The "Prediflood" database of historical floods in Catalonia (NE Iberian Peninsula) AD 1035-2013, and its potential applications in flood analysis

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Abstract

"Prediflood" is a database of historical floods occurred in Catalonia (NE Iberian Peninsula), beetween 11th Century and 21th Century. More than 2700 flood cases are catalogued, and more than 1100 flood events. This database contains information acquired under modern historiographical criteria and it is, therefore, apt to be used in multidisciplinary flood analysis techniques, as meteorological or hydraullic reconstructions.

Keywords:
historical floods, database, historiographical criteria, multidisciplinary flood analysis

1. Introduction

Floods have always been among the most destructive natural hazards, in part due to the traditionally high exposition and vulnerability of most human settlements. Indeed, only between 1998 and 2009, Europe suffered more than 213 severe floods, which caused 1126 casualties, the displacement of half a million people and more than EUR 60 billion in economic losses (EEA, 2010).

Unfortunately, both the frequency and magnitude of floods are likely to increase in the near future due to climate change, thus worsening the effects of floods on the human population. This is all the truer in the Mediterranean region, where climatic models foresee an increase of rainfall irregularity: in Catalonia (NE Iberian Peninsula), for the period 2070-2100, the models estimate a 15% decrease in total rain depth but, at the same time, a 15-30% increase in the number of days with heavy precipitation (Barrera and Cunillera, 2011). In central Europe, torrential precipitations will also increase in the near future, although this cannot be assured to cause an increase in river flows, due to the short length of the data series (IPCC, 2014; Kovats and Valentini, 2014).

The increase of flood hazard will force the undertaking of protection measures, which are going to need information about floods frequency and magnitude. Unfortunately, river flow instrumental series are usually too short (when they exist at all) to analyse low frequency events, such as flash floods (Gaume *et al.*, 2009).

However, these series can be lengthened with historical floods information. In this sense, the European Union Floods Directive on the assessment and management of flood risks, 2007/60/EC of the European Parliament and of the Council, 26 November 2007 encourages the use of historical information in flood risk assessment.

Regrettably, historical floods compilations in Spain have always had a low quality, due to the lack proper historiographical methods and, hence, they are useless in flood risk assessment. Actually, in order to ensure a good quality of information, historical floods compilations in Spain should be created anew.

The main objective of this article is to present the "Prediflood" database, a new database of historical floods in Catalonia that encompasses the period AD1035-2013, created from scratch with modern historiographical methods; a secondary objective is to show its potential applications in flood analysis and in flood risk assessment. More specifically, this article describes the process of creation of the "Prediflood" database from past experiences, the issues that can be improved and the potentiality of the organized information. Initial research project, where this work is framed (see acknowledgements), analyzes past 500 years but data collection does not set time limits to the information found. This process is an opportunity to reassess previous procedures and to incorporate historiographical criteria regarding the sources of information.

PREDIFLOOD is acronym of a Spanish research project. The general aim of the project is to improve the capacity of ***Predi***ctivity on ***Flood*** events after a large collection of historical information and modern data for all possible flood events in our study area. With these materials, hydraulic-hydrologic reconstructions and synoptic meteorological reconstructions will improve the knowledge enough to produce tools for improvement of preventive/early warning procedures for risk management situations.

Considering topography and climatology of Catalonia, with large number of ungauged basins, small dimension of basin but strong torrential rainfall events and high demographic concentration on the littoral in conflict with mouth of rivers, improved knowledge on early warning procedures is strongly positive for management of these situations

2. Review of historical floods compilations in Spain

2.1 Early attempts in floods collection (1850-1980)

The first attempts to gather information on historical floods in Spain began in the second half of 19th century, with the prevalence of positivism in historiography. These attempts take advantage of the network of historical archives created and managed by the public administration. However, these first works lack scientific objectives beyond the mere compilation of data. On the other hand, period's context without technological resources, made impossible the systematic collection and analysis of large quantity of historical information and data. Consequently most of these works do not have minimum conditions, hence, many of these works do not meet the minimum historiographical rigor.

Nevertheless, some Spanish compilators took as a reference the work of the French historian Maurice Champion (Champion, 1858-1864). In this line, two local studies stand out: one in the town of Girona (Chía, 1861) and one in town of Murcia (Hernández, 1885), this last one including an analysis of the causes and effects of floods. A remarkable synthesis of all the basins in the Iberian Peninsula was also published (Bentabol, 1900).

The first half of the 20th century saw a stop in flood compilations due to a movement of rejection towards historiographical determinism. However, highly destructive floods occurred in this period reignited the interest in this area of research and several local works with an increasing methodological rigor appear, such as those of the Turia River (Almela, 1957), the Ebro River (Blasco, 1959), the Segura River (Couchoud, 1965), the Llobregat River (Codina, 1971) and the junction of the Ter and the Onyar rivers at Girona (Alberch *et al.*, 1982). At the same time, analytical studies began to appear, focused either on single events (Iglésies, 1971) or on the general characteristics of floods (López Gómez, 1983).

2.2 The involvement of the administration (since 1980)

In the last thirty years, the Spanish administration has made several attempts to gather historical floods information and to render it useful. More specifically, two types of organisms have led the way: basin authorities (called in Spanish "Confederaciones Hidrográficas") and civil protection authorities ("Dirección General de Protección Civil y Emergencias").

On the one hand, basin authorities early began to search and use information about historical floods as a complement of instrumental data, with the objective of better assess floods' frequencies, flows, duration and behaviour. To this end, they launched several initiatives of historical floods data collection. Unfortunately, the personnel involved in those projects were civil engineers and, therefore, with a poor background on historiographical methods; they looked for information in ill-organized compilations of uneven quality, which didn't allow a clear identification of the documentary sources. Furthermore, the information thus found was only used in comparing some extreme historical flood to those of the instrumental period and in creating flood chronologies that lacked any methodological criteria of exhaustiveness and, hence, had a mere informative objective. Besides all this, over the years, basin authorities have been placed under different ministries due to their diverse competencies on water (irrigation, drinkable water, waste water, infrastructures, taxes), and this hampered long-term projects, such as historical floods compilations.

Civil protection service is relatively recent in Spain (Law 2/1985, 21 January 1985). This new concept of emergency prevention and management gives a new challenge to collection and analysis of historical information. Indeed, this service needs greats amounts of reliable information in order to perform the multidisciplinary analysis required both in emergency planning (prevention, rescue, evacuation, safe and vulnerable areas) and in urban planning.

Membership of the European Union also places new demands. Water Framework Directive (2000/60/EC of the European Parliament and of the Council, 23 October 2000) defined new work elements on water resources management and their severe manifestations, as droughts and floods. But it was the EU Floods Directive (EU Floods Directive on the assessment and management of flood risks, 2007/60/EC of the European Parliament and of the Council, 26 November 2007), that, for the first time, specifically commanded the EU State members to assess flood hazard and risk. In Spain, this task was already underway with the mapping of flooding areas ("Sistema Nacional de Cartografía de Zonas Inundables", SNCZI).

Regarding historical floods, the transposition of the EU Floods Directive into the Spanish legislation (Real Decreto 903/2010, 9 July 2010), in its articles 6 and 7, define the use of historical information in flood risk assessment.

However, the results of the actions ordered by the EU Floods Directive are uneven in Spain. Instrumental information has been successfully catalogued and homogenised. But available historical information has not been thoroughly confirmed by systematically consult of reliable documentary sources. Indeed, in what regards historical floods information, the work has been reduced to organize and digitize the data from the previous flood compilations done by the basin authorities (Catálogo Nacional de Inundaciones Históricas, 2006-2010). This is a mere accumulation of information, but not an improvement in its quality, quantity or applicability, because the source compilations are fragmentary and they lack both flood selection criteria and references to primary documentary sources.

Unfortunately, this has been the usual procedure in the treatment of historical floods information until now. Therefore, although powerful software programmes support these modern compilations, their applicability in flood analysis is very limited and they are seen as mere collections of anecdotes for informational pieces into calendars or yearbooks.

2.3 Scientific approaches

Apart from the administration efforts, there have also been scientific approaches to collect historical floods information these last years. In this case, with the aim to create flood compilations of European-homologable quality.

The first doctoral thesis on the subject was by Grimalt on the island of Mallorca (Grimalt, 1988), which was later published as a book (Grimalt, 1992). Since then, several research projects acquired historical information with specific criteria in order to produce consistent and reliable data series. However, these projects, which were costly and lasted from two to four years, were limited to a scarce number of chronologies in small areas; some examples are the compilations of Maresme County (Barriendos and Pomés, 1993), of the Spanish Mediterranean coast (Barriendos and Martín-Vide, 1998), and of the basins of the Ter, Llobregat and Segre rivers (SPHERE Project, “Systematic, Palaeoflood and Historical data for the improvEment of flood Risk Estimation”, EU Project EVG1-CT-1999-00010, 2000-2004). Besides, the Geological Institute of Catalonia started a campaign of systematic collection of information between 2008 and 2010 in order to map natural risks, but budget limitations stopped the survey and only the Pyrenees area was completed.

