2009) which were reactivated during the 2005 flood.

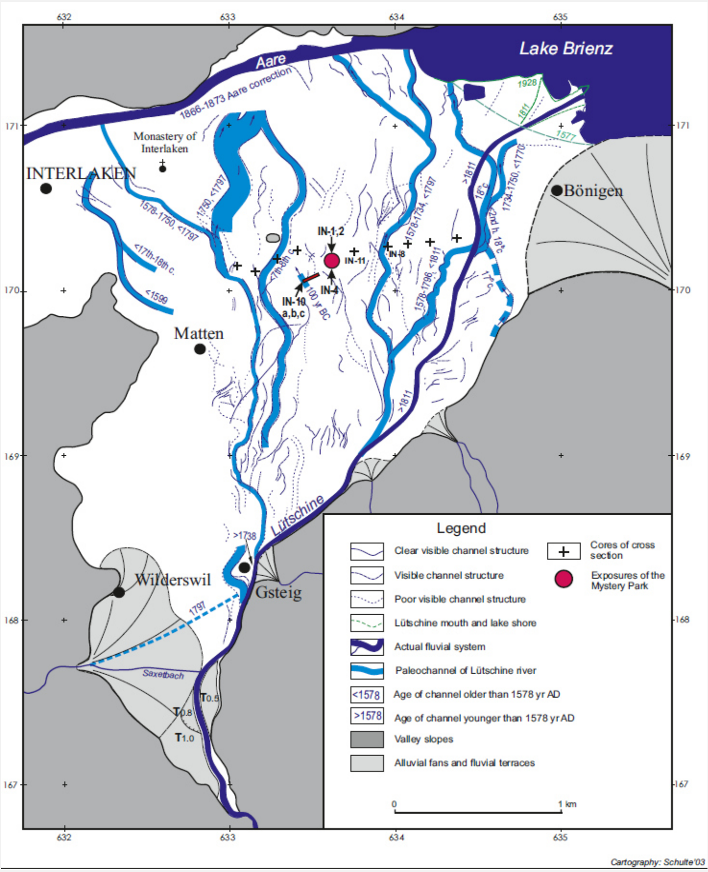

Figure: Morphological map of the historical evolution of the fluvial channels on the Lütschine fan delta (from SCHULTE et al. 2009*).*

Take-Home Messages

- Documentary flood information can be used to reconstruct flood frequency and flood magnitudes beyond the measurement period for several centuries into the pre-instrumental (measurement) past affected by human modifications to the landscape and rivers. Long-term anthropogenic influence on runoff conditions can be semi-quantitatively assessed.
- Reconstructed and homogenized long-term flood magnitudes in combination with incorporated (anthropogenic) changes to runoff conditions improve the assessment of extreme value statistics and the definition of design flood events (e.g. HQ100).
- All reconstructed historic flood series in Switzerland and Europe show changes in flood frequency over time intervals between 30 and 100 years. Flood-rich periods do not occur at the same time for all investigated rivers, but differ between regions and between catchments of different sizes. The latter can be explained with scale effects of mechanisms causing floods: e.g. long duration, large-scale rainfall and snowmelt events in the Rhine to local small-scale convective heavy precipitation events in small Alpine catchments.
- It is very likely that long-term changes in atmospheric circulation play an important role in causing these changes in flood frequency. However, due to the lack of good quality data about the atmosphere in the past it may be difficult to establish a clear cause-and-effect chain.