Reconstruction of flood events based on documentary data and transnational flood risk analysis of the upper Rhine and its French and German tributaries since AD 1480

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Abstract This paper presents the long-term analysis of flood-occurrence along the southern part of the upper Rhine River system and of 14 of its tributaries in France and Germany covering the period from 1480BC. Special focus is given on the temporal and spatial variations of flood events and their underlying meteorological causes over time. Examples are presented how long-term information about flood events and knowledge about the historical aspect of flood protection in a given area can help to improve the understanding of risk analysis and therefor transnational risk management. Within this context special focus is given on flood vulnerability while comparing selected historical and modern extreme events, establishing a common evaluation scheme.

The transnational aspect becomes especially evident analyzing the tributaries: on this scale flood protection developed impressively different on the French and German side. We argue, that the comparing high technological standards of flood protection, which had been initiated by the dukes of Baden on the German side starting in the early 19th century, misled to the common believe that the mechanical means of flood protection likewise dams and barrages guarantee for security from floods and their impacts. This lead to widespread settlings and the establishment of infrastructure as well as modern industries in potential unsafe areas until today. The legal status in Alsace on the French side of the Rhine did not allow for continuous flood protection measurements leading to a constant – and probably at last annoying – reminder, that the floodplains are a potentially unsafe place to be. From a modern perspective of flood risk management this leads to a significant lower aggregation of value in the floodplains the small rivers in Alsace compared to those on the Baden side – an interesting fact – especially if the modern European Flood directive is taken into account.

1. Introduction

The knowledge about the occurrence of floods in historical times, their meteorological causes and their distribution within the (hydrological) year does provide a deeper understanding of the natural variability of the severity of flood events by providing long-term knowledge about changes in the causes, frequencies and gravities of the floods as it had recently been discussed in detail e.g. by Seidel & Bárdossy (2010) or Grünewald (2010). Pursuing the ideas from Glaser et al. (2010) to research climate responses of rivers and creeks with small catchments, this paper focusses on the tributaries of the Rhine within the Upper Rhine Graben. Flood research on smaller rivers as presented in this paper complement the research related to larger river systems for two main reasons. Creeks and small rivers show a more direct response to the atmospheric forcing. Similarly they are much more susceptible to changes of land use or alterations of the floodplain due to an increase of settlements and infrastructure as those alternations also directly affect discharge.

From a perspective of transnational risk research those creeks and small rivers are equally interesting to look at. The flood risk management of these smaller catchments lies within the responsibility of smaller communities while the large river systems are under control of larger and stronger administrative units. This however sums up the similarities between the French and German side: Due to its roots in the Roman jurisdiction in the state of France had no rights on the non-navigable rivers and therefore could not develop plans of their flood protection. The German tributaries however, stood under the undisputed sovereign of the Dukes of Baden since the 18th century, who opted for technical flood protection with dams and barrages to protect the floodplains.

This administrative difference concerning flood control and management plays an important role in modern flood risk management. In France flood risk-management on non-navigable rivers is handled by PPRIs (Plan de prévention du risque d'inondation) which are negotiated by the communities and the responsible parts of the administration. Their goal is to determine the area with a risk of being flooded along the examined rivers and to discriminate between zones where different human activities can be allowed or has to be forbidden.

In Germany (especially in Baden-Wuerttemberg) the flood risk management of smaller tributaries (water bodies of the 2nd category) resides with the legal responsibility of communities while the large non-navigable rivers (water bodies of the 1st category) are under control of stronger administrative units like regional councils. Still the category of water body changes from 2nd category (the upper parts of the river) into the 1st category at positions which had been specified according to the master plan of Johann Gottfried Tulla (1770-1828) in the 19th century.

This study presents the results from the project TRANSRISK, which was realized between 2008 and 2011 in collaboration between CRESAT of the University de Haute Alsace in Mulhouse funded by the French "Agence Nationale de la Recherche" (ANR-07-FRAL-025) and the department of Physical Geography of the Albert-Ludwigs-University of Freiburg founded by the "Deutsche Forschungsgemeinschaft" (DFG-Gl 358/5-1).

2. Study area

The study area is located within the Upper Rhine Rift and stretches approx. 110 km between Basel / Switzerland and Strasbourg / France including the rims of the Black Forest and Vosges Mountains (Figure 1). The elevation of the Upper Rhine Rift ranges from about 250 m a.s.l. in Basel to 130 m a.s.l. at Strasbourg. The highest mountaintops of the region are the Feldberg (1493 m a.s.l.) in the Black Forest and the Grand Ballon d'Alsace (1424 m a.s.l.) in the Vosges. The area is located in the mid-latitudes a zone of predominant westerly winds and in the transition of maritime too continental climate. The climate is moderately mild due to its location around 48°N and decent protection against cool air masses from the surrounding low mountain ranges. Warm southwesterly winds which originate from the Western Mediterranean region can reach the area only moderately modified through the 'Belfort gap'. This however might only happen in less than 10% of the year. The westerly winds and approx. 1000m of mean height difference between the rims and the valley floor account for a heterogeneous distribution of precipitation between the Vosges Mountains and the Black forest as well as within the Upper Rhine valley. Precipitation varies greatly from as little as 550mm/a at Colmar leeward of the Vosges Mountains to more than 2200mm/a at the summits. Two precipitation maxima can be identified in the course of the year: one in July and another in December. The July-maximum is generated mainly by convective rainfall, resulting usually from thunderstorms.

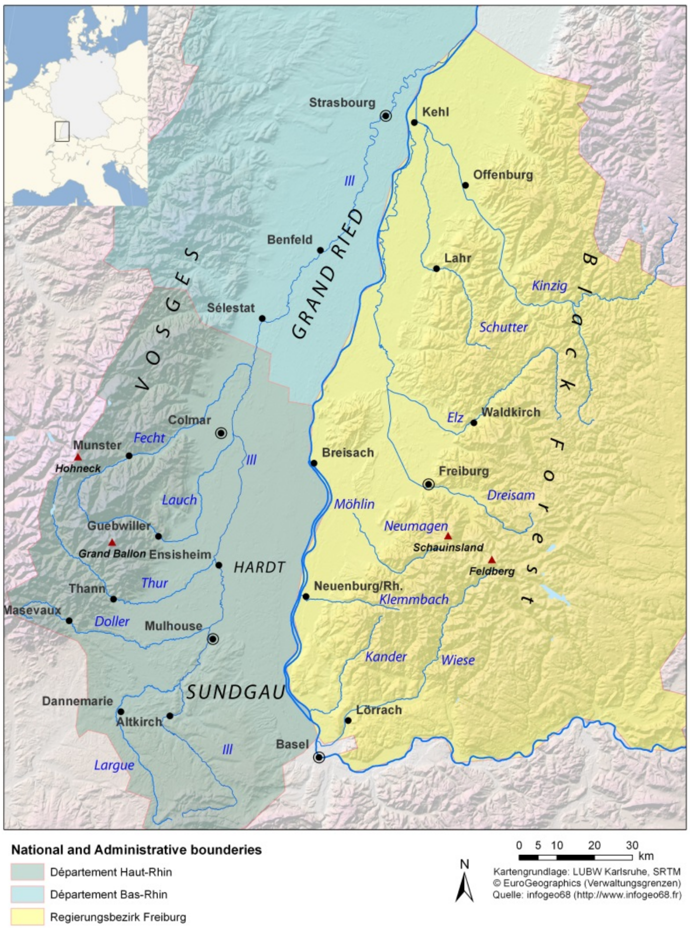


Figure 1. Study area including the researched rivers and actual administrative districts in France and Germany

Large parts of the study area belong to the European Region "RegioTriRhena" and nearly the whole study area is also part of the Trinational Metropolitan Region "Oberrhein" (TMO-MRO) forming a multicore, tri-national conurbanisation combining more than six million people and industrial hot spots. Both concepts try to improve the transnational collaboration on the fields of science, commerce, technology and politics as well as civil societies. Strasbourg is one of the European capitals. In history the researched area was affected from many territorial conflicts since the 17th century. Between 1871 and 1919 and again from 1940 to 1945 Alsace was occupied by Germany. As far as flood control management is concerned, those different administrations tried to realize their own concepts and ideas however both administrations had not been able to come up with and enforce any own master plan for flood protection due to traditional water rights (see below).

3. Methods and Data

Within the TRANSRISK project the Rhine between Basel and Strasbourg and 14 of its tributaries had been analyzed: in Alsace the rivers Largue, Ill, Doller, Thur, Fecht and Lauch, in Baden the rivers Wiese, Klemmbach, Kander, Neumagen/Möhlin, Dreisam, Elz, Schutter and Kinzig.

