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Flood risk along the upper Rhine since AD 1480

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Abstract

This paper presents the occurrence, cause and frequency changes of floods, their development and distribution along the southern part of the upper Rhine River and of 14 of its tributaries in France and Germany covering the period from 1480 BC. Special focus is given on the temporal and spatial variations and underlying meteorological causes which show a significant change over space and time. Examples are presented how long-term information can help to improve transnational risk and risk management analysis while connecting single historical and modern extreme events.

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. Flood research on smaller rivers presented in this paper complement those related to larger river systems for two main reasons: first, creeks and small rivers show a more direct response to the atmospheric forcing and second, especially smaller catchment areas are subject to major land use changes and alterations in the floodplain due to increase in settlement areas and infrastructure. The flood risk management of these smaller catchments resides with the legal responsibility of smaller communities while the large river systems are under control of larger and stronger administrative units. 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 define the area of the flood risk along a river and his zonage in different sectors where different human activities are allowed or forbidden (see Sect. 6).

This study presents the flood history of 14 tributaries of the river Rhine on the French and German side as well as floods of the river Rhine between Basel and Strasbourg itself. The analyzed time period stretches from 1480 to 2007. The results presented here emanate from the project TRANSRISK, which was realized between 2008 and 2011 in collaboration between CRESAT of the University de Haute Alsace in Mulhouse and the department of Physical Geography of the Albert-Ludwigs-University of Freiburg, funded by the French "Agence Nationale de la Recherche" (ANR-07-FRAL-025) and the "Deutsche Forschungsgemeinschaft" (DFG-GI 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 (Fig. 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 to 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" ("Burgundische Pforte"). This however might only happen in less than 10 % of the year. The westerly winds and approx. 1000 m of mean height difference between the rims and the valley floor account for a heterogeneous precipitation within the Upper Rhine valley. Precipitation varies greatly from as little as 550 mm a^{-1} at Colmar to approx. 1000 mm a^{-1} around Freiburg representing the leeward and windward side of the valley floor. Two precipitation maxima can be identified in the course of the year: one in July and another in December (mountain range). The July-maximum is generated mainly by convective rainfall, resulting usually from thunderstorms.

Large parts of the study area belong to the European Region “RegioTriRhena”. Nearly the whole study area also belongs to the Trinational Metropolitan Region “Oberrhein” (TMO-MRO) a multicore, tri-national conurbanisation with Bale, Freiburg, Lörrach and Mulhouse for the RegioTriRhena and Karlsruhe and Strasbourg for the MRO. The region is inhabited by more than six million people and is characterized by industrial hotspots of the chemical, pharmaceutical, automobile and food industry as well as by education and administration units. The MRO also serves as a European traffic junction and stands for a highly productive agriculture as well as for cultural and historical high lights. The area is also well known for innovative ideas in civil societies, likewise participation and alternative life style and manifold recreation possibilities. An increasing population and a – in comparison to the European average – younger population are some more indicators. 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. All in all the density in economic, scientific, cultural and societal values is very high; some of them are vulnerable to floods.

3 Material and methods

Within the TRANSRISK project the Rhine between Basel and Strasbourg and 15 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 as of yet been conducted. So the first interest was to reconstruct the flood events between 1480 and 2007, their meteorological causes and their temporal distribution. As data source written evidence, flood-marks, drawings, flood-maps, newspapers, gauges data and contemporaneous administrative reports and chronicles had been considered. Flood-risk-management and perception had been analyzed on the basis of well-established methods introduced in Historical Climatology such as critical source analysis, the derivation of indices and the analysis of the hydro-climatic factors (Pfister, 1985; Glaser and Stangl, 2003; Jacobeit et al., 2003a, b, 2006; Glaser et al., 2010; Wetter et al., 2011; Himmelsbach, 2014).

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 distinguish 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.

4 Data set

At last a total 2830 flood-events could be found and evaluated within the research area. In Germany we identified 1302 events with an emphasis on the 20th century. In contrast to that most of the flood events identified on the French side dates earlier than the 19th century. A reason for that can be found in a higher number of written chronicles which had been passed through time in France. However not as many gauge data had been collected in France in comparison to the German side (Table 2).

5 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.

5.1 Occurrence and definition of spatial patterns of flood types

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 at the German tributaries and Floods on French and German tributaries. These types are described below (see Figs. 2 to 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.

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”: low pressure systems cause intense and persistent westerly air flow to the Upper Rhine Valley and initiate an early Christmas thaw. Rain up to the summit level further speeds up the snowmelt the frozen ground however prohibits the melt- and rainwater to infiltrate causing surface runoff (Weischet and 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.