These compilations done with scientific purposes, although scarce and modest, follow the methods of European research. This allows complex analyses such as: the improvement of climate behaviour estimations from multi-centennial flood chronologies (Llasat *et al.*, 2005; Barriendos and Rodrigo, 2006); the study of flash floods (Llasat *et al.*, 2003; Barrera *et al.*, 2006; Balasch *et al.*, 2010a, 2011); or the reconstruction of the peak flows and the impacts of one of the worst floods in the Iberian Peninsula, that of November 1617 (Thorndycraft *et al.*, 2006).

3. Characteristics of the "Prediflood" database

The “Prediflood” database contains information about historical floods occurred in Catalonia (NE Iberian Peninsula) between AD1035 and AD2013.

State-of-art of historical floods in Spain described and potentialities of our contribution showed in our manuscript are strongly different. Previous official databases mostly took information only from a selected number of bibliographical references, but not defined with historiographical criteria or any specific order. The obtained database included large amount of information, but with important weaknesses. On the other hand, previous research projects on this field have been working focused on documentary and bibliographical sources, but located on very specific geographical sites.

We suggest and apply systematic approach to bibliographical sources obtaining a complete identification of primary sources (historical documentary sources with full reliability: objectivity, eyewitness in real time...). New on line database and tools help a lot on this new criteria and objectives of research.

On the other hand, the research is focused in long flood-chronologies for specific sites, but we also collect, integrate and analyze information from all existing flooded sites. This new approach change "floods occurring in one location" by "all locations recording overflow during one flood event".

To our opinion, flood events are so complex on atmospheric and surface processes that all possible information contributes to a better understanding of it.

Catalonia is a quite mountainous region of 32114 km^2 on the east Mediterranean coast of the Iberian Peninsula (Fig. 1). Due to both its location and its relief, it is prone to several flood-causing weather phenomena: severe thunderstorms, long frontal rain events, and massive snow thaw.

Furthermore, it is a quite populous area and it has recently undergone a period of massive construction, sometimes in flooding-prone areas, promoted by an effect of speculative bubble in the building trade sector. Therefore, exposition and vulnerability have grown in the last few decades.

3.1 General criteria

Due to the state of research in Spain, it is advisable to take general criteria when managing historical floods information, in order to make it usable in future multidisciplinary studies.

<u>Considerations on modern-day situation:</u>

a) Bibliographical review on which are based modern databases is partial, obsolete, and not acquired with conventional historiographical criteria.

b) The search in historical documents with continuous, objective information of floods (local administration sources) has hardly reached c. 3% of the total documents available in National Documentary Heritage.

c) The use of primary documentary sources is rare. Then, uncertainty about reliability and accuracy of data available is very high.

d) The databases have a closed design, with precise structures to organize information, very adequate for instrumental data, but frustrating and not operative for historical information and its level of detail.

e) Closed-structure databases deem all their information certain, although research can bring many corrections, enlargements and even detection of serious errors, such as date or location of the flood, repeated flood records, floods that never occurred.

An example of working without a critical analysis of sources (historiographical procedures) is the next: one bibliographical reference with wrong information describes one flood in 1897 in Girona city caused by the overflow of the Guell River. If this reference is taken into account, we introduce wrong information in flood frequency analysis for this sector. Taking different documentary and bibliographical references in a crossed analysis, we concluded that this "flood" it was only a problem on rainfall infiltrations on the roof of City Hall.

Proposed criteria (used in the “Prediflood” database)

a) Open structure: with so many documentary and bibliographical sources not yet searched, designing fixed-structure databases is premature. The most operative alternative is having a collection of information entries in their original formats and, in parallel, a list or catalogue of these entries which can be used as a temporary database.

b) Positive error management: an open structure allows a quick detection, correction and substitution of erroneous information. The addition of a new case from not contrasted information must be avoided if there already are reviewable elements. New cases are generated from imprecise and doubtful information

c) Traceability: every flood record should have a complete reference to a primary documentary source, from which the printed sources derive: monographs, articles, reports. A flood record is reliable only when its sources are completely traceable. In addition, this allows the maximum access to generated information.

Because of these previous factors and future needs, the information organization structure has two different parts. On the one hand, all the found materials in documentary and bibliographical sources are stored in their original formats. The minimal transformation and reduction permits the use of the information in successive improvements and corrections that would come up after new material gathering. On the other hand, a spreadsheet records the basic information required for all kinds of queries but, at the same time, allowing quick changes in the created categories and items.

In order to do that, the “Prediflood” database information is organized in three areas:

Area 1: Digital Archive. Most of the information already available in official/public databases is contained in digital archives supported by different software, from complex files developed by specific DB software (i.e. Access) to simple scanned materials on .pdf format. All these materials are considered "Digital Archive". We also include digital files of publications, technical reports, academic works, as well as instrumental data.

Area 2: Factual Archive. It's a relation of references to materials in different physic formats. Basically materials preserved in historical archives, as old photographs, pictures, painting, cartography, ... we also include epigraphic flood marks (old buildings, bridges...). In the best case, we can find direct testimonies of oral history preserved in old cassette tapes, etc.

Area 3: Textual Archive. It's the core of our research work. We have performed a "reset" of the information available in different databases returning to text format (Word files) for a better management of large and complete amount of information. We are exploring more new bibliographical and documentary sources. New information must be added with detailed insertions case-by-case, date-by-date. All this work is made in descriptive texts (of course, including numeric and instrumental data).

3.2 Location and codification system

The “Prediflood” project’s research area is Catalonia as administrative unit, which is divided in two group of basins: a part of the Ebro River basin (corresponding to the Segre River basin, a tributary of the Ebro’s), final part of Ebro River between Riba-roja and the mouth and the “Catalan Interior Basins”, which flow directly into the Mediterranean sea.

The studied period is the last 500 years, which is the usual length that law requires to define flooding areas under extreme magnitude events. Nevertheless, strict time limits are unadvisable in historiographical research. Historical events information is not always complete and detailed but sometimes has cross references to previous events and, therefore, an extension of the studied period contributes to an improvement of the first information.

One example of convenience to collect all possible references:

Event 1380, March 7th. Onyar River, Girona city. Level 5 (Catastrophic).

- Chía (1861) describes mentions this flood flowing by Argenteria Street, damaging 2 monasteries, destroying one gate of city and provoking 3 deaths.

This report is based on section of correspondence of City Council Archive of Girona, volume of year 1380.

- Marqués (1979a, 1979b) describes this flood giving a measurement of 8 spans of flooding level on "Força" Gate (1,56m) and destruction of other gate of the city.

This source doesn't mention primary (documentary sources).

- Alberch et al. (1982), describes this flood with partial collapse of wall of the city, affecting one building in Argenteria Street (3 deads).

This source is based of City Council Minute Books, year 1381, preserved in City Council Archive of Girona.

The information has been singularized to the locations where a flood is described or documented. For the geographical location, the ACA (Catalan Water Agency) procedure has been used:

1. Basin
2. River
3. Town
4. Element

A full identification up to level 3 is the most usual, using the official name of municipalities, the basic local administrative unit in Spain. The use of smaller units has not been envisaged due to the great diversity of the descriptive level of the different flood records. It’s preferable to keep this information in a raw state for eventual specific analyses when needed. All details are preserved with original names and descriptions. Most of them must be cross-checked with new data sources, if proceed, during next future.

Time location is not excessively complex. The consulted documentation is usually precise with dating. Fortunately, we focus on administrative documentary sources and local newspapers. Dating of this type of documents is exact. Only calendar adjustments are required (i.e. Julian to Gregorian calendar style).Curiously, the worst indeterminations are found in bibliographical sources; this justifies the effort to reach original documentary sources for the historical period events. In contrast, the local press provides rich information, even allowing hour resolutions, very useful in hydrological and meteorological reconstructions.

The only issue that deserves attention is the possibility to record the duration of some events. In larger rivers, the precise dating of the beginning of floods and of their peak flows can be very helpful.

Dates are the key-element proposed to identify every flood record, because of high reliability of them. Every record will have a code composed of the complete date (YYYYMMDD) and an order number. When only one record is available for a flood event, this order number is "01". When different flood cases have the same date, order number simply shows the order in which records have entered the database.