For none of those tributaries a flood research or a comparative survey regarding flood-protection measures had hitherto been conducted. So the first interest was, to reconstruct the flood events between 1480 and 2007 as detailed as possible, their underlying meteorological causes together with their spatio-temporal variation. Our approach followed the method of critical source analysis which can be regarded as well established in the field of Historical Climatology (Pfister 1985; Glaser & Stangl, 2003; Jacobeit et. al., 2006; Glaser et al., 2010; Wetter et al., 2011; Himmelsbach, 2014). Following these well-established principles of critical source analysis, the multitude of information gathered had been critically reviewed in a hermeneutic approach due to their informational content mainly analyzing diction of the source as well as additionally information about the author like level of education or social environment, intention etc., which might have influenced or motivated the writings. Equally important is the cross-validation within different sources describing the same event. Another valuable aspect for critical source analysis and evaluation is the described impact of the floods and the damages, which are very often given in detailed images. Of course there is always a time shift in historical records, the kind, that such detailed information decreases through time. Even though more than 2800 flood events had been identified by a total of over 4000 references, cross validation becomes more difficult for early events. Therefor the level of uncertainty diminishes through time, which has to be taken into account for all given results.

The use and usefulness of information derived from historical sources is an ongoing discussion within the scientific, and even more so, within the hydraulic engineering community. In contrast to measurement data historical data never promises modelling results with seemingly mathematical exactness. Dealing with historical information always means dealing with uncertainties, which is also a fundamental issue for all kind of statistical analysis. But besides loads of additional information which might been regarded useful for some research questions historical data offer, so the methodology of critical source analysis had correctly been applied, sound information on the occurrence of past events and allow for a reliable estimation of the magnitude of the past flood event. That those insights offer added value was proven amongst others by the work of Bürger et al. (2006) for the river Neckar or by Grünewald (2010) for the river Elbe where the return intervals of flood events had to be recalculated due to data originated from historical sources.

As data source written evidence, flood-marks, drawings, flood-maps, newspapers, gauges data and contemporaneous administrative reports and chronicles had been considered. All possible information regarding flood events, their duration and spatial extent or mitigation strategies for helping those who were affected had been extracted. To estimate and rank the intensity of the flood event a classification scheme had been applied, in which the intensity and spatial dimension as well as the impacts as primary indicators, the duration as secondary indicators and the mitigation strategies as tertiary indicators were taken into account (Table 1). With this scheme it is possible to differentiate between smaller, medium size, strong and extreme events (see Glaser et al., 2012). For some case studies, detailed information on impacts had been used to analyze and quantify the vulnerability. To compare the spatial and economic dimension of single events of selected historical with modern events, the economic values had been standardized.

Class	Classification (Intensity and spatial dimension)	Primary indicators (Damages)	Secondary indicators (temporal structure)	Tertiary indicators (Mitigation)
- 1	No classification possible	no Information	no Information	no Information
1	Small flood Regulated rivers: up to HQ_{20}-equivalent	Little damage: e.g. on bankside fields and gardens; no bigger damages named.	Short flood	Little (local) supporting measures
2	Above-average , big or supra-regional flood Regulated rivers: HQ_{20} to HQ_{100}-equivalent	Strong decline: damages on bridges and bankside buildings; flood-protection systems like dams or barrages are affected or damaged; loss of cattle and people; Morphodynamical processes.	Flooding of average duration to few days	Coordinated supporting measures with participation of regional organizations
3	Extreme / supra-regional flood of a catastrophically	Strong decline:severe damages / destruction of flood-protection systems bridges and buildings;	Long-lasting flooding (several weeks)	Supra-regional (national), coordinated measures of

	dimension Regulated rivers: bigger than HQ_{100}-equivalent	damages on the bankside fields and gardens, loss of cattle and people;		major extent. The event is followed by long lasting discussions about security and a better prevention. The flood-event became part of the long-term-memory and resides as a reference figure.

Table 1. Classification scheme for flood-events (meso-scale)

Gathering information on extreme events in historical sources is generally not overly difficult as catastrophic events are of a certain interest and widely recorded. In as far as medium or small events are concerned information however become more sparse and a correct differentiation between them is difficult.
The availability of sources describing flood events on the French and the German side show some distinct differences. In Alsace data on flood events is provided by a long tradition of writing chronicles, which was shared by municipalities, abbeys or individuals and holds until the 19^{th} century. Examples could be the town-chronicles of Murbach, Mulhouse, Ensisheim, Colmar, Sélestat, Ribeauvillé or Strassbourg. Famous is the chronicle from the Abbey of Thann by Malachias Tschamser (1678-1742) who reports on extremes also outside of Alsace. Even so gauging data is sparse in Alsace until the 1870^{th}, the fact that all creeks discharge into the river Ill before discharging in the much bigger river Rhine allow for possible cross validation of flood events as the flood wave can be tracked on its way and chronicles will (normally) state the villages and towns affected. The floods of 1511 (mentioned by 14 sources) or 1529 (mentioned by six sources) can be used as examples. Gauging data is available in Alsace from 1870 to the 1930^{th} and from the 1950^{th} onward.

The situation is different on the German side. Here chronicles came “out of style” since the middle ages and the few, which indeed had been written mainly concentrate on reporting political events. Even by researching alternative sources like transcripts of the city councils or the building authorities it is not possible to gather the same quantity of sources which is available in Alsace. Exceptions are the flood events of the river Rhine, which are often described in great detail by the chronicles of Switzerland especially from Bern and Basel, like the floods of summer 1480 and 1511 or December 1506. Especially for Basel the given information is exact enough to assess the biggest ones (Wetter et. al. 2011). Following the idea of Johann Gottfried Tulla (1770-1828) Baden begun with the installation of official gauging stations during the early 19^{th} century and expanded the measuring network to the tributaries during the 1820^{th}. In the early 1870^{th} the duchy of Baden initiated the “Nachrichtendienst bei Hochwasser” – a news service which was activated in case of flood events which was to establish communication with the downstream communities in case of rising water levels. The related laws provide detailed information on the water level, which had been regarded as dangerous.
With the 19^{th} century newspaper started to appear within the research area which complemented the information about past flood events by providing for a once more widened information base.

A total of 2830 flood-events were found in written sources and gauge data and were evaluated within the research area (Table 2). In Germany a total of 1302 events have been identified with an emphasis on the 20th century. In France we identified 1201 events and for the river Rhine 327 events could be found. We found more events in France for the time before the 19th century, than for the German part of the research area. A main reason for that is the existence of many chronicles in Alsace and nearly none for the German part, which can be regarded as a result of the existence of more cities and monasteries in Alsace along the rivers and a deeper tradition to jot down personal histories (“Livres de raison”). On the other hand, we could identify much more flood-events on the German side on a basis of gauges data, because of the work of Johann Gottfried Tulla, who ordered the installation of gauging stations on every river since 1816, as a basis for his rectification plans. In contrast the limits of the

French water rights prohibited the rectification of the rivers in Alsace during the 19th century (see Sect. 5) there was no need to put gauges on the rivers and working with mobile devices seemed sufficient. This led to only a minor number of data concerning water levels. During the German occupation (1871-1919) some stationary gauges had been active, but were decommissioned by the French administration in the early 1930th. (Table 2).

To make this impressive data set accessible to the interested scientific community and the public, the data will be presented on the Collaboratvie Research Environment www.tambora.org.

River	15th	16th	17th	18th	19th	20th	21th	Total
Ill	6	37	28	74	116	210	18	489
Fecht	2	16	12	17	45	56	9	157
Lauch	3	21	11	16	26	38	9	124
Thur	5	28	18	16	39	30	3	139
Doller	3	13	9	16	28	43	8	120
Largue	2	14	8	27	43	60	18	172
Total France:	**21**	**129**	**86**	**166**	**297**	**437**	**65**	**1,201**
Kinzig	1	8	26	39	88	160	10	332
Schutter	1	3	4	2	21	32	5	68
Elz	1	6	4	23	53	96	5	188
Dreisam	1	3	10	22	57	115	10	218
Neumagen/Möhlin	2	3	3	8	15	115	10	156
Klemmbach	1	3	2	6	10	11	1	34
Kander	1	3	2	2	5	18	0	31
Wiese	1	3	8	14	60	176	11	237
Total Germany:	**9**	**32**	**59**	**116**	**309**	**723**	**54**	**1,302**
Rhine	28	81	41	28	86	59	4	**327**
Total amount:								**2,830**

Table 2. Occurrence of reconstructed flood-events per century and catchment area

4. Results

The highly spatio-temporal resolved data set and the detailed information on damages and impacts on the society offers interpretation towards two main directions. First, different types of spatial flood occurrences had been classified into five major groups and the underlying meteorological causes had been determined. There is evidence about the changes of these underlying causes and changes in seasonality of the flood occurrences in the context of the overall climatic change debate.