5.2 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 and Stangl (2003) and Glaser et al. (2010) focus 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. 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 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 shows a significant increase of convective-rain-events – with one exception the Wiese, while ice break-up almost vanished in modern times. 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 Fig. 7).

In a second step the changes in seasonality have been analysed. 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). From our data it is evident, that only during a period lasting from the 1820th to the 1860th the river Rhine displayed pronounced summer runoff. That event might be linked to the ending of the Little Ice Age (LIA) around 1850. But 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 changed the runoff regime. 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 Fig. 8). In contrast to the period around the 1950th where the elevated winter runoff did not occur in conjunction with extreme events (see Fig. 10), the period at the ending of the LIA was, at last to a certain degree, induced by 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 (Figs. 10 to 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.

5.3 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 analyse 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 (Grünewald, 2010; Bürger et al., 2006), the concepts to evaluate vulnerability is subject of recent and further research. Integrating historical gauging data for definition of return periods likewise 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 HQ_{1000} to a HQ_{150}. A case study for the extreme flood event 1824 at river Neckar at Stuttgart showed that flood, 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. Pfister et al. (1999) underlined the importance of the social dimension and can be regarded as first step for vulnerability assessment. The given examples for the river Dreisam and Mulhouse demonstrate, how HQ_{100} events can be used for a better understanding of the spatial dimension of flood damages and to evaluate vulnerability aspects as integrating part of modern and historical flood risk management.

In a second approach, the flooded areas had been compared with the modern HQ_{50} 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).

5.3.1 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 : 25 000), to get a spatial view of the concentration of the damages, like on bridges, sluices dams and the areas which were flooded. We determined, that a raster-cell of 625 m^2 fits best in this case to show the normalized damage in four classes from “no damage” (white) to “high damage” (red) (Jeworutzki, 2010).

In Fig. 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 is the fact, that the part east of the city of Freiburg is not protected in the same way against floods: there are no dams along the river and the creeks. There was an increase of human activities during the last 100 years in this region, concerning settlements and industrial areas. Both developments led to the fact that the pattern of the damages in this region has not changed very much between 1896 and 1991.

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

The comparison of the historical inundation areas of 1896 and 1991 events 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 more differentiated and partly contradictory pattern (Fig. 15). After 1991 only minor changes in the riverbed and small flood protection measurements were establisched (Riach, 2014). There is an ongoing debate whether differences are due to modern alterations and land use changes or misinterpretation and incomplete modelling.

5.3.3 Mulhouse – changes in flood frequency due to technical alterations

For the city of Mulhouse and the river Ill a 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 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 contradicting water rights.

In Fig. 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 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, 2011).

6 Trans-boundary aspects

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: On both sides one worked on dams, sluices and other flood-protection projects since the 18th century. But the quality of the technical protection buildings was not only a technical question, but also a question of financial opportunities and was not coordinated between France and the German domains along the Rhine. First in 1840 a contract was handled out between the states of France and the Grand Duchy of Baden, which leads to a controlled and planned development of the river Rhine according to the plans and projects of Johann Gottfried Tulla (1770–1828) (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 analyse the different laws, bylaws and regulations concerning the flood control. While there had been a distinct flood control in the different communities mostly by fishermen and by associations (Genossenschaften) the official regulative started on the German side after the foundation of the Grand Duchy of Baden in 1806 whereas on the French side the first administration for bridges and roads, the "Corps des ingénieurs des ponts et chaussées" already started their work nearly 100 years before in 1716.

Therefore, the administrative experience with the flood regulations has a much longer tradition on the French side. In the following decades after 1716 many small regulations were conducted, in most of the cases where the main roads in Alsace cross rivers. This was mainly due to the legal situation regarding the non-navigable Rivers, which were neither in Alsace nor in Baden accessible to the state but under control of the respective landlords. Even changes in the legal system after the French Revolution and during the Napoleonic era were not able to change this: The French riparian rights based on the Roman legal tradition, where the non-navigable Rivers were part of the owners property. Only with their permission the administration could implement her plans.