After this identification of "Case Code", when a group of records are suspected, according to hydrological or meteorological evidences, to correspond to a same event, an independent code for the event is also generated (YYYY-MM). For different flood events into the same month, we distinguish with successive letters (a, b, c...). After this provisional coding, when quantitative amount of information be enough, a definitive procedure for coding should be applied, considering duration, extension, severity of flood event:

Location	*River*	*Year*	*Month*	*Day*	*Order*	*Case Code*	*Event Code*
Flix .	Ebro	1787	October	8	3rd	1787100803	1787-10
Xerta .	Ebro	1787	October	8	4th	1787100804	1787-10
Tortosa .	Ebro	1787	Octubre	9	1st	1787100901	1787-10

3.3 Classification system by assessment of impacts

The collected floods require a minimal common characterization in order to be classified. Most of the flood records are still to be completed with more precise and reliable information search, but, for the moment, the most evident traits can be used. The more common elements to an event of any time are those referring to its basic hydrological behaviour and the impacts it caused. The combination of the two criteria has been used in many studies at a European level. In the case of Spain, the first proposal had three levels of classification (Barriendos and Pomés, 1993; Barriendos and Martin-Vide, 1998; Llasat *et al.*, 2005):

1) Non-overbank flood + disturbances? . .	: ordinary flood
2) Overbank flood + disturbances + damages? .	: extraordinary flood
3) Overbank flood + damages + destructions .	: catastrophic flood

The analysis of many and very diverse floods during project SPHERE led to refining of the classification system, hereby presented with the latest improvements:

ERR)	Erroneous information . . .	: The flood never existed
0)	Unnoticeable flood, no damages . .	: No flood
1)	Non-overbank flood + disturbances .	: Ordinary flood
2)	Non-overbank flood + disturbances + damages	: Ordinary/extraordinary flood
3)	Overbank flood + disturbances . .	: Extraordinary flood
4)	Overbank flood + disturbances + damages. .	: Extraordinary/catastrophic flood
5)	Overbank flood + damages + destructions. .	: Catastrophic flood

In general, the basic criteria are the occurrence of flood and whether it is an overbank flood or not. Besides, there are two levels more. First, the capacity to damage nonpermanent elements (vehicles, cattle, stored goods) or light structures (catwalks or temporary wooden structures). Second, the capacity to destroy completely or partially permanent structural elements, either in an urban or in a rural environment: stone bridges, walls and other defensive elements, watermills, buildings, irrigation systems, or roads and railroads. Regarding agriculture, a flood is considered destructive if it has rooted out large fields, or if it has destroyed the harvest or the productive plants (grapevines, fruit trees), removing the productive soil and leaving large fluvial deposits of any kind. In summary, catastrophic situations that will need important economic resources and several years for a full recovery, or that mean the abandonment of the affected elements.

The classification system does not take into account human fatalities due to occurrence of this kind of impact being random in relation with the severity of the flood. Regarding human victims, a lot of interesting considerations could be described and analyzed. In historical time, victims are very low. We think high vulnerability provoked an automatic mechanism of reduction of exposition. On the other hand, after Industrial Revolution, people vulnerability is strongly reduced by new technical resources. Then, exposition increase and fatalities increased. Wrong attitudes are also an important factor for explaining victims in flood events in the area under study.

Consequently, we considered first that human impacts (displaced, injured, dead victims) are related to inhomogeneous and hazardous factors. They cannot be applied to an initial general floods event analysis. In a second stage of the research, when we will introduce vulnerability indices, hoping this information will be useful to improve flood events knowledge.

To fix the evaluation of impacts on permanent structural elements is a more objective approach and more adequate for this task. The effects on population is recorded but only used in specific studies.

A last issue to take into account is the lack of a criterion of severity classification according to the number of affected catchments. Due to the characteristics of the Mediterranean regions, with intense torrential but not always extensive rainstorms, and with a complex orography, this territorial affection criterion would be not much representative of the magnitude of the floods. Nevertheless, the accumulation of information will lead to the application of these kind of criteria in the near future, and they will be useful in identifying and classifying large floods.

Firstly, we focus on a physical/natural event. To reduce bias produced by human presence changing along time (new structural elements, population growing, new land uses....), we center the research on two basic criteria (overflooding and impacts) on the same sites when it's possible. For example, we generate different levels of classification fixing one group of streets, one bridge or dike (unchanged on time), and observing when these elements are overflooded, when are damaged, when are destroyed, but taking into account always the same elements, when it's possible. When changes are very important, we finish flood chronologies on this site.

On a next step to be developed in future research, we want to maintain physical event considerations, but introducing human aspects. We want to collect urbanistic and demographic information by municipalities (demographic evolution, quantity and type of buildings...) to generate vulnerability indices (of course, considering evolution in time). An improved flood-event classification will be developed considering this information applied in different temporal frames, adjusted to singularities of every municipality. We recognize this new generation of data analysis is in a preliminary stage. We will need a few years to have it for all Spanish Mediterranean basins.

3.4 Meteorological and hydrological information

Historical accounts usually have complete information about time and space location of the flood and the most relevant damages. This detailed information is because of use of administrative sources of local authorities. The main objective of these documents is to record exact and detailed description of impacts and causes, in order to define and apply a program of reconstructions of public infrastructures under its responsibility. However, information on meteorological and hydrological issues is scarcer, only frequent in the most recent accounts. Because of that, it is convenient to identify and singularize the information that can be of special interest in the reconstruction of those issues.

The database have cells to confirm the presence of meteorological information, such as duration and behaviour of the precipitation, previous rain events, or any other described variable, as pressure or wind speed and direction and associated phenomena. Regarding the hydrological behaviour, the data to be taken into account are: maximum water height, flood behaviour and other hydrological information such as changes in the channel, sediment accumulation, landslides, etc.

4. Firsts results of the "Prediflood" database

The results of the first compilation of flood material (June 2013-March 2014) are very positive. But the error of consider this effort as the final of a process can not be repeated. Regrouping already known information is not a research objective in itself. It is just the initial phase of an open process, which must lead to the maximum gathering of information about an unsuspectedly high number of events that have been detected.

The work will be gradual and it will go beyond the initial “Prediflood” project itself, but it is the only way to acquire the historical floods information truly useful in meteorological and hydrological reconstruction of severe events. Thus, the results hereby presented are a mere starting point, which keeps open to future campaigns of improvement and applied research.

As of April 2014, the “Prediflood” database has the following structure and contents:

- *2711* flood cases (flood records) in Catalonia, organized in *1103* flood events.
- Period effectively covered: *AD1035-2013*.
- Accumulation of textual materials: *1246 pages*.
- Accumulated material from other basins in the Iberian Peninsula, with no exhaustiveness:
    - Peninsular basins . . . 873 flood cases
    - Insular basins (Balearic Islands) . 111 flood cases
    - Basins in Roussillon (SE France) . 250 flood cases

- Total absolute: *3945 flood cases*.

The distribution in time of the flood cases and events (Fig. 2a and 2b) shows a logical concentration in the last 200 years, as a result of a greater availability of information, but also of an increase in exposition and vulnerability in the face of risk due to the population growth, the industrialization of river areas in the 19th century, and the intensive urban development in the coast during the second half of the 20th century.

For this reason, data analysis in different later works will be developed considering internal periodization. Every basin has its specific historical context evolution, but general periods could be:

Years ca. 1000-1500: information poorly detailed and scattered. Population in small location with low exposition to flood events.

Ca. 1500-1750: Qualitative detailed and homogeneous information. Stable locations with important level of exposition to flood events.

Ca. 1750-1850: Highest level of qualitative information. First quantitative data available (meteorological, demographic statistics, tributary reports). Strong demographic growing produce important increase of vulnerability.

Since ca. 1850: Quantitative information is available and qualitative primary information is diversified (administrative sources, local newspapers, technical reports...). Locations increase exposition but also different preventive structural works reduce vulnerability. Case-by-case analysis are required.

The number of flood cases in relation with the identifiable events reveals some interesting matters:

1 case per event . . : 756 flood events
>1 to <10 cases per event. . : 306 flood events
≥10 cases per event . . : 41 flood events

The great number of events with only one documented flood case highlights the typical regime of torrential precipitations, very intense but not large, which cause serious but localized overbank floods. But it highlights, as well, an insufficient historiographical research that has not more completely defined flood events. A single-cased flood event is a stimulus to deepen the research in those area and date.

The greatest events, with ten or more documented cases, are optimal starting points to deepen the research. They occurred in a relatively recent period, thus their study will be more efficient. Besides, their already proved severity can be definitely characterized and bring more information for the meteorological and hydrological reconstruction. The detail study of these high-impact events can be one of the immediate applications of the "Prediflood" database (see Tables 1 and 2).

Finally, the results of the "Prediflood" database can be compared to those of the compilations of the competent institutions: basin authorities and civil protection service. (see Table 3).