A second part deals with the vulnerability of HQ 100 year events and the possibility of incorporation of historical information into modern, integrated flood risk management. There is also another example about technical alterations regarding the city of Mulhouse.

4.1 The derivation of specific spatial patterns of floods

In a first step all flood events had been clustered regarding their spatial patterns. Five types can be identified: floods only at river Rhine, Floods at river Rhine and all its tributaries, floods on the French tributaries, Floods on the German tributaries and Floods on the French and German tributaries. These types are described below (see Figure 2 to Figure 6).

Type 1: Floods occur only at the river Rhine without involving its tributaries. Examples for that type are the floods of July 1343, June 1876, September 1881 or July 1910. The cause for this flood-type is located in the Alps and/or in the Swiss midlands. For extreme summer events high temperatures and long lasting rain in addition to a quick snow-melt in the higher regions of the Alps are in most cases the reasons for those events. In the hydrological winter half-year an early snow-fall and afterwards a quick snow-melt in addition to longer and/or stronger rainfall are the meteorological conditions for extreme floods of the river Rhine. In other cases it might be a Vb weather situation, which causes heavy rainfall in the Swiss midlands (Wetter et al. 2011, Wetter, Pfister (2011))

Type 2: Affects the river Rhine and all its tributaries in the study area at the same time. Examples are the floods of July 1480, December 1882 or January 1910. In historic times as well as recently this flood type is characterized by the biggest spatial extent of heavy damages. For this reason it is necessary to give the meteorological causes of this type a special attention. Large scale and intensive rainfall events and/or rain on heavy snow pack characterize this type.

Type 3: This type only affects the French tributaries in Alsace. Examples are the floods of March 1876 or February and December 1999. Small scale low-pressure systems with snow melt characterize this type.

Type 4: This type only affects the German tributaries in Baden. An example is the flood of December 1991, which was a so called "Christmas-flood": the flow turns to the northwest and Lows, as part of a Cyclone family, initiate an early Christmas thaw. The precipitation falls into the summit level of the average mountains as rain, which could not infiltrate into the frozen ground (Weischet & Endlicher, 2000).

Type 5: This type represents flood-events, where only the French and German tributaries of the river Rhine are affected, but not the Rhine itself. Examples are the events of May 1872, February 1877, March 1896, December 1919, December 1947 or April 1983.

The spatial pattern types can be connected with prevailing weather situation and therefore are of specific interest for further climatological interpretation. This connection will be subject of further research (see Jacobeit et al., 2003a/b). In the following chapter the changes in underlying meteorological causes through times is elaborated.

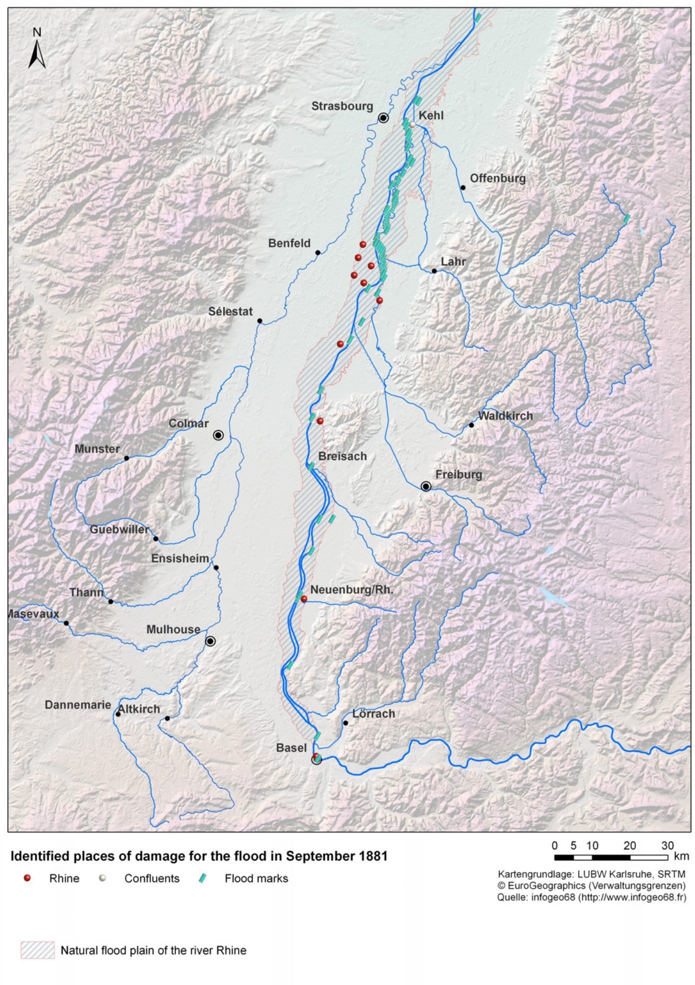


Figure 2. Damage map of the flood in September 1881 (Type 1)

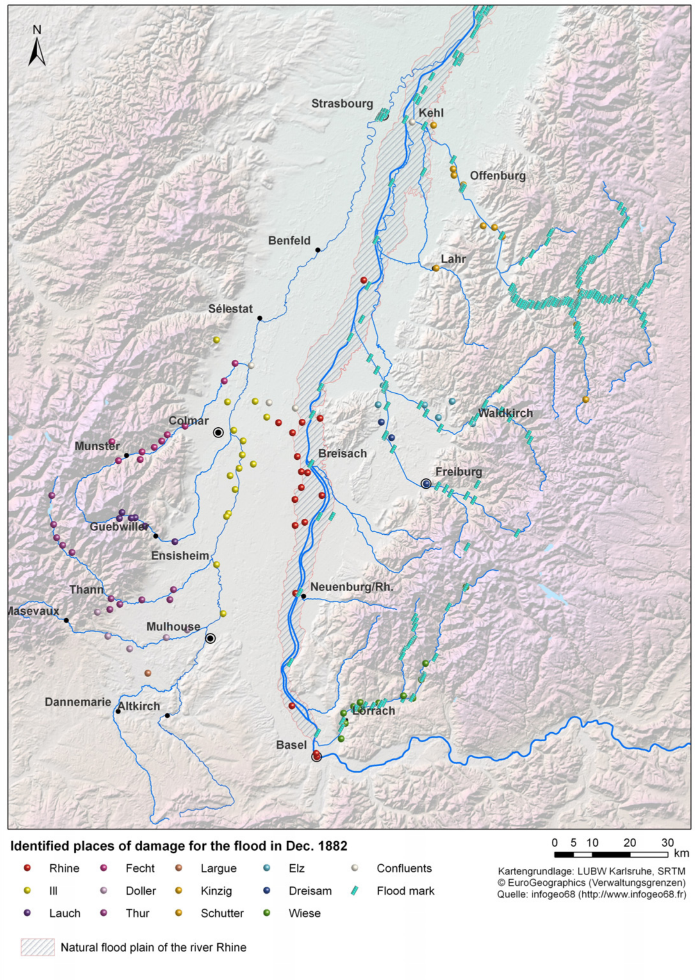


Figure 3. Damage map of the flood in December 1882 (Type 2)

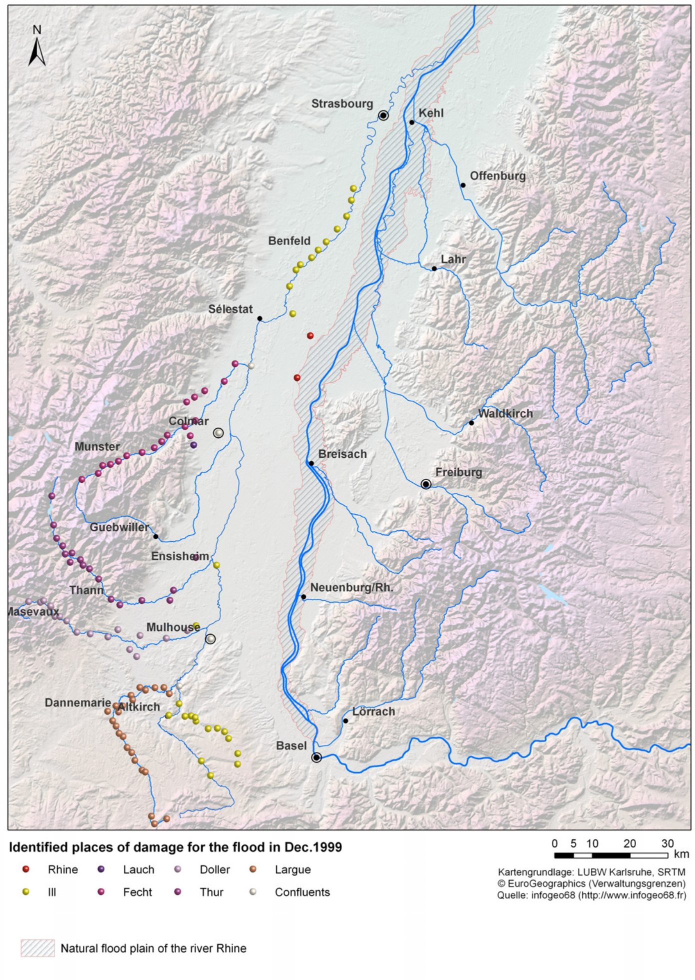


Figure 4. Damage map of the flood in December 1999 (Type 3)