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 (1770–1828). This was only possible, because the Grand Duke of Baden had the self-concept of being not only the sovereign of the people but also landlord for all types of the rivers in his country. This position reminded undisputed. 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 build so called “river training syndicates” (“Syndicats fluviaux”) failed in this time 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 to them: One part was only interested in water for agricultural needs, the other part were industrials (mainly from the drapery), which wanted to canalise the rivers, to get constant water into their factories and to protect them against flooding. The farmers worried, that a canalisation of the rivers led to a loss of the possibility to irrigate their grassland. This conflict could be solved neither by the French nor by the German administration after 1871. The only noticeable 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 one has to respect the natural flooding areas. So in Baden-Wuerttemberg the attitude evolved, that behind the technical flood protection systems one can build nearly anything, from industrial areas to apartment houses. In France one has to respect the natural flood areas at the non-navigable rivers and as a consequence, flood protection gets part of a site protection. Now – 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?

7 Conclusions

The reconstruction of historical floods at high spatial and temporal resolutions allows detailed insights into flood hazard and flood hazard perception. The spatial patterns of flood concurrencies reveal local, regional and supra-regional dimensions of flood events.

Changes in flood frequencies (long-time series) are not coherent between the different rivers and tributaries. The reconstruction of underline climatological causes is possible at different scales and leads to a clear and systematic image. The derivation of damage maps as part of the vulnerability analysis is also possible. It's even more detailed in the historical context due to the restrictive regulations on public data access in modern times. Flood control was exploited for political objectives in many times on both sides of the border and the border is reflected in the risk perception but also risk management and risk assessment clearly. Since 2007 the flood risk management is controlled by the EU-policies (EU 2007) but we see many differences in the implementation on the regional and local level, where uncertainties occur, regarding the perspective of private and economic operations in the future.

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

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 [Return-period up to 20 years]	Little damage	Short flood	Little (local) supporting measures
2	Above-average, big or supra-regional flood [return-period 21–100 years]	Average damage	Flooding of average duration to few days	Coordinated supporting measures with participation of regional organizations
3	Extreme/supra-regional flood of a catastrophically dimension [return-period is higher than 100 years]	Serious damage	Long-lasting flooding (several weeks)	Supra-regional (national), coordinated measures of major extent

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

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	1201
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	1302
Rhine	28	81	41	28	86	59	4	327
Total amount:								2830

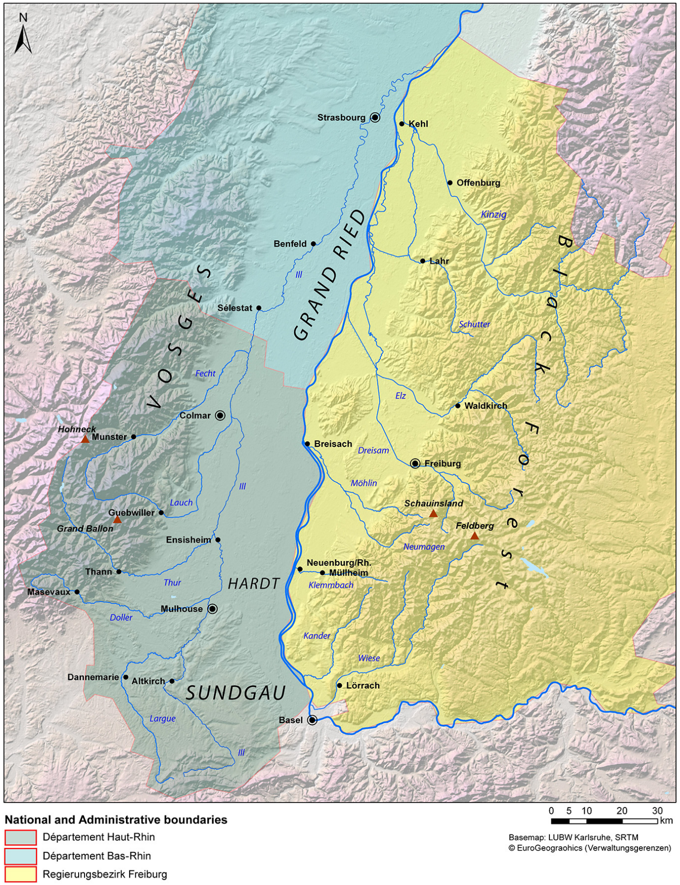

Figure 1. Study area including the researched rivers and actual administrative districts in France and Germany.

