



**The “Prediflood”  
database of historical  
floods in Catalonia  
AD 1035–2013**

M. Barriendos et al.

# 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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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 did not allow a clear identification of the documentary sources.

5 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,  
10 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 great  
15 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  
20 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  
25 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.



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.

5 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., 2010, 2011); or the reconstruction of  
10 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 AD 1035 and AD 2013.

15 Catalonia is a quite mountainous region of 32 114 km<sup>2</sup> 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.

20 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.

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### 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.

5 *Considerations on modern-day situation:*

- 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 ca. 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.

15  
20 *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.

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## 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) 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.

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 is preferable to keep this information in a raw state for eventual specific analyses when needed.

Time location is not excessively complex. The consulted documentation is usually precise with dating. Curiously, the worst indeterminations are found in bibliographical sources; this justifies the effort to reach original documentary sources for the historical

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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):

<i>Location</i>	<i>River</i>	<i>Year</i>	<i>Month</i>	<i>Day</i>	<i>Order</i>	<i>Case Code</i>	<i>Event Code</i>
Flix	Ebro	1787	October	8	3rd	1787100803	1787-10
Xerta	Ebro	1787	October	8	4th	1787100804	1787-10
Tortosa	Ebro	1787	October	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 Martín-Vide, 1998; Llasat et al., 2005):

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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               |

5 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 non-permanent 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  
10 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  
15 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. 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.

### 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. 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.

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#### 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: *AD 1035–2013*.
- 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 b) 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

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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

- a.\* Documentary sources
- b.\*\* Local newspapers

### 2. Secondary sources

Information obtained from primary sources by not eyewitness authors

- a.\* Scientific literature
- b.\*\* Historiographical sources and thematic works

### 3. Tertiary sources

Information obtained from secondary sources by not eyewitness authors

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- a.\* Technical reports
- 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)

- a. Instrumental sources
- b. Paleolimnometry: 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.

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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.
- 5 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.
- 10 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 desirable information but, at least, all information kept until now.
- 15 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

20 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 hietograph of the rain event that caused the flood.







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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 (Fig. 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.

Thus, a sensitivity analysis is 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:

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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 (Rasmussen 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 0.25° 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. First 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

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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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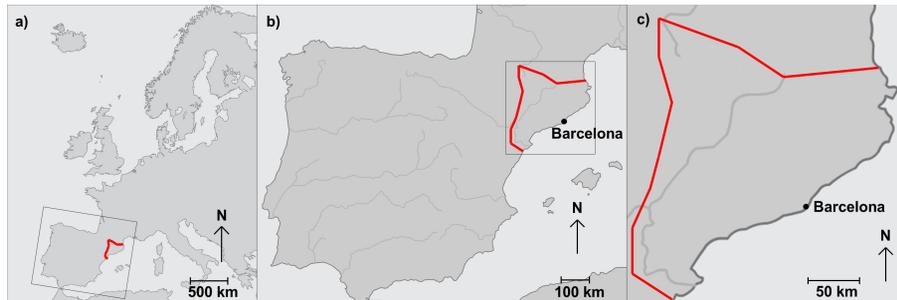


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