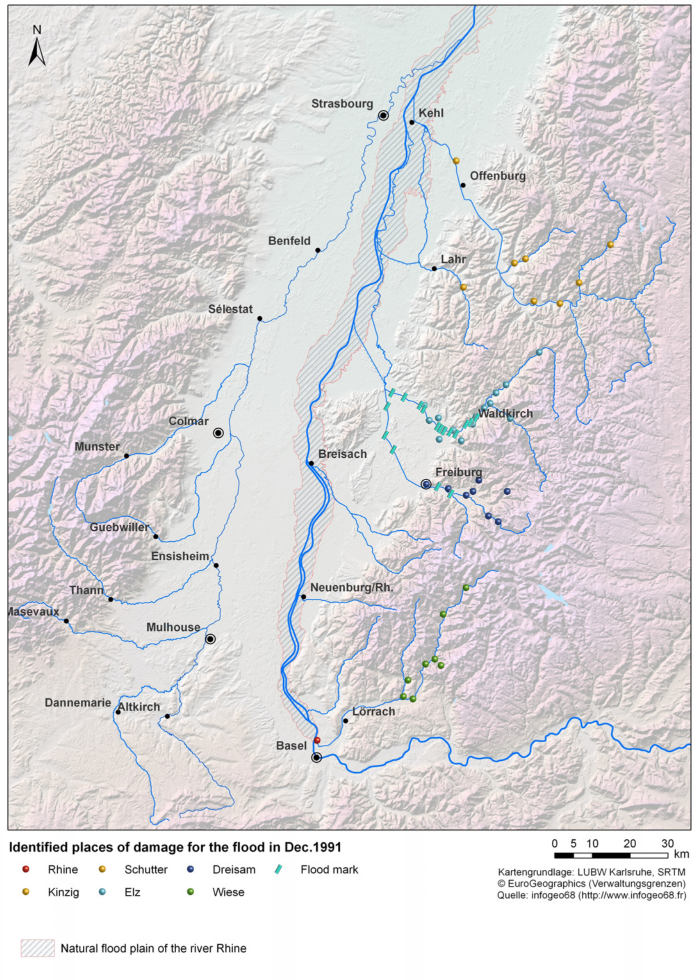


Figure 5. Damage map of the flood in December 1991 (Type 4)

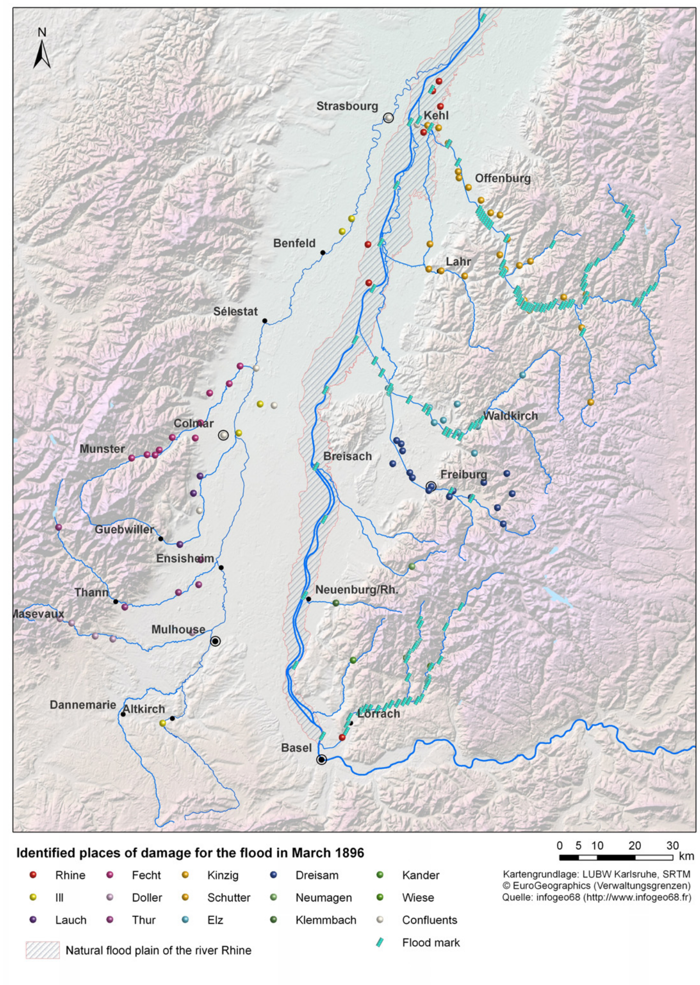


Figure 6. Damage map of the flood in March 1896 (Type 5)

4.2 Changes in underlying meteorological causes and seasonality

Everyone, who deals with reconstructing and evaluating historical floods from historical data with hermeneutical methods has to determine indicators to differentiate the severity of the floods. Glaser & Stangl (2003) and Glaser et al. (2010) focused on the effects and the damage caused by floods. However, it is important not only to collect data about the consequences of the flood events, it is also important to record timing and, in case hints can be found, meteorological causes of the event. Often historical sources provide that kind of information. Their collections might be useful to help reconstructing the initial meteorological situation which led to the researched event. Based on meteorological information which further described the researched flood events we tried to display the temporal development of meteorological causes of floods for some of the researched tributaries. To classify meteorological causes the classification scheme from Bauer (1952) is used, which distinguishes five causes: convective and continuous rainfall, snowmelt, ice breakup and rain on snow.

A comparison of the meteorological causes which induced flood events on some selected tributaries shows, that over the whole period "snowmelt/rain on snow" is the most important cause which is followed by "long-lasting rainfall". Events which are triggered by "convective rain" are currently discussed in connection with a changing climate (REMO, 2006; Zebisch et al., 2005) played a less important role as well as "icebreak". However: comparing the meteorological causes of the floods for the whole time-period with the last five decades a distinct increase of convective-rain-events can be noted. It is reasonable to assume, that convective events gain intense due to an increased hydrological cycle intensified by higher temperatures. Likewise ice break-up has almost vanished as a reason for flood events in modern times. This however can not only be attributed to generally higher temperatures, but to a variety of reasons with the widespread loss of floodplains and induction of coolants being some major reasons. There is also an increase in snowmelt related events. Floods caused by rain on snow show antithetic development. Changes in occurrence of floods caused by long lasting rain range from pronounced to minor decrease (see Figure 7).