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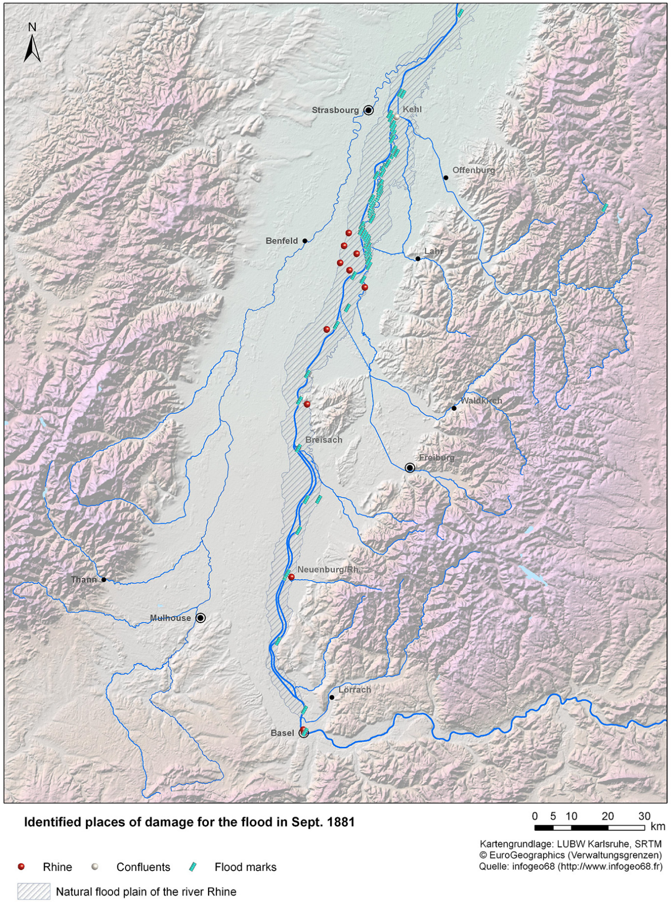

Kartengrundlage: LUBW Karlsruhe, SRTM
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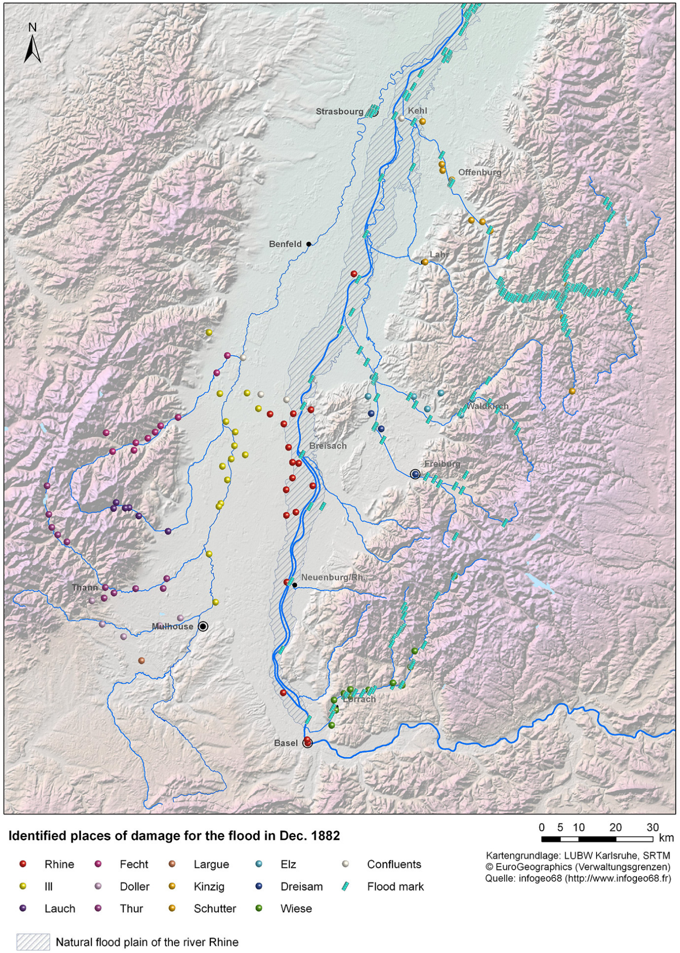
Quelle: infogeo68 (http://www.infogeo68.fr)