The available databases, organized in hydrographical basins, have uneven time coverage. In some cases, importance has been attached to very ancient events, whereas other basin authorities have preferred to focus their study in a more realistic period, of about 500 years long, to be used in the 500-year return period calculations required in different land planning instruments. However, these databases contain few events: between 150 and 250 events per basin. The Ebro and the Guadalquivir basins outstand with about 500 events, a number very much due to their large areas. Catalonia, with an average area compared to other basins, reaches 1103 flood events.

The use of an objective criterion to compare the general results in Spain with those of the "Prediflood" project in Catalonia (Gaume *et al.*, 2009), show a space and time coverage obviously greater for the whole of Spain compared to Catalonia (413.8 years*surface/10^6 km^2 and 31.4 years*surface/10^6 km^2, respectively). However, considering the number of events in Spain (2579 events) and Catalonia (1103 events), the density of events in relation to their space and time coverage reaches a value of 6.2 events/coverage in Spain and 35.1 events/coverage in Catalonia, which is almost six times greater.

5. Historiographic data collection procedures

5.1 Justification for a historiographical research

Historical floods information has specific sources, documentary and bibliographical, traditional area of research of historians. However, natural events are not, in general, appealing to this collective. Floods simply appear as mere anecdotes in local historiography, and only deserved some systematic effort during the positivist period.

The present context of natural risks in their interaction with human activities makes interesting this research field. In a few years, historical climatology has shown its development capacity in scientific literature from information exclusively collected in historical documentary sources on the issue of floods (among others: Camuffo and Enzi, 1996; Glaser, 1996; Pfister, 1998; Brázdil *et al.*, 1999; Brázdil *et al.*, 2006; Wetter *et al.*, 2011).

Situation in Spain is optimal to this kind of research thanks to the great Documentary Heritage preserved. However, historiographical research has focused in political and social issues. Until present, only 3% of the documentary sources of specific interest to floods have been explored. In Catalonia, this percentage can be 5% approximately. Local historiography has accessed a greater number of documentary sources, but just to generate lists of flood dates.

The administrations competent with managing basins and emergency situations have used these bibliographical sources and the results have been scarce and limited despite the potentiality of the available documentation. The solution to this situation can come from historiographical research itself, and the results can be as positive as those of previous European experiences.

The majority of flood events in Spain are based on an insufficient exploitation of historiographical sources. Reaching a complete identification of these sources is, by itself, a study with multiple positive aspects (see Fig. 3).

5.2 Proposal of classification of information sources

The development of a study on so large and diverse historical source requires a good classification of them. The following proposal is based in their reliability levels and formats of contents:

1) Primary sources

Information for flood events generated by contemporary eyewitness authors

1.a.* Documentary sources
1.b.** Local newspapers

2) Secondary sources

Information obtained from primary sources by not eyewitness authors

2.a.* Scientific literature
2.b.** Historiographical sources and thematic works

3) Tertiary sources

Information obtained from secondary sources by not eyewitness authors

3.a.* Technical reports
3.b.** Non-specialized works and social networks collections

Q) Quantitative Data

Information recorded in numeric or quantifiable formats (All sources can contain quantitative data, generated by themselves or copied and transmitted)

Q.a. Instrumental sources
Q.b. Paleolimnimetry: epigraphic and textual flood marks

* Objective sources, quasi-complete data series
** Subjective sources, uncomplete data series

The level of the sources defines their proximity to the events. Besides, every level of sources has some objective ones, with which data gathering is almost complete, and some subjective ones, which offers incomplete information.

5.3 Proposed procedures

The first analysis of the compiled floods shows the levels of the sources of information. Its exploitation can be immediate, but the classification of sources can highlight as well the reliability and quality of used sources and, therefore, of the available information. If required, the origin of the information can be investigated until arrive to the primary level sources.

According to the present state of references on flood cases, the research effort should focus in finding the primary sources for most of them ensuring, at least, one reliable and objective source of information. Application of this principle of traceability would suppose positive aspects:

1) Starting point would be already available information, thus not limiting its availability but consolidating and improving its reliability.

2) Reaching primary sources of a public administrative nature, information endorsed by a public notary would be available. Maximum reliability provided by such testimony would strengthen reconstruction studies based on the information contained in these sources.

3) New bibliographical and documentary sources would be brought to light. This would enlarge the available information and new floods cases and events would be detected subsequently, in a sort of chain reaction.

4) A line of research would be defined for historians. In the case of Spain, it would doubtlessly mean many years of work. The possibility would come up to expand the research into poorly explored areas or to deepen into events that deserve a more detailed study.

5) The accumulation of the maximum available description of impacts and quantifiable information about hydrological and meteorological information, up to an

acceptable degree of exhaustiveness, would be reached. It would not be all the desiderable information but, at least, all information kept until now.

6) This studies, besides detecting unknown floods information, could detect as well information about other infrequent natural risks (earthquakes, landslides and rare meteorological phenomena).

6. Reconstruction methodology

Our multidisciplinary reconstruction of historical floods consists of three parts:

1) Hydraulic reconstruction, the objective of which is the calculation of the peak flow (or, when possible, the whole hydrograph) of the flood.

2) Hydrological reconstruction, the objective of which is the calculation of the hyetograph of the rain event that caused the flood.

3) Meteorological reconstruction, the objective of which is to analyse the meteorological processes before and during the rain event that caused the flood

These three parts are linked between them, in that the results of the hydraulic reconstruction (flood's peak flow or hydrograph) are needed in the hydrological one, and that the results of the hydrological reconstruction (hyetograph) should agree with the results of the meteorological one (Figure 4).

Besides, the three reconstructions occur in very different spatial scales: typically, the hydraulic reconstruction takes place along a river reach (up to a dozen km^2 area); whereas the hydrological one takes into account the whole catchment (from some dozens to thousands of km^2); and the meteorological reconstruction is done, depending on the meteorological phenomenon causing the event, from a local (hundreds of km^2) to a regional scale (1 million km^2). Whatever the case, all of them need historical information in order to feed the models used with the required input data and initial and boundary conditions.

6.1 Hydraulic reconstruction

The objective of the hydraulic reconstruction is to calculate the flood's peak flow from the maximum water height observed or flood mark, recorded in a plaque or in a written document.

This calculation could be quickly done (although with a high uncertainty) with Manning's empirical equation, which relates, in one section of the stream, the flow of water with the geometrical and friction characteristics of the section, summarized in only four values: the section's area and wet perimeter, the longitudinal slope and a roughness coefficient.

However, the precision of a peak flow calculation is improved with the use of hydraulic models. Typically, these models use physically-based equations (e.g. Bernouilli, one-dimensional Saint-Venant) in dozens of sections along a reach of river several hundreds metres long. The major drawback is that they need more input data.

Simple hydraulic models (e.g. WSPRO, QUICK-2, CAUCES) can only operate in steady flow conditions (that is, no variation in time is allowed: they calculate the situation of a still instant), while others (e.g. HEC-RAS, DAMBRK, SWMM, Mike 11 HD) can calculate in unsteady flow conditions, thus obtaining more accurate results, especially in river reaches with floodplains with a great water-storing capacity.

Similarly, some simpler models do their calculations in one dimension only (all flow lines are perpendicular to the cross-section), while more sophisticated and accurate ones (e.g. Iber, Sobek, Mike 21 and FLO-2D) do them in two dimensions (flow lines can be oblique to the cross-section). The difference in accuracy between 1-D and 2-D models increases in winding stretches, in those in which the water velocities in the channel and on the floodplain are very different, and in those were the flow is clearly not unidirectional.

However, the gain in accuracy with the use of unsteady flow conditions or 2-D models comes at a higher effort in input data acquisition and, especially, in computation time, which can even make the use of complex models impractical in historical floods reconstruction, because they have to be applied iteratively. Besides, a high standard of accuracy in the calculations is not essential in reconstructing historical flows, because the input data have themselves a high degree of uncertainty. Because of this, and for the sake of homogeneity between data-rich and data-poor sites, we systematically use the 1-D hydraulic model HEC-RAS in steady flow conditions (USACE, 2008), which gives accurate enough results (Balasch *et al.*, 2010a; Balasch *et al.*, 2011). Nevertheless, we also apply the 2-D model Iber (Iber 2010; Ruiz-Villanueva *et al.*, 2013) in some cases that would produce excessive inaccuracy: highly urbanized or very sinuous reaches or with large floodplains.

It must be noted that models calculate hydraulic parameters (water velocities and depths) from a given peak flow, whereas we need the opposite: to calculate the peak flow from a given water height. Thus, the hydraulic model has to be applied iteratively, feeding it with tentative peak flows until the observed water height is approached enough (Fig. 5).

The input data that the model needs, besides the tentative peak flow, are the stretch's geometry and friction it shows against water flow, the former given by the digital elevation model, and the latter given by Gauckler-Manning roughness coefficients, found in tables that relate friction with type of surface, sinuosity, vegetation, obstacles and cross section's contractions or expansions (Chow, 1959). Besides, a hydraulic model has to be given boundary conditions, which link what happens inside the modelled river reach with what happens upstream and downstream.