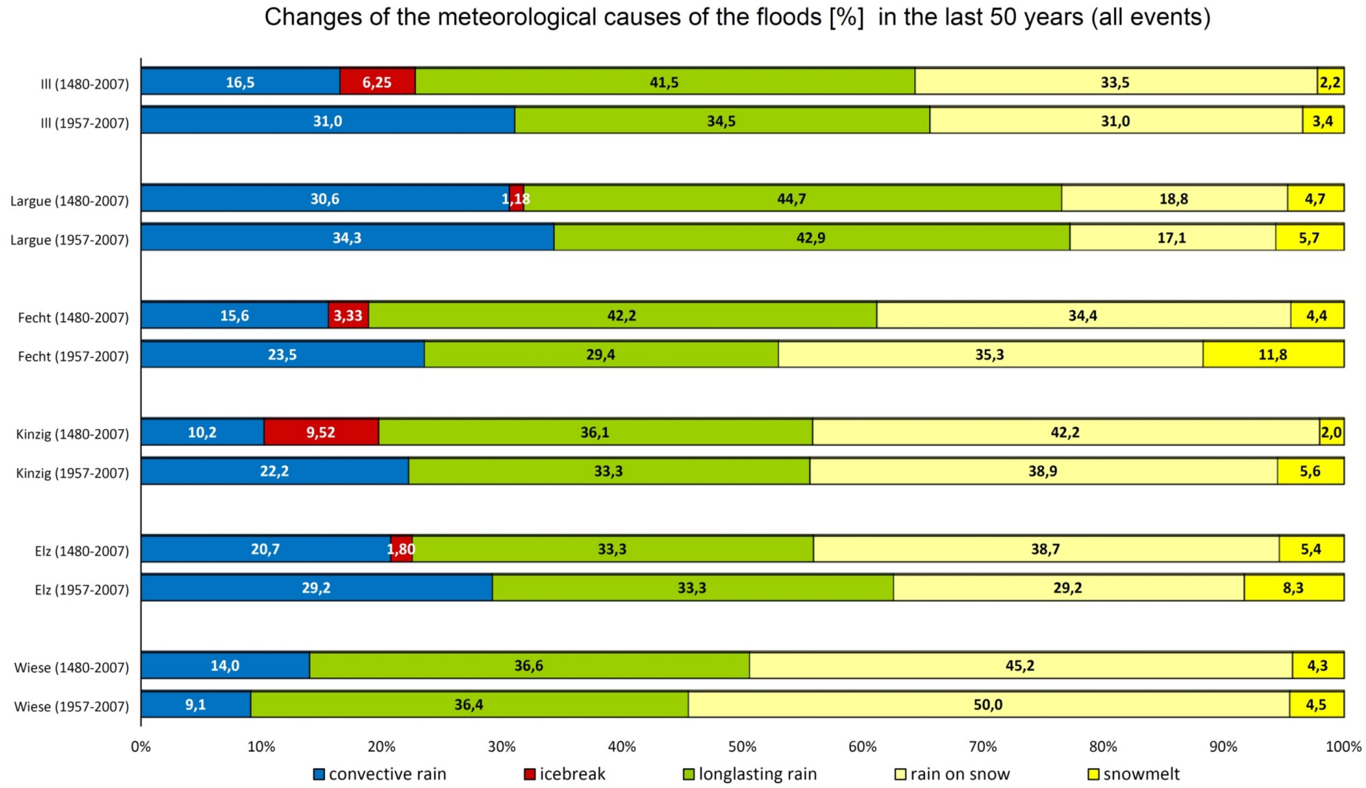


Figure 7. Changes of the meteorological causes of the floods in the last five decades in comparison to the period from 1480-2007

In a second step the changes in seasonality of flood events happening at the river Rhine have been analyzed. Previous studies concluded that the runoff regime of the river Rhine changed during the 20th century from a main discharge during the hydrological summer- to the hydrological winter half year (IKHR, 2007; IKSR, 2011). Our data suggests, that only during a period lasting from the 1820th to the 1860th the river Rhine displayed a phase with an accentuated and rather unusual occurrence of summer floods. That event might be linked to the ending of the Little Ice Age (LIA) around 1850. However it has to be taken into account that from 1817 onwards the massive alterations in the context of the rectification of the river Rhine system by Tulla and successors likely increased awareness to even minor flood events and the installation of numerous new gauging stations raised the availability of data. This alone might interpret the risen number of flood events as a pure data signal – which will, of course, give no reasonable explanation for the observed decline of flood events. All other decades from 1500 to now did not show a distinct emphasis towards one season. The only exception might be the period between the 1940th and the 1970th where winter runoff dominated (see Figure 8). In contrast to the period around the 1950th where the elevated winter runoff did not occur in conjunction with extreme events (see Figure 10), the period at the ending of the LIA was, at last to a certain degree, induced by big and extreme events.

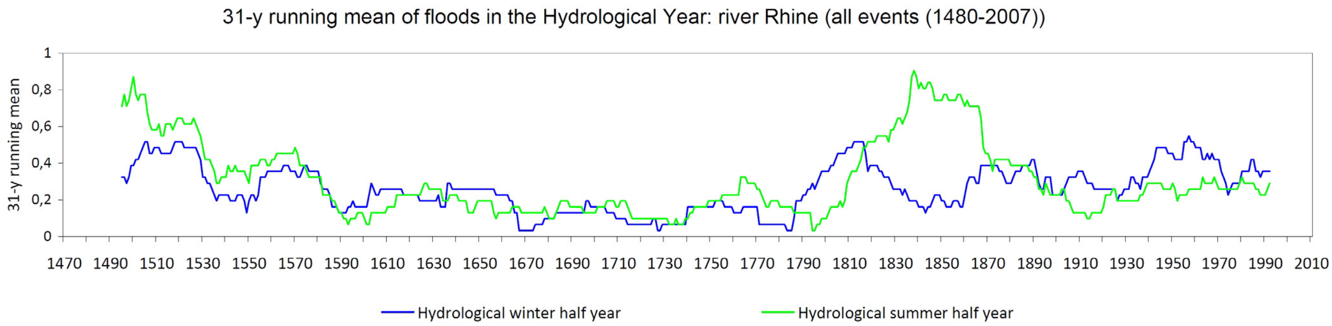


Figure 8. Floods of the river Rhine in the Hydrological Summer- and Winter-Year (all events)

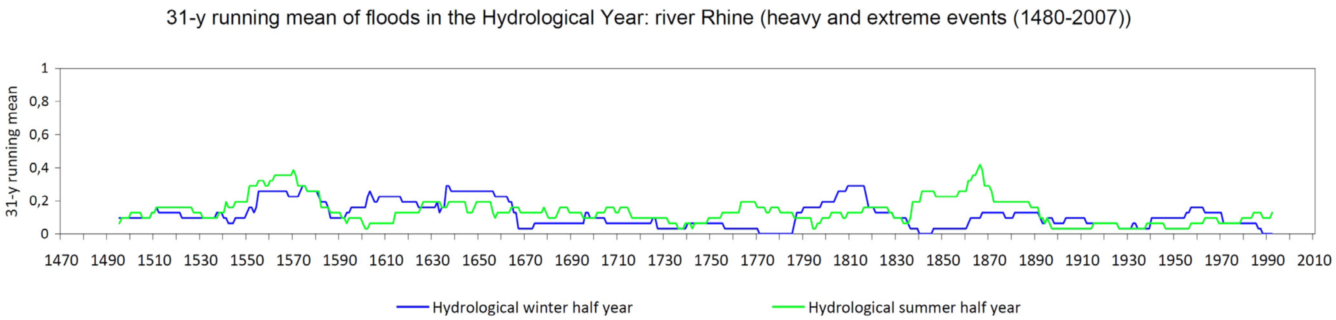


Figure 9. Floods of the river Rhine in the Hydrological Summer- and Winter-Year (big and extreme events)

Looking at the two most important tributaries of the river Rhine in the study area (the French Ill and the German Kinzig) it is noticeable, that up to the present day no major changes in the flood-regime has taken place (Figure 10 to Figure 13). It is evident, that most flood events occur during the hydrological winter half year with a strong increase in the total number since the second half of the 18th century. This however can most likely be attributed to a data related signal. Furthermore the Ill displays a noteworthy increase in summer flood events recently, which however is not triggered by extreme flood events.

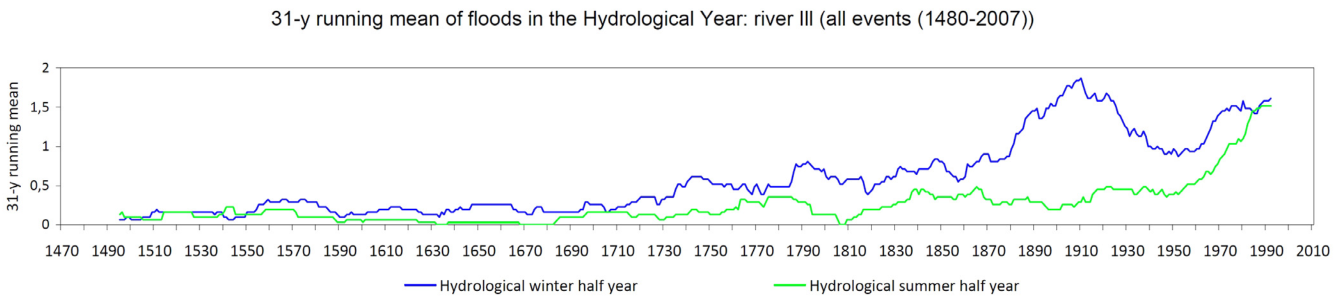


Figure 10. Floods of the river Ill (Alsace) in the Hydrological Summer- and Winter-Year (all events)