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



Identified places of damage for the flood in Dec. 1882

Kartengrundlage: LUBW Karlsruhe, SRTM
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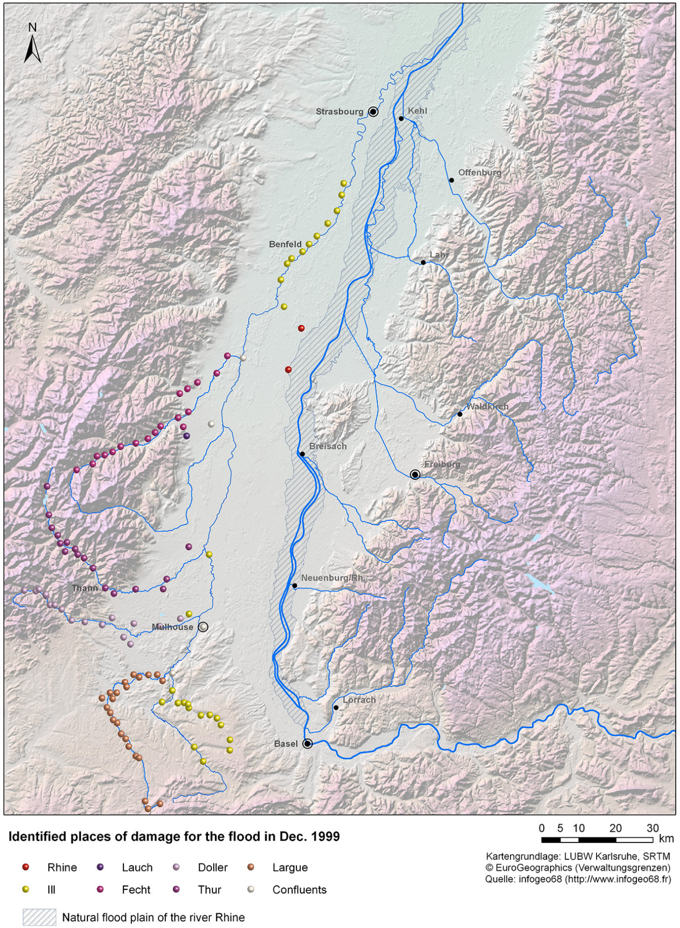
Quelle: infogeo68 (http://www.infogeo68.fr)

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



Kartengrundlage: LUBW Karlsruhe, SRTM
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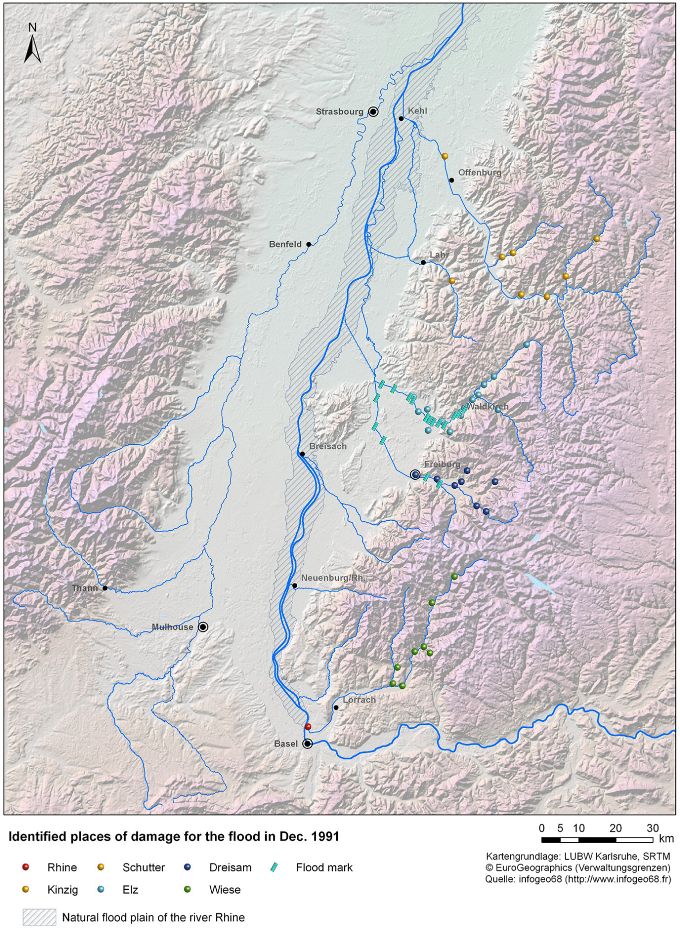
Figure 4. Damage map of the flood in December 1999 (Type 3).



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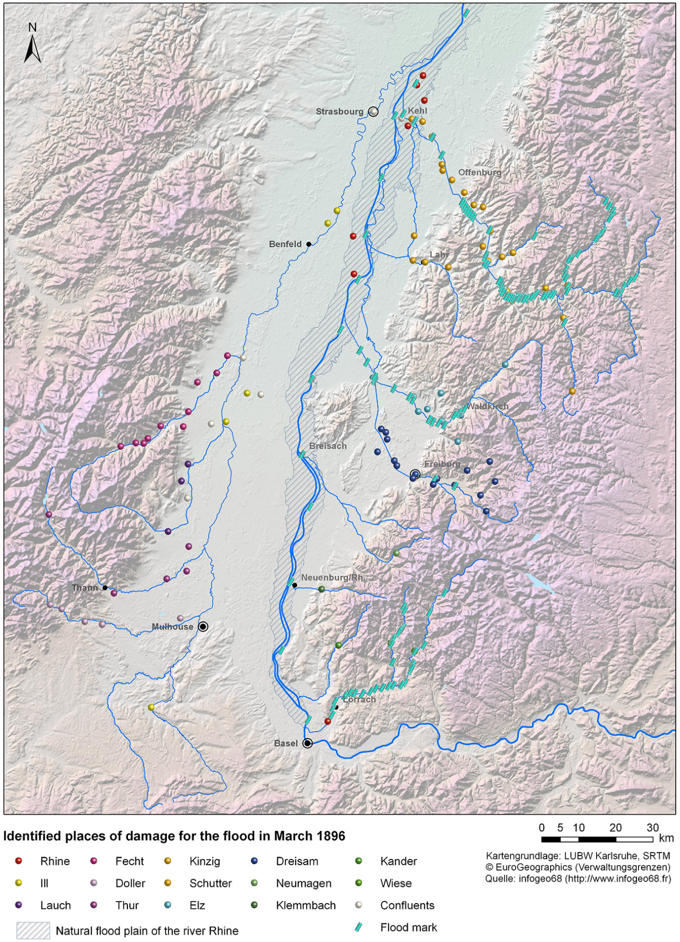
Quelle: infogeo68 (http://www.infogeo68.fr)

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



Kartengrundlage: LUBW Karlsruhe, SRTM
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Quelle: infogeo68 (http://www.infogeo68.fr)

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

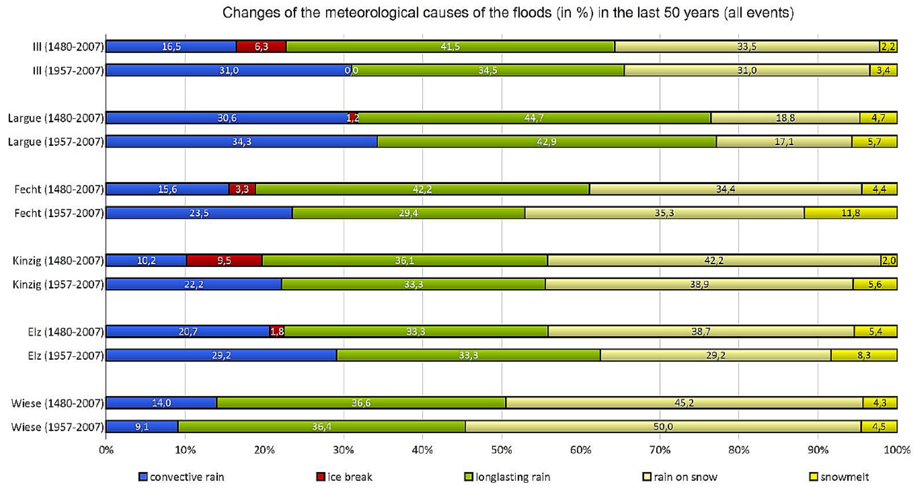

Figure 7. Changes of the meteorological causes of the floods in the last five decades in comparison to the period from 1480–2007.

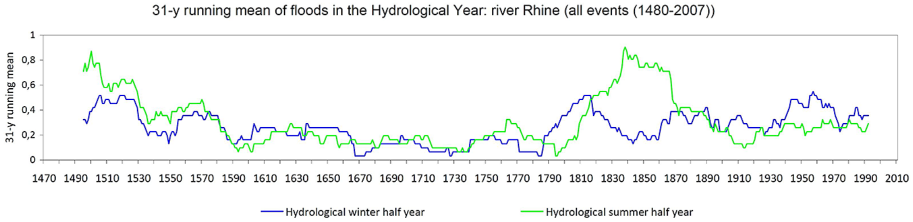

Figure 8. Floods of the river Rhine in the Hydrological Summer- and Winter-Year (all events).

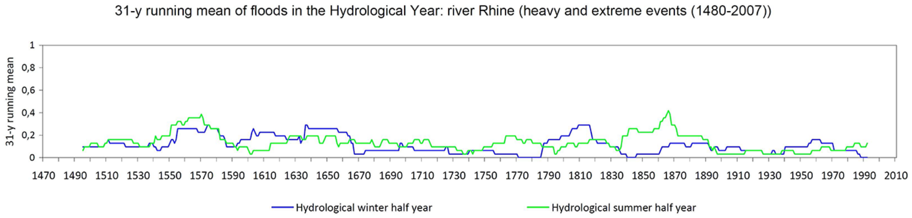

Figure 9. Floods of the river Rhine in the Hydrological Summer- and Winter-Year (big and extreme events).

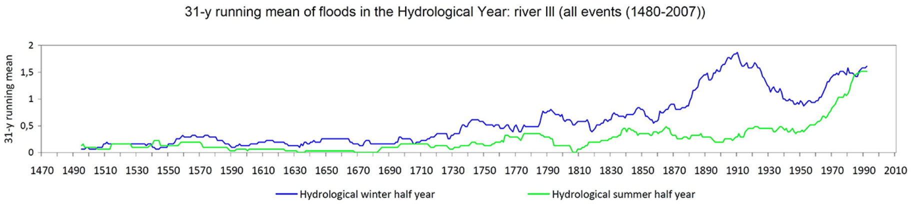

Figure 10. Floods of the river Ill (Alsace) in the Hydrological Summer- and Winter-Year (all events).

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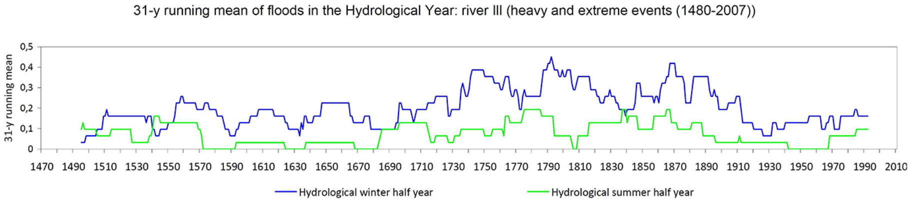


Figure 11. Floods of the river Ill (Alsace) in the Hydrological Summer- and Winter-Year (big and extreme events).

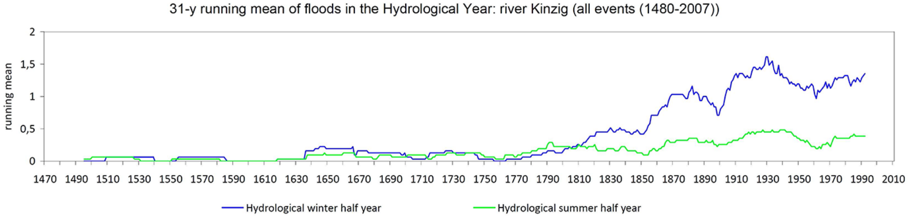


Figure 12. Floods of the river Kinzig (Baden-Wuerttemberg) in the Hydrological Summer- and Winter-Year (all events).

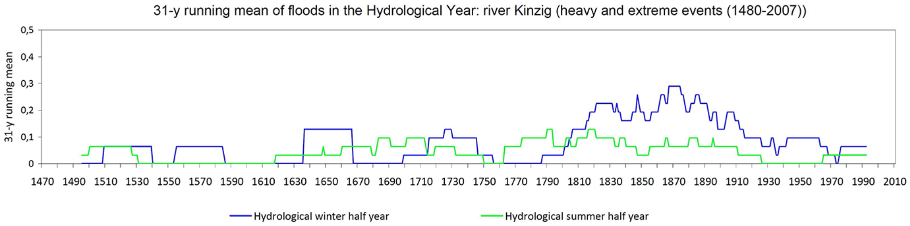
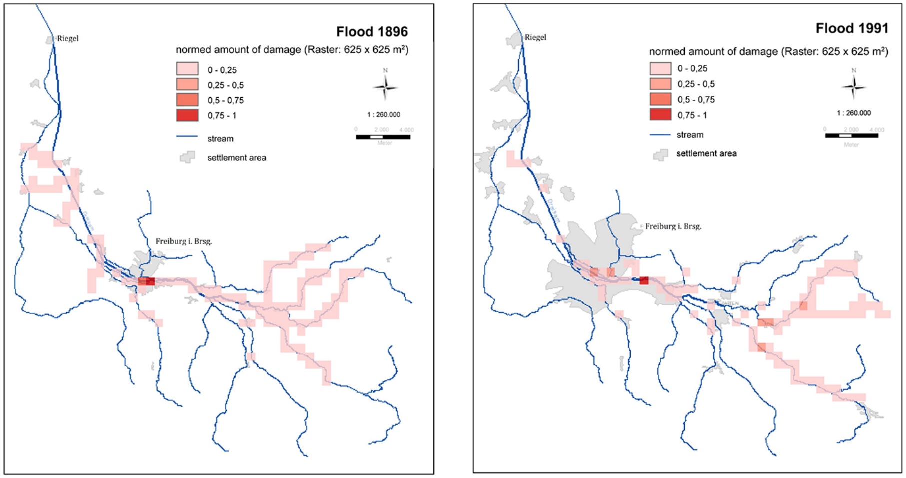


Figure 13. Floods of the river Kinzig (Baden-Wuerttemberg) in the Hydrological Summer- and Winter-Year (big and extreme events).



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.

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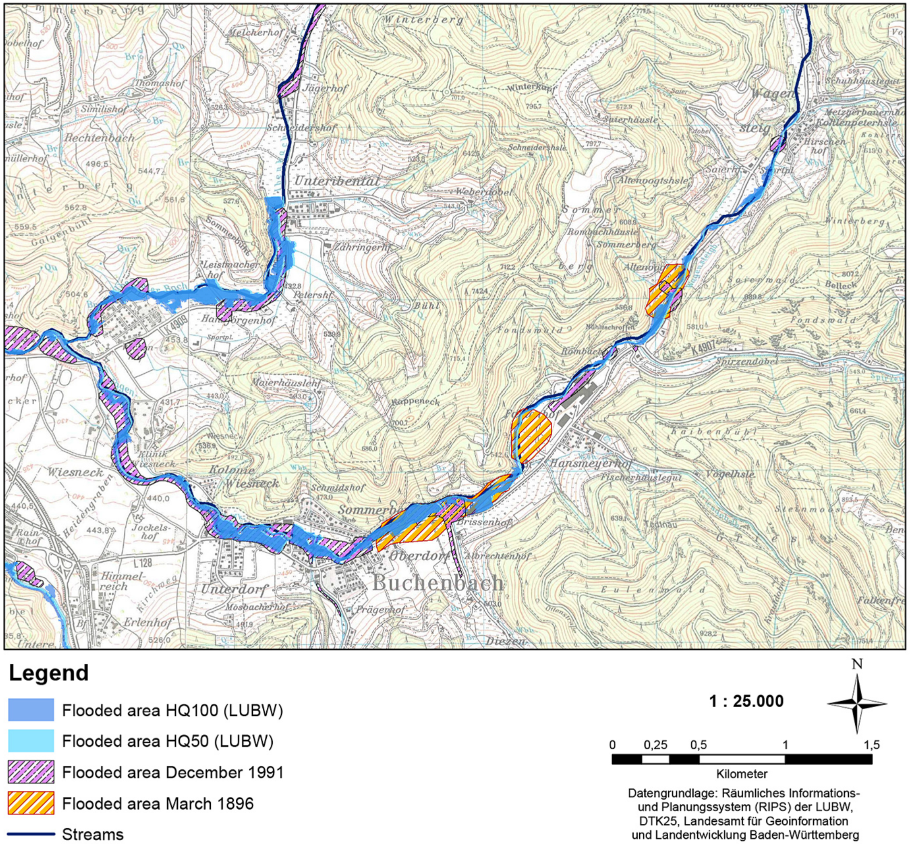

Datengrundlage: Räumliches Informations- und Planungssystem (RIPS) der LUBW, DTK25, Landesamt für Geoinformation und Landentwicklung Baden-Württemberg

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).

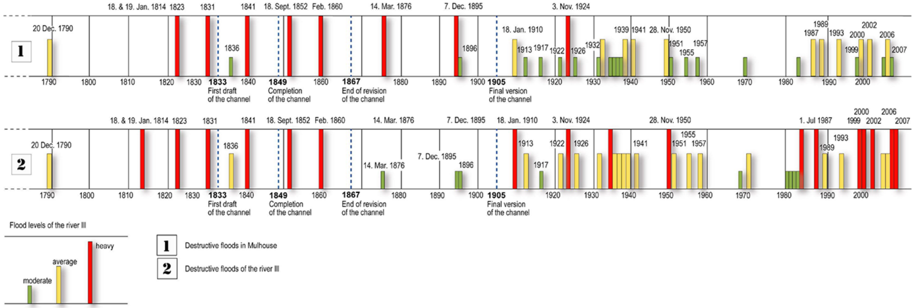

Figure 16. Changes in flood intensity due to technical alterations in Mulhouse.