All these input data have to be adequately adapted to be as close as possible to their values at the time when the historical flood to be reconstructed took place. Therefore, old maps and documents are essential in reconstructing the channel and floodplain morphology at the time of the flood (obstacles, meanders, islands) and in hypothesizing the roughness coefficients. It must be noted that since they are acquired by estimating and hypothesizing from old documents, the input data have a high degree of uncertainty. Again, this process adds a high degree of uncertainty to the input data.

In those rare cases where measured flow data are available, they should be used in calibrating the hydraulic model in that reach, that is, in estimating more accurately roughness coefficients and boundary conditions (Lang et al., 2004).

As said above, hydraulic reconstruction involves a great deal of assumptions about input data; therefore, sensitivity analyses should be performed to delimit the effect of a given variation in input data on the results, that is, to estimate the error of the results.

6.2 Hydrological reconstruction

The objective of the hydrological reconstruction is the hyetograph of the rainfall that caused the flood.

A hydrological model summarizes the characteristics of the catchment that conform its hydrological response, that is, the way how it transforms rainfall into runoff and, eventually, into river flow. In other words, a model tries to quantify the hydrological processes occurring between the rain precipitation and the water exiting the catchment through its outlet.

There are three main types of hydrological models: the stochastic ones, the empirical ones and the physics-based ones. Firstly, the stochastic models use large amounts of paired rainfall-flow data to calculate non-dimensional parameters that describe the catchment's hydrological response; an example is GR4J (Perrin *et al.*, 2003). Secondly, the empirical models use simplified empirical equations and methods (such as the Curve Number method; NRCS, 2007). Finally, the physics-based models use complex physics equations and need a lot of precise field measurements; an example is InHM (VanderKwaak and Loague, 2001).

Hydrological models can also be classified according to their treatment of space as well: lumped models calculate processes at the catchment or subcatchment scale (e.g. HEC-HMS), whereas distributed models do it in smaller areas and afterwards aggregate the results (e.g. r.water.fea, Vieux *et al.*, 2004).

Due to the scarcity of data typically found outside heavily instrumented catchments and for the sake of simplicity, we use HEC-HMS, an empirical, lumped hydrological model (USACE, 2010). HEC-HMS allows the user to choose among an array of different empirical methods for each one of these three hydrological processes: runoff generation, transformation of runoff into river flow, and river flow routing. For each of these processes we chose, systematically and respectively, the SCS Curve Number, the Synthetic Unit Hydrograph and the Muskingum-Cunge methods, because of their simplicity of use, their moderate requirements in input data and their being generally accepted and commonly used (NRCS, 2007).

Similarly as in the hydraulic reconstruction, the calculation procedure is iterative, because the result (that is, the hyetograph) is, actually, an input datum required by the model (Figure 6). Therefore, a tentative hyetograph must be built using the available historical information about the rain event, such as, its duration, the affected area (in which subcatchments it rained and in which it did not), or indications that can lead to a rough estimation of the rainfall volume. Besides this tentative hyetograph, the model needs input data describing the catchment (or subcatchments) hydrological characteristics, such as soil type, land use, antecedent soil moisture and the stream's slope.

The result of the hydrological model (the peak flow) is then compared to the one calculated in the hydraulic reconstruction; if the two are similar enough, the tentative hyetograph is provisionally accepted. If this provisional hyetograph agrees with the meteorological processes found in the meteorological reconstruction, it is definitely accepted.

The kind of inputs variables and empirical methods used have a great degree of uncertainty (Willems, 2001), all the more in the case of historical floods, because the data have to be adapted from present-day values to the estimated ones at the time of the studied flood. Thus, a calibration of the model should be made whenever measured data are available. For the same reason, a sensitivity analysis should be performed once the hydrological reconstruction is done in order to estimate the real amount of uncertainty in the results.

6.3 Meteorological reconstruction

The objective of this reconstruction is the analysis of the meteorological processes before and during the rain event that caused the flood. This analysis has two direct applications: the estimation of the antecedent soil moisture condition (an input required in the hydrological reconstruction) and the classification of floods according to their meteorological causes, which can, eventually, become a useful tool in flood forecasting.

The meteorological reconstruction is done in three different levels depending on the data availability or, more specifically, on the horizontal, vertical and temporal resolution of the available data, which decreases as we move back in time. Indeed, there are three different periods according to the quality of the available data, and a different level of reconstruction is applied to the floods in each one of them:

1. Events occurred since ca. 1750 (available data: surface temperature, pressure and precipitation recorded at several European locations): since second half 18th century, several observatories in Europe recorded surface temperature and pressure. Some of them additionally recorded accumulated precipitation. Surface temperature and pressure records are used to analyse the synoptic conditions at a regional scale and to calculate zonal pressure indexes (Luterbacher *et al.*, 2002).

2. Events occurred since 1871 (Available data: 20th Century Reanalysis data from NOAA). Surface and upper levels meteorological charts since 1871 from the reanalysis made by the Earth System Research Laboratory of the National Oceanic and Atmospheric Administration (NOAA) (Kalnay *et al.*, 1996) are used to estimate the synoptic conditions of each episode: temperature, atmospheric circulation at different vertical levels, and precipitation estimates.
Additionally, the reanalysis data allow us to calculate several parameters related to the convection intensity, such as the Vertical, Cross and Total Totals indexes (Miller, 1972), the *K* index (George, 1960), the Humidity index (Litynska *et al.*, 1976), the Ko index (Andersson *et al.*, 1989), the Lifted Index LI (Galway, 1956), the Integrated Convective Available Potential Energy -ICAPE- (Mapes, 1993. Doswell and Rasmussen, 1994), the Vorticity Generating Parameter (Rassmussen *et al.*, 1998), the difference between the LCL and LFC, the wind shear between surface and 1, 3 and 6 km height, among others. In addition, the reanalysis data can be used to obtain information about wind field, moisture, and column of precipitable water, among others.

3. Events occurred since ca. 1960 (available data global models with larger resolution and mesoscale numerical simulations): finally, for more recent events, version 3.3 of the WRF-ARW mesoscale model (Skamarock *et al.*, 2008) is used at high horizontal resolution (up to approximately 1 km) to analyse synoptic, mesoscale and local conditions during the floods. The initial and boundary conditions to run the model are obtained from the ECMWF model reanalysis up to 0.25º horizontal resolutions.

7. Concluding remarks

The Prediflood database meets the internationally accepted scientific standards. It is, therefore, a repository of reliable and contrasted information that allows accurate flood analysis. Actually, some of its data have already been successfully used in several flood reconstructions; at the same time, the density of the information in both the space and the time scales gives this database a great potentiality in time series analysis.

The Prediflood database is in a permanent state of data incorporation. The present-day information comes from the search of about 5% of documentary sources with interesting information in Catalonia. Consequently, definition of any kind of conclusions is premature. Firsts steps are showing that this research with an interdisciplinary framework is possible in Spanish context and may be fruitful.

This effort is focused not only in quantity of flood events detected, but also in qualitative aspects, putting especial effort to increase reliability and detail of information collected to be subjected to hydraulic, hydrological, meteorological reconstructions, as is made for climatic reconstruction during recent years. It produces a substantial improvement of quality and quantity of obtainable results: quality because results are more credible; quantity because spatio-temporal scales covered by reconstructions can be enlarged.

For next future, most immediate objectives for the Prediflood database are:

- Enlarge the percentage of primary sources worked for flood events reconstruction.
- Explore the archives of presently poorly-represented areas or flood events interesting but not known enough.

At present, Prediflood database is a heterogeneous amount of information well catalogued. But potentiality has been tested immediately. Large or severe events can be easily identified and classified. Information quantified allows basic reconstruction of hydraulic and hydrological processes involved.

Atmospheric conditions producing strong rainfall events and floods will be also better analyzed with enlargement of number of cases for NE Iberian Peninsula. Detection and definition of patterns of the synoptic conditions, compared between different flood events will improve comprehension of atmospheric processes producing floods.

When long data series be available, after homogenizations needed by different demographic and social contexts existing for different flood events, an improved climatic variability analysis related to flood events will be possible. Application for meteorological forecasting services and flood risk managers will be strongly positive.

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Table 1. Relation of flood events selected according to severity (10 or more cases per event). Chronologically sorted.

Nr. Order	Year	Extreme Dates	Nr. cases
1	1617	30 Oct-6 Nov	47
2	1787	25 sep-9 Oct	13
3	1842	23-26 Aug	29
4	1850	15-21 Sep	26
5	1853	23-26 May	19
6	1856	8-16 Jun	11
7	1863	7-8 Oct	12
8	1866	19-25 Oct	10
9	1874	22-23 Sep	69
10	1890	18-19 Sep	15
11	1898	15-18 Jan	25
12	1901	21 Sep	13
13	1907	10-16 Oct	30
14	1907	21-25 Oct	89
15	1913	29-30 Sep	16
16	1919	6-9 Oct	13
17	1921	16-18 Aug	17
18	1926	31 Aug-4 Sep	16
19	1932	11-17 Oct	11
20	1937	25-28 Oct	43
21	1940	16-18 Oct	21
22	1942	27-28 Apr	12
23	1943	15 Dec	21
24	1944	24-25 Feb	12
25	1951	2-12 Oct.	13
26	1962	24-26 Sep	26
27	1962	10-17 Oct	19
28	1962	4 Nov	17
29	1963	3 Aug	11
30	1963	11-14 Sep	11
31	1965	4-9 Oct	12
32	1969	3-5 Apr	17
33	1970	10-12 Oct	31
34	1971	20-21 Sep	26
35	1973	7-8 Sep	11
36	1977	18 Oct	17
37	1982	15-16 Feb	17
38	1982	6-8 Nov	38
39	1984	29 Sep	11
40	1987	3-10 Oct	16
41	1994	10-11Oct	29

Table 2. Relation of flood events selected according to severity (10 or more cases per event). Sorted by number of documented cases

Nr. Order	Year	Extreme Dates	Nr. cases
14	1907	21-25 Oct	89
9	1874	22-23 Sep	69
1	1617	30 Oct-6 Nov	47
20	1937	25-28 Oct	43
38	1982	6-8 Nov	38
33	1970	10-12 Oct	31
13	1907	10-16 Oct	30
3	1842	23-26 Aug	29
41	1994	10-11 Oct	29
4	1850	15-21 Sep	26
26	1962	24-26 Sep	26
34	1971	20-21 Sep	26
11	1898	15-18 Jan	25
21	1940	16-18 Oct	21
23	1943	15 Dec	21
5	1853	23-26 May	19
27	1962	10-17 Oct	19
17	1921	16-18 Aug	17
28	1962	4 Nov	17
32	1969	3-5 Apr	17
36	1977	18 Oct	17
37	1982	15-16 Feb	17
15	1913	29-30 Sep	16
18	1921	31 Aug-4 Sep	16
40	1987	3-10 Oct	16
10	1890	18-19 Sep	15
2	1787	25 Sep-9 Oct	13
12	1901	21 Sep	13
16	1919	6-9 Oct	13
25	1951	2-12 Oct	13
7	1863	7-8 Oct	12
22	1942	27-28 Apr	12
24	1944	24-25 Feb	12
31	1965	4-9 Oct	12
6	1856	8-16 Jun	11
19	1932	11-17 Dec	11
29	1963	3 Aug	11
30	1963	11-14 Sep	11
35	1973	7-8 Sep	11
39	1984	29 Sep	11
8	1866	19-25 Oct	10

Table 3. Comparative values between the flood compilations of Civil Protection-Spain and the "Prediflood" Project. Source: "Catálogo Nacional de Inundaciones Históricas" (2006-2010), Ministerio del Interior, España.

Basin	**Area (km^2)**	**Period**	**Nr. Events**	**Years**	**Coverage[a]**	**Density[b]**
Duero	78954	1483-1985	278	503	39.7	7.0
Segura	18869	1482-1982	214	501	9.5	22.5
Júcar	42989	1088-1983	217	896	38.5	5.6
Tajo	55645	849-1979	159	1131	62.9	2.5
Ebro	85399	BC49-1984	554	2034	173.7	3.2
Guadalquivir	63972	1483-1985	474	503	32.2	14.7
Norte+Galicia	40894	1482-1983	141	502	20.5	6.9
Guadiana	59677	620-1985	149	1366	81.5	1.8
Sur	17969	1544-1983	162	440	7.9	20.5
Pirineo Oriental[c]	16418	1483-1983	162	501	8.2	19.8
Total Spain	493838		2579	838 (av.)	413.8	6.2
Prediflood	32114	1035-2013	1103	979	31.4	35.1

[a] Coverage: (years*surface)/10^6 km^2 (according to Gaume *et al.*, 2009)
[b] Density: Nr. ev./coverage (according to Gaume *et al.*, 2009)
[c] Pirineo Oriental Basin: data provided directly by Catalan Water Agency (ACA)

RELATION OF FIGURES

Figure 1.
Location of Catalonia within Europe (a) and the Iberian Peninsula (b), and map of Catalonia (c). Own elaboration from a map Copyright © 2009 National Geographic Society, Washington, D.C.

Figure 2.
Bidecadal distribution of flood cases (a) and flood events (b) of the Prediflood database information (own elaboration).
*: 3 flood cases/events are out of the period AD1035-2013

Figure 3.
Overview of the methodological procedure of historical floods data collection (own elaboration).

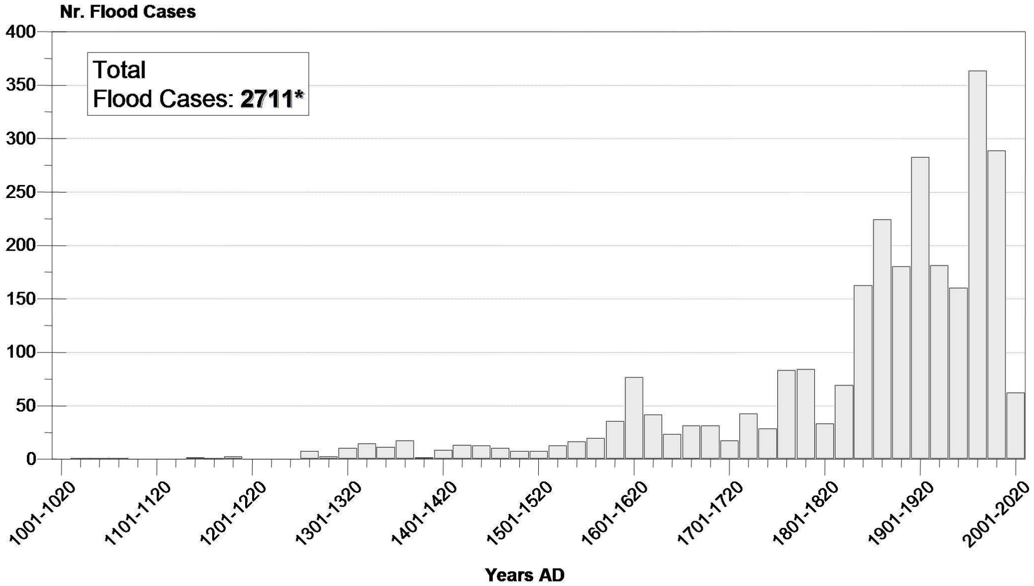
Figure 4.
Overview of the multidisciplinary reconstruction methodology of historical floods (own elaboration).

Figure 5.
Iterative procedure used in the hydraulic reconstruction of peak flows (Modified from Balasch e al. (2010b).

Figure 6.
Iterative procedure used in the hydrological reconstruction of hyetographs (Modified from Balasch et al. (2010b).

Figure 1

Figure 2a



Nr. Flood Cases
Total
Flood Cases: 2711*
400
350
300
250
200
150
100
50
0
1001-1020
1101-1120
1201-1220
1301-1320
1401-1420
1501-1520
1601-1620
1701-1720
1801-1820
1901-1920
2001-2020
Years AD

Figure 2b

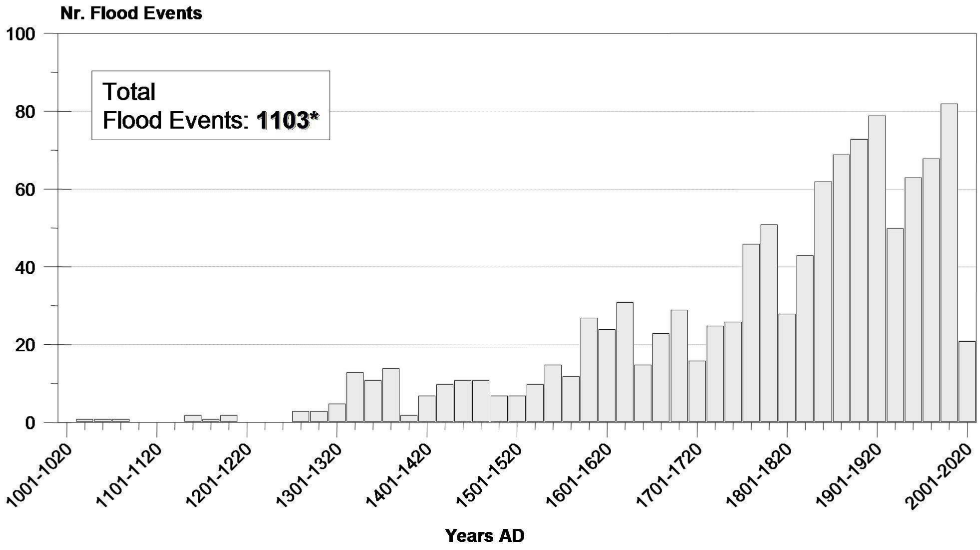

Nr. Flood Events
100
80
60
40
20
0
Total
Flood Events: 1103*
1001-1020
1101-1120
1201-1220
1301-1320
1401-1420
1501-1520
1601-1620
1701-1720
1801-1820
1901-1920
2001-2020
Years AD

Figure 3

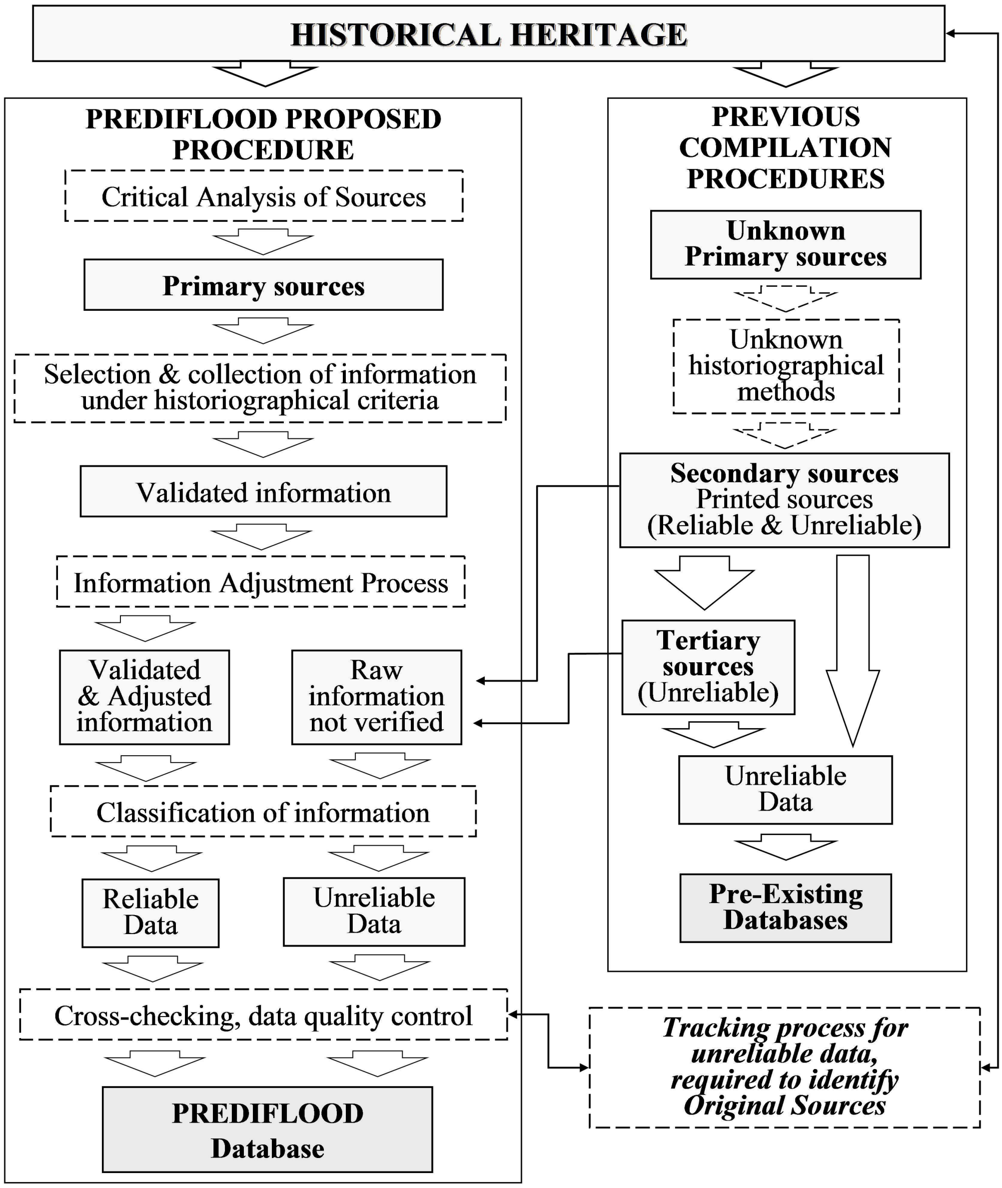

HISTORICAL HERITAGE
PREDIFLOOD PROPOSED PROCEDURE
Critical Analysis of Sources
Primary sources
Selection & collection of information under historiographical criteria
Validated information
Information Adjustment Process
Validated & Adjusted information
Raw information not verified
Classification of information
Reliable Data
Unreliable Data
Cross-checking, data quality control
PREDIFLOOD Database
PREVIOUS COMPILATION PROCEDURES
Unknown Primary sources
Unknown historiographical methods
Secondary sources Printed sources (Reliable & Unreliable)
Tertiary sources (Unreliable)
Unreliable Data
Pre-Existing Databases
Tracking process for unreliable data, required to identify Original Sources

Figure 4

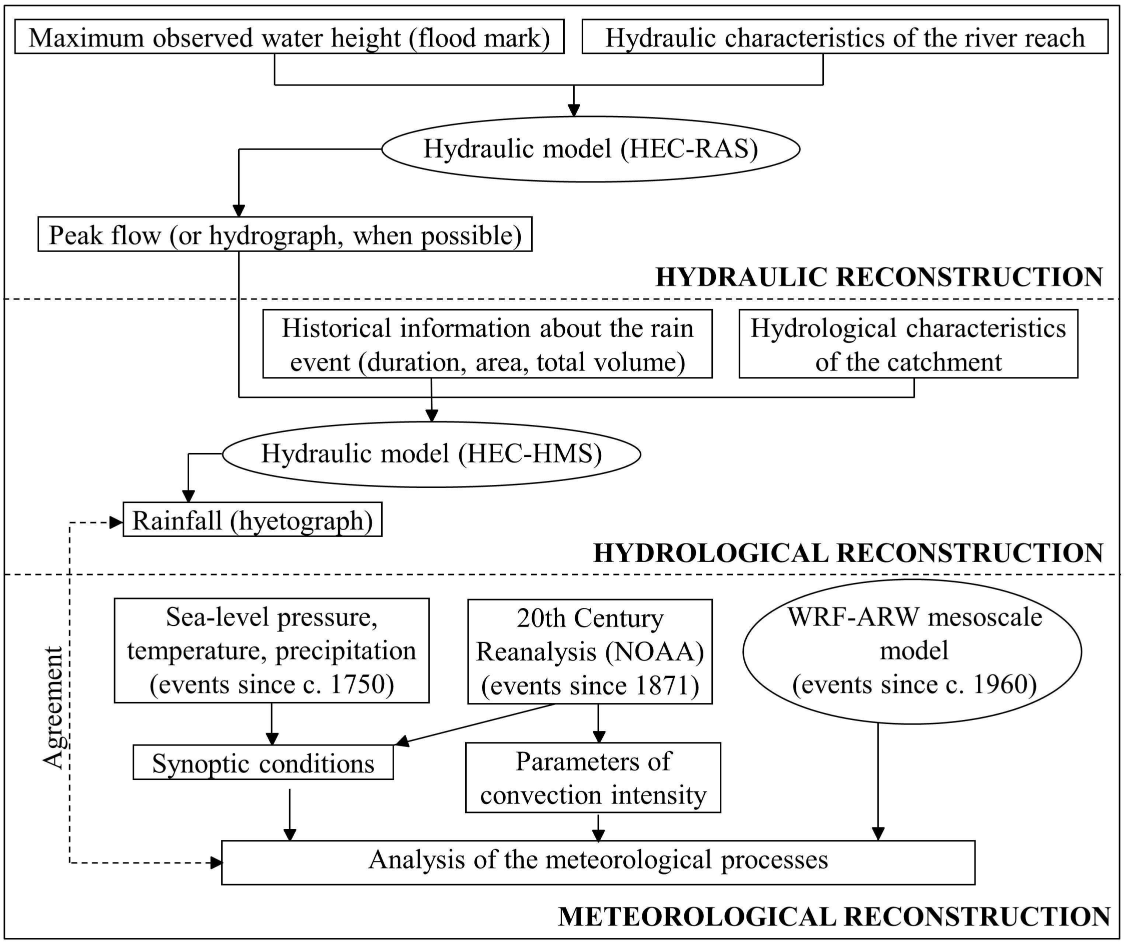

Maximum observed water height (flood mark)
Hydraulic characteristics of the river reach
Hydraulic model (HEC-RAS)
Peak flow (or hydrograph, when possible)
HYDRAULIC RECONSTRUCTION
Historical information about the rain event (duration, area, total volume)
Hydrological characteristics of the catchment
Hydraulic model (HEC-HMS)
Rainfall (hyetograph)
HYDROLOGICAL RECONSTRUCTION
Sea-level pressure, temperature, precipitation (events since c. 1750)
20th Century Reanalysis (NOAA) (events since 1871)
WRF-ARW mesoscale model (events since c. 1960)
Agreement
Synoptic conditions
Parameters of convection intensity
Analysis of the meteorological processes
METEOROLOGICAL RECONSTRUCTION

Figure 5

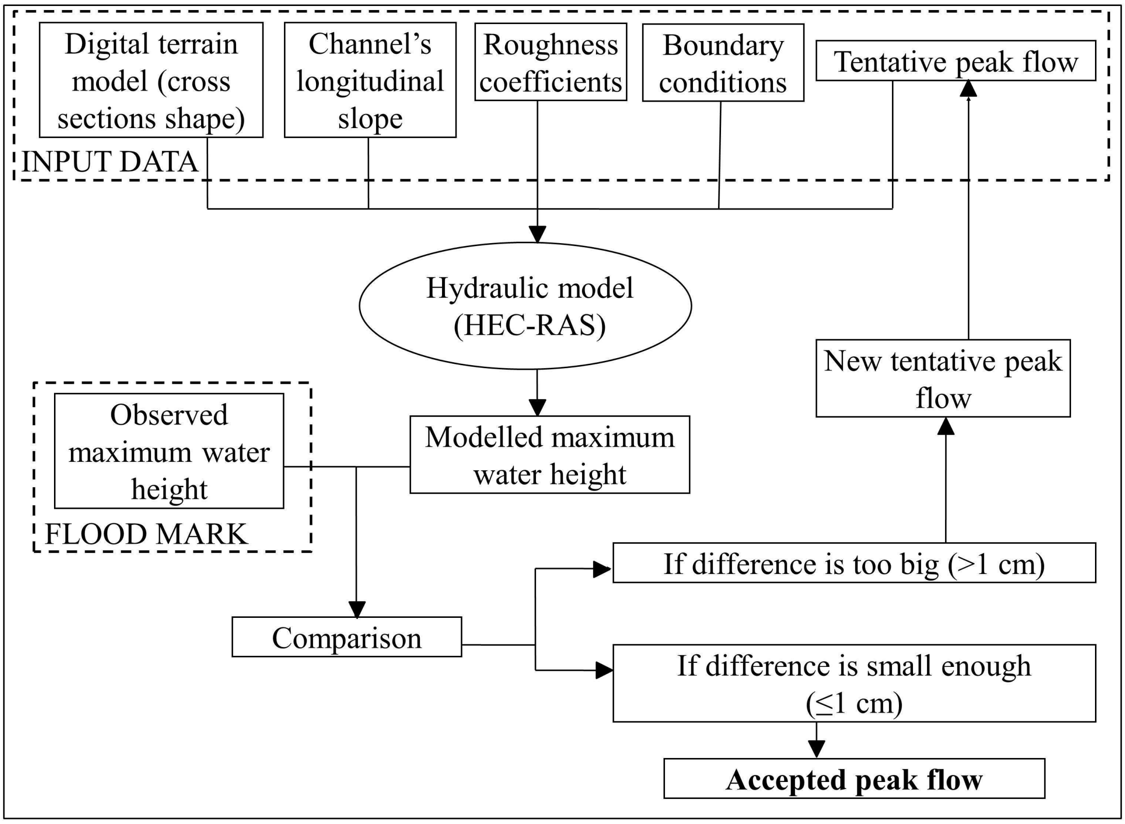
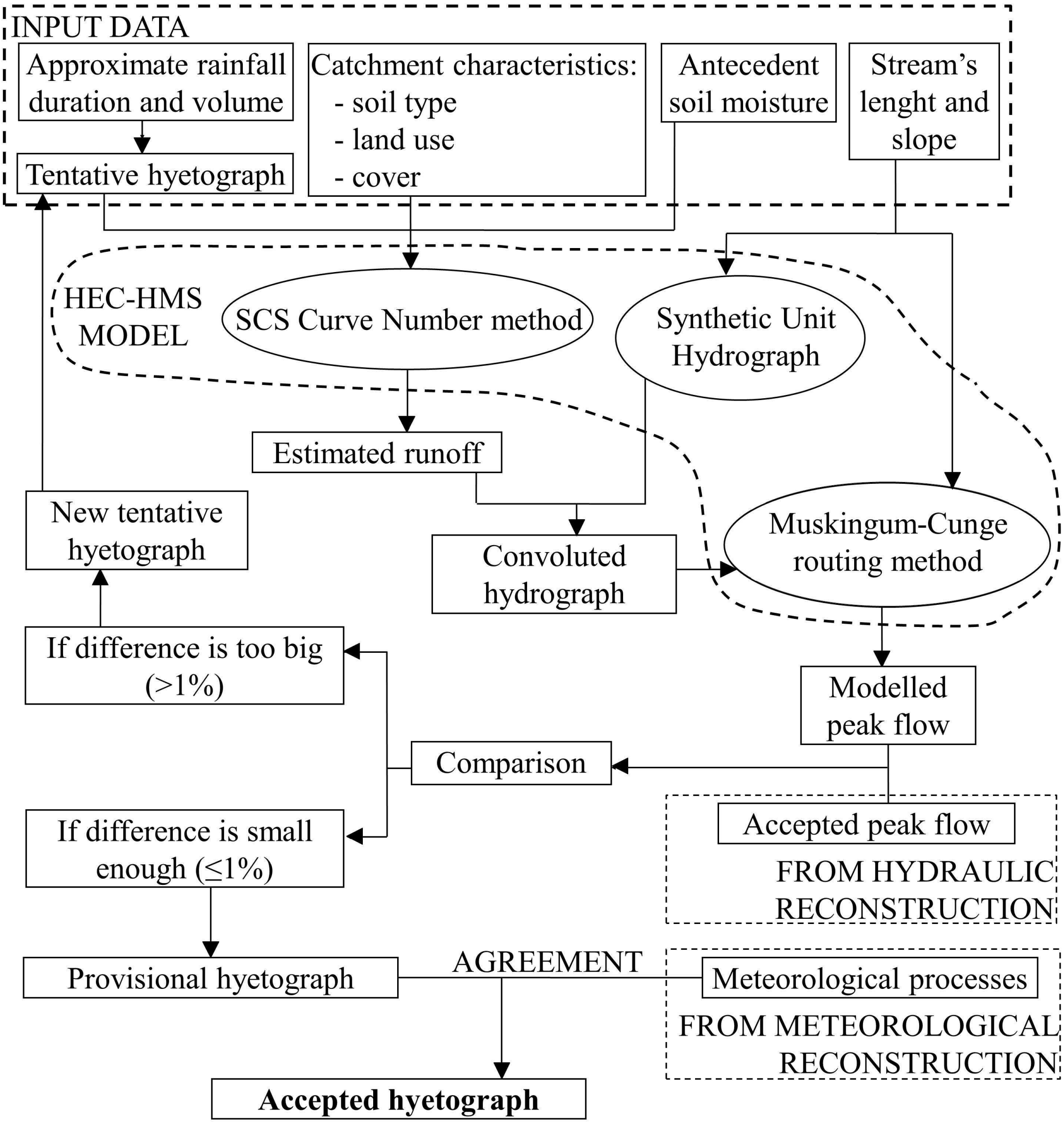

Digital terrain model (cross sections shape)
Channel's longitudinal slope
Roughness coefficients
Boundary conditions
Tentative peak flow
INPUT DATA
Hydraulic model (HEC-RAS)
New tentative peak flow
Observed maximum water height
FLOOD MARK
Modelled maximum water height
If difference is too big (>1 cm)
Comparison
If difference is small enough (≤1 cm)
Accepted peak flow

Figure 6


INPUT DATA
Approximate rainfall duration and volume
Tentative hyetograph
Catchment characteristics:
- soil type
- land use
- cover
Antecedent soil moisture
Stream's lenght and slope
HEC-HMS MODEL
SCS Curve Number method
Synthetic Unit Hydrograph
Estimated runoff
New tentative hyetograph
Convoluted hydrograph
Muskingum-Cunge routing method
If difference is too big (>1%)
Modelled peak flow
Comparison
If difference is small enough (≤1%)
Accepted peak flow
FROM HYDRAULIC RECONSTRUCTION
Provisional hyetograph
AGREEMENT
Meteorological processes
FROM METEOROLOGICAL RECONSTRUCTION
Accepted hyetograph