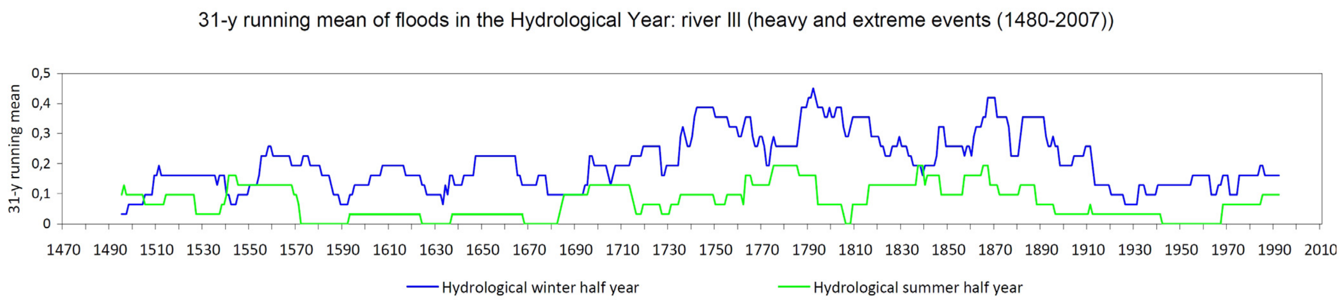


Figure 11. Floods of the river Ill (Alsace) in the Hydrological Summer- and Winter-Year (big and extreme events)

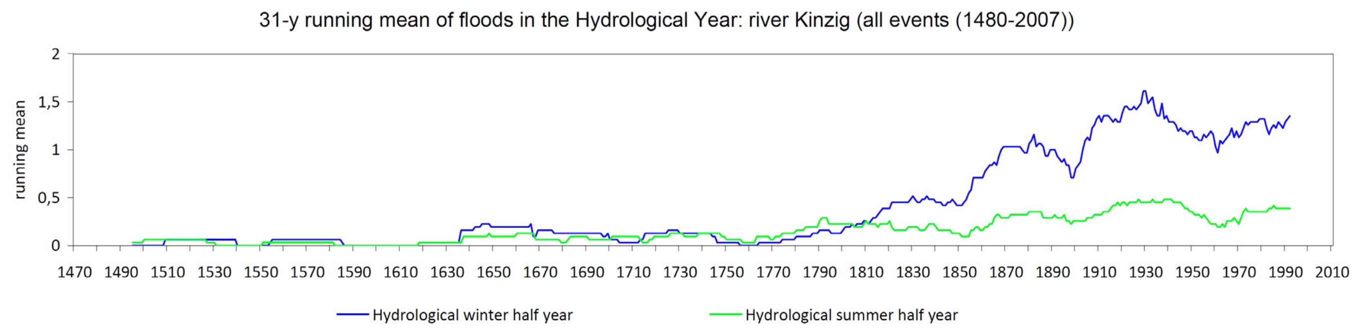


Figure 12. Floods of the river Kinzig (Baden-Wuerttemberg) in the Hydrological Summer- and Winter- Year (all events)

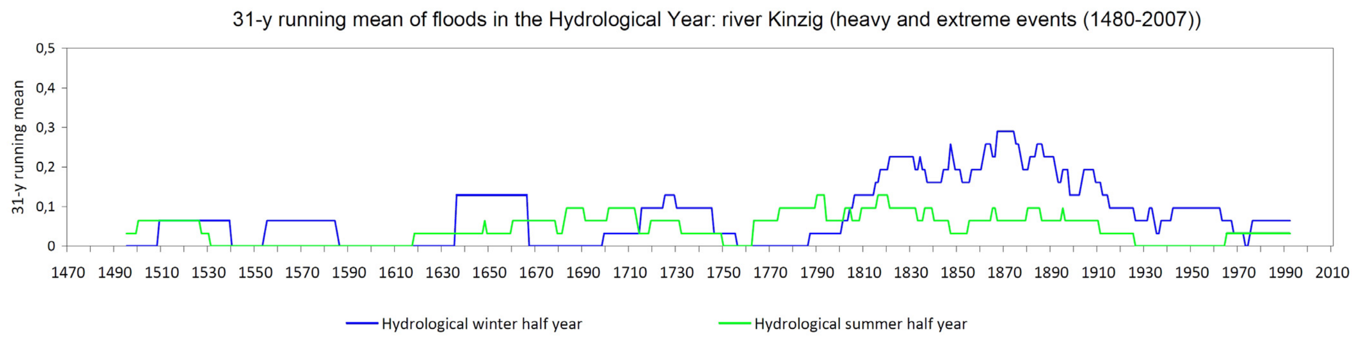


Figure 13. Floods of the river Kinzig (Baden-Wuerttemberg) in the Hydrological Summer- and Winter- Year (big and extreme events)

5. Trans-boundary aspects of flood protection

The different legal traditions of France and Baden led to different Flood protection concepts that exist in their essential features until today. The significant differences developed in the 17th century. Until that time flood protection on the non-navigable rivers was a particular interest of all those who had to or wanted to protect something alongside the river. Here the differences can be seen between the towns and the rural communities: rich towns, like e.g. Strasbourg, were able to protect their goods very well until wars or economic crisis made it impossible to pay the price for the flood protection or military arguments required a change. The little communes, resp. their habitants, had to protect their land on an unpaid basis, so only the most critical points were protected with dams, which were furthermore not conducted by technical knowledge, so in most cases their protection level was not very high and the lifespan of those actions was limited.

For the navigable rivers, like the river Rhine, there was not a big difference between the French and the German part of the research area regarding flood protection measurements: both sides relied on dams, sluices and other flood-protection projects since the 18th century. For the German part of the research area many particular states had been responsible: e.g. the Duchy of Baden, the Habsbourg-Monarchy and many sovereign landlords. That leads to the fact that the quality of flood-protection was not only a technical question, but also a question of financial opportunities and was coordinated neither between the different German authorities nor with the French side. However, the legal situation on both sides was similar: the responsibility for navigable rivers where by the highest authorities, but action was not always taken. In later times all contracts and plans could be handled out between the representatives of the states of France and the Grand Duchy of Baden. In 1840 the controlled and planned development of the river Rhine according to the plans and projects of Johann Gottfried Tulla (1770–1828) started (Himmelsbach, 2014).

The real difference in terms of flood control developed between Baden and France along the non-navigable rivers. To underline the political and administrative dimension of flood control it is necessary to analyze the different laws, bylaws and regulations concerning the flood control.

In France the riparian rights based on the Roman law, which means in this case, that every private and commune had to protect their particular owned land and goods for themselves. In other words: the non-navigable rivers were part of the owner's property. Only with their permission the administration could implement plans of flood protection. The start of the so called administration of the "Ponts et chaussées" in 1716 in Alsace, the French government tried to get access at least to the roads and bridges for military and economic connections from Paris to the river Rhine. In the following decades many bridges across the non-navigable rivers were renewed or built. But bigger and continuous flood protection projects were not possible because of the water-rights. Only where towns paid for the work of the administration, limited projects could have been brought forward like the canal protecting Mulhouse (see sect. 5.3.3). Neither the French administration after the revolution of 1789, nor the German administration between 1871 and 1919 were able to get a full access on these kinds of rivers. In the end flood protection in Alsace on the non-navigable rivers developed more as a chain of random individual actions. That led the consequence that the natural flood plains of the rivers had to be respected as a potentially unsafe area to settle.

In the German part of the study area the Grand Dutch of Baden followed another tradition of law: Since 1716, were parts of the river Murg (outside the study area) were rectificated to protect the town of Rastatt it was obvious, that the administration had no problem to see the non-navigable rivers as part of their responsibility. That claim was unchallenged since. The German riparian rights were first fixed in the so called "Sachsenspiegel" in the beginning of the 13th century. The non-navigable rivers became part of the feudal system which means that the feudal landowner had all rights on them. Without that legislation the work of Johann Gottfried Tulla and those who followed him would have never happened. In the state of the Grand Duchy of Baden the first attempt to work on the non-navigable rivers was done in 1816 by founding the first river training syndicate of the Grand Duchy of Baden ("1.Großherzoglich-Badischer Flussbauverband"), which was a result of the engagement of Johann Gottfried Tulla. The fact that the state incurred 2/3 of river construction costs offered at some rivers a "win-win-situation" between the state, the riparian and the communities. On other rivers, e.g. the Wiese, some communities left the syndicate (1822) to rejoin in 1882 after some serious floods (Bär, 1870; Zentralbüro für Meteorologie und Hydrographie des Großherzogtums Baden, 1887). Up to the middle of the 19th century nearly all non-navigable rivers in the Grand Duchy of Baden were canalized.

In Alsace the riparian rights prohibit technical flood protection outside the towns on the non-navigable rivers. The attempt of the French government, to challenge that by launching so called "river training syndicates" ("Syndicats fluviaux") failed because of the complicate structures, the insufficient support by the administration but most frequently because of the divergent interests of the members which had been ordered into them. One part was only interested in water for agricultural needs, the other part were industrials (mainly from the drapery), which wanted to canalize the rivers, to get constant water into their factories and to protect them against flooding. The farmers worried, that a canalization of the rivers hinders irrigating their land. This conflict could be solved neither by the French nor by the German administration after 1871. The only bigger project that was done was the correction work on the river Ill between Meyenheim and Colmar between 1878 and 1888 (Bordmann, 2004, Himmelsbach, 2014).

In a long-term consequence these different concepts of flood protection led to two different points of view regarding the natural stream channel: in Baden all rivers were canalized while in Alsace no significant flood protection was archived the natural flooding areas needed to be respected. In Baden-Wuerttemberg the attitude evolved, that behind the technical flood protection systems one can build nearly anything, from industrial areas to apartment houses. Now as the European Flood-Risk-Management directive from 2007 (EU 2007) is implemented by publishing the flood- and risk-maps, a big and controversial discussion has started in the concerned communities regarding the consequences for the private people and the enterprises, who reside near the rivers, what will happen to the prices of their properties besides the rivers (and behind the dams) and which possibilities will the enterprises have in the industrial areas (which in many cases were placed in the natural flood areas) if they want to expand?

5.1 Vulnerability analysis

Historical sources provide not only information about floods and climate but also on damages and impacts on society, which can be used to analyze vulnerability and resilience aspect. Both, hazards and vulnerability are fundamental elements of risk analysis. One major task of the TRANSRISK project is to bridge modern and historical information.

While there are convincing examples concerning flood events and hazard analysis, the concepts to evaluate vulnerability is subject of recent and further research. Integrating historical gauging data for definition of return periods like the mega-flood of 2002 at Dresden leads to a significant changed reassessment of this important parameter. Taking the gauging data from 1879-2002 into account in comparison to merely using the data for the time period from 1936 to 2002, changes the return period from a HQ1000 to a HQ150 (Grünewald, 2010). A case study for the extreme flood event 1824 at river Neckar at Stuttgart showed that flood events, water level, return period and rainfall intensity were underestimated using modern data alone. For this purpose, historical data on precipitation pattern and intensity and inundation areas were incorporated into modern the hydrological budget model LARSIM (Bürger et al., 2006) and led to a redefined design flood for the river Neckar. Pfister et al. (1999) underlined the importance of the social dimension and can be regarded as first step for vulnerability assessment.

The below given examples for the river Dreisam and Mulhouse demonstrate, how HQ100 events can be used for a better understanding of the spatial dimension of flood extent and damages and to evaluate vulnerability aspects as integrating part of modern and historical flood risk management.

For the tributaries of the river Dreisam, the flooded areas at the water bodies category II east of Freiburg had been compared with the modern HQ50 and HQ100 flood prone area as lined out by administration authorities as part of the risk maps of the European water directive (EU 2007; Santato et al., 2013; Kjellgren, 2013) and the actual status of the bridges within a HQ100 or higher event was added to underline our point of an missing flood protection of the water bodies category II.

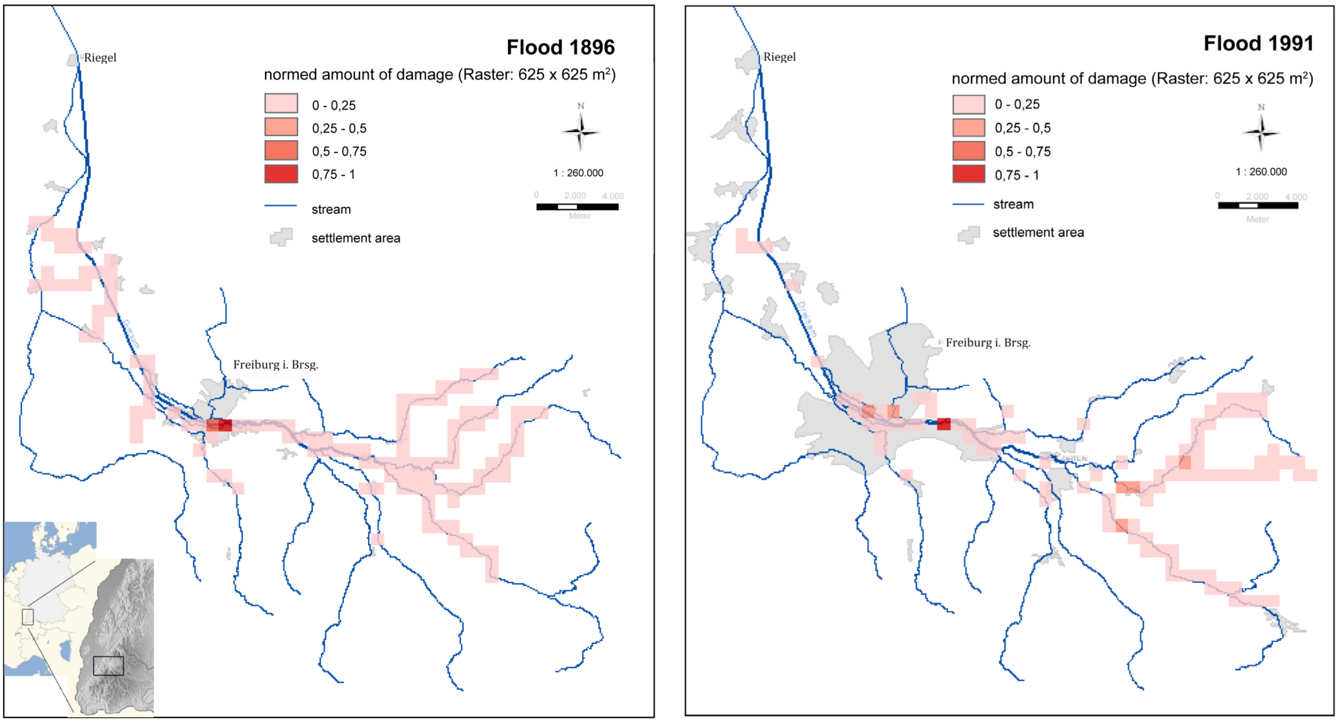
For Mulhouse it was possible to reconstruct the build-process of the so called “Canal de décharge”, a major part of the flood-protection system of Mulhouse, which was started in the early 19th century, as an example for the a historical dealing with flood-risk-management accompanied by technical problems.

5.1.1 River Dreisam: Flood March 1896 vs December 1991

For parts of the German river Dreisam catchment area it was possible to summarize and map the damages, which were caused by two HQ_{100}-events. To show the differences between the damage of the two flood- events, we worked with raster maps (1:25000), to get a spatial view of the concentration of the damages, like on bridges, sluices dams and the areas which were flooded. We normalized the damage in four classes from “no damage” (white) to “high damage” (red) (Jeworutzki, 2010).

In Figure 14 different patterns for the damages can be observed which are specific to each flood situation. For the inner city of Freiburg the comparison shows that the damages in 1896 had been more concentrated along the Dreisam river itself, while the one of 1991 had been more disperse around the modern city and also touches a canal in the city. The map of the accumulative damages for 1896 shows that the smaller villages like Zarten have been much more affected by the flood than the city of Freiburg.

The background for this observation is the fact, that the part east of the city of Freiburg (some of the tributaries of the river Dreisam) were and are not protected in the same way against floods: there are no dams along the river and the creeks. Anyway there was an increase of human activities during the last 100 years in this region, concerning settlements and industrial areas. The displayed tributaries are waterbodies of the category II, and the responsibility of their flood protection lies in the hands of the communities, which hadn't had the financial resources and /or the knowledge to take the needed actions. Both developments led to the fact that the pattern of the damages on the tributaries had not changed very much between 1896 and 1991 in total. However in the upper parts of the researched creeks the more damage was caused. However it had to be noted, that due to a multitude of reasons the available data is in all likelihood not complete. So the spatial distribution of the damages might to a certain degree also be influenced by the data availability.



Spatial damage raster of the Dreisam catchment area

Spatial damage raster of the Dreisam catchment area

Figure 14. Normed damages of the floods from March 1896 (left) and December 1991 (right) near Freiburg

5.1.2 Comparison of flooded areas of 1896 and 1991 with modern HQ50 and HQ100 risk maps

The comparison of the flooded areas of the 1896 and 1991 flood with modern HQ50 and HQ100 inundation areas as published by LUBW (Regional planning authority of Baden-Württemberg) as part of the EU water directive (EU 2007) shows that the modelled areas do not always correlate with those which actually had been flooded in recent events. In addition it seems that important actions had not been taken since 1991. So bridges and their bases were not up to a HQ100-event, because they are either weak constructed or their spread was too small so that swells could be caused (Figure 15). Even if the results from past flood events cannot be translated into modern times without adaptation the comparison of the flooded area from the 1896 and the 1991 events with the expected flood area of a future HQ-100 event demonstrates that at a local scale the necessary (technical) development of the creeks and rivers is not only a question of perception but also of planning intervals, communication processes with the affected local administration and the financial priorities and the acceptance of the planned measures by the residents.

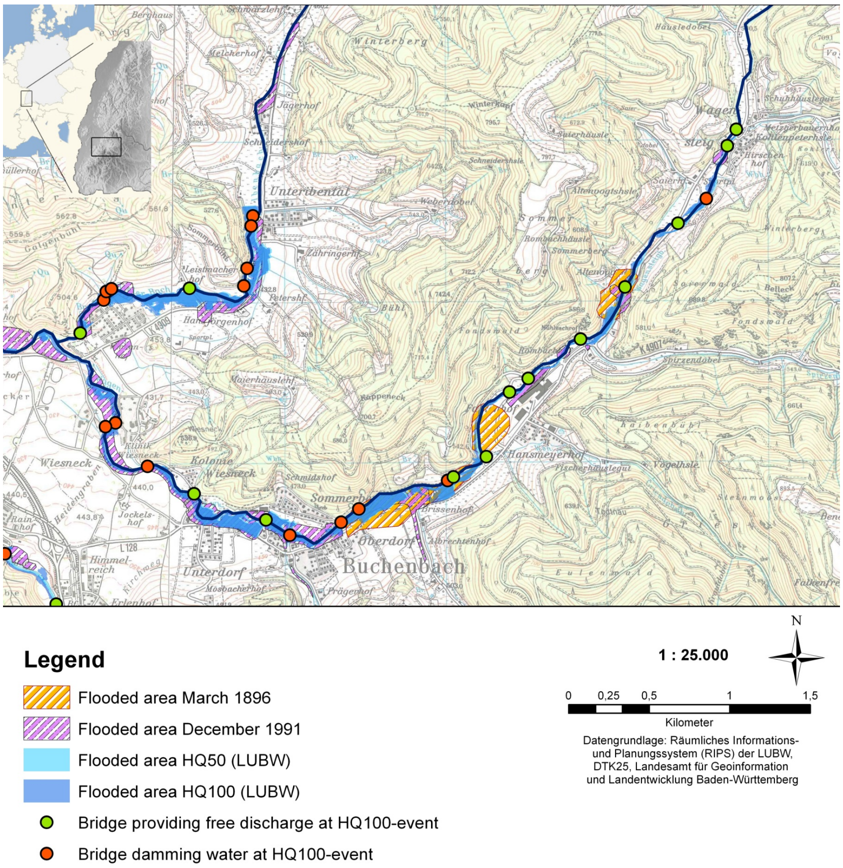


Figure 15. Comparison of flooded areas of 1896 and 1991 with modern HQ50 and HQ100 inundation areas as published by LUBW as part of the EU water directive (EU 2007).

5.1.3 Mulhouse – Changes in flood frequency due to technical alterations

For the city of Mulhouse and the river Ill an analysis shows that technical alterations, in the case of Mulhouse the building of a diversion canal (“Canal de décharge”), had positive effects on flood events and flooding of the city of Mulhouse. There was only one major flood event in 1924 after the establishment of this bypassing channel. The situation is very different for the rest of the Ill basin, where such strong technical alterations were not possible due to water rights.

In Figure 16 an inventory of the historic floods in the basin of the Ill and a classification in a scale of three levels of damage is shown. Two separate chronologies are displayed, in order to compare the evolution of the number and intensity of the damaging floods, respectively in Mulhouse and in the rest of the Ill basin.

The comparison between the two chronologies turns out to be very instructive for the evaluation of the process of increasing the safety against the flood risk for Mulhouse, which is mainly due to the role of the channel. Its construction has an impact on the random effects of flooding (due to its indirect influence on the dynamics of floods) and thereby on the vulnerability of the city, through the protection it provides, enabling the urbanization, which became possible after its completion.

Until 1860 there is a high coherence between floods at Mulhouse and the rest of the basin as to the number and intensity of the floods. So, the efficiency of the diversion canal has only become manifest very progressively. There was a huge demand for building land, and the urbanization (factory buildings and housing estates) was carried out in parallel with, and even in anticipation of the construction of the canal.

And the new districts, working-class and industrial, developed on land liable to flooding, were those that proved highly vulnerable owing to the weaknesses of the early versions of the canal. Conversely, after the year 1905 when the final version of the canal was completed, Mulhouse appears clearly marked off from the rest of the Ill basin, with fewer and above all less damaging floods (Martin et al., 2010; Martin et al., 2011).

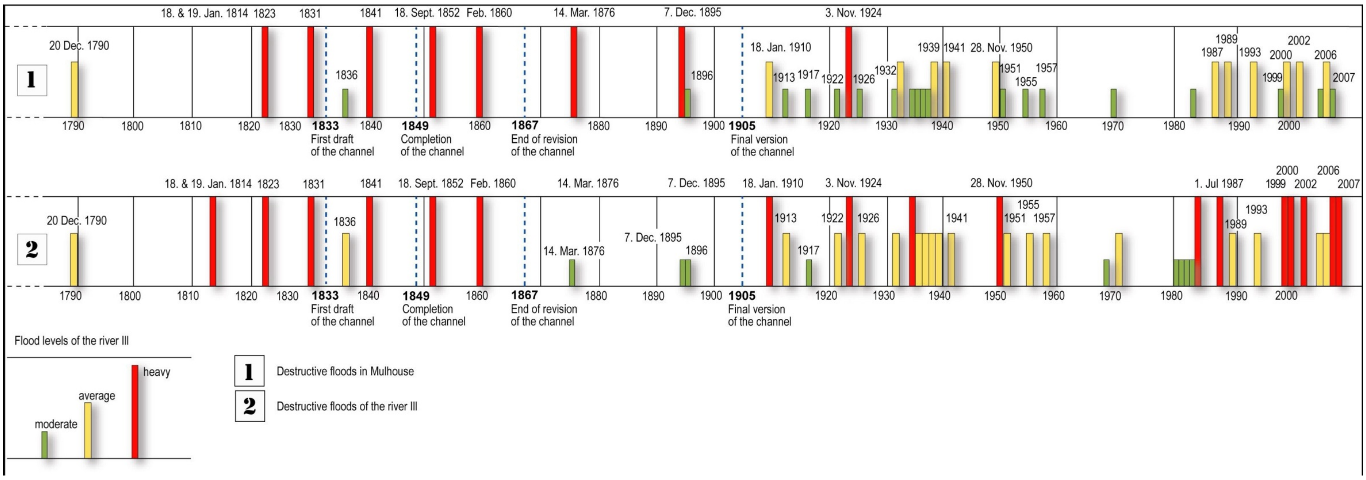


Figure 16. Changes in flood intensity due to technical alterations in Mulhouse

6. Conclusions

The French-German transboundary project Transrisk demonstrates that it is feasible to identify record and evaluate historical flood events on both sides of the border with high temporal and spatial resolution from documentary sources by using a common classification scheme. Often the sources itself contains additional information which allow for detailed insights into flood hazard and flood hazard perception. The derived 500 yearlong flood chronology identified different spatial patterns of flood concurrencies which reveal local, regional and supra-regional dimensions of flood events. The identification of flood triggering meteorological causes allows identifying changes in the climatological flood regime.

Regarding the social-political context, flood control was exploited for political objectives in many time periods on both sides of the border. The border is clearly reflected in the risk perception but also risk management and risk assessment. This aspect clearly shows the different history of the both nations as far as legal water-rights is concerned, which leads to different ways of flood-protection: The German side set focus on a technical development of the rivers. In Alsace this was legally not possible so the flood plains remained an unsafe place to be and had to be evited.

The examples of the river Dreisam and Mulhouse show, that the derivation of damage maps from historical sources as part of the vulnerability analysis is also possible. Especially the example of the river Dreisam shows, that the vulnerability on minor tributaries could increase if the flood-protection measurements will not keep pace with the development of the human occupations of the riverside. Since 2007 the flood risk management is controlled by the EU-policies (EU 2007) which does not extend to small tributaries, flood risk management remains in the responsibility of the communities.

For the future it is necessary to focus on risk perception, risk acceptance and the communication structures between the administration and the concerned persons regarding the implementation of flood protection systems also on minor tributaries in congested areas. This could lead to a comprehensive and integrative flood risk management. The aim should be a holistic understanding of the flood risk management, which traces the changing aspects in perception, policy decisions, assessment of technology and the role of risk- and public-discourse at the interface between climate change and social conceptualization in their temporal dynamics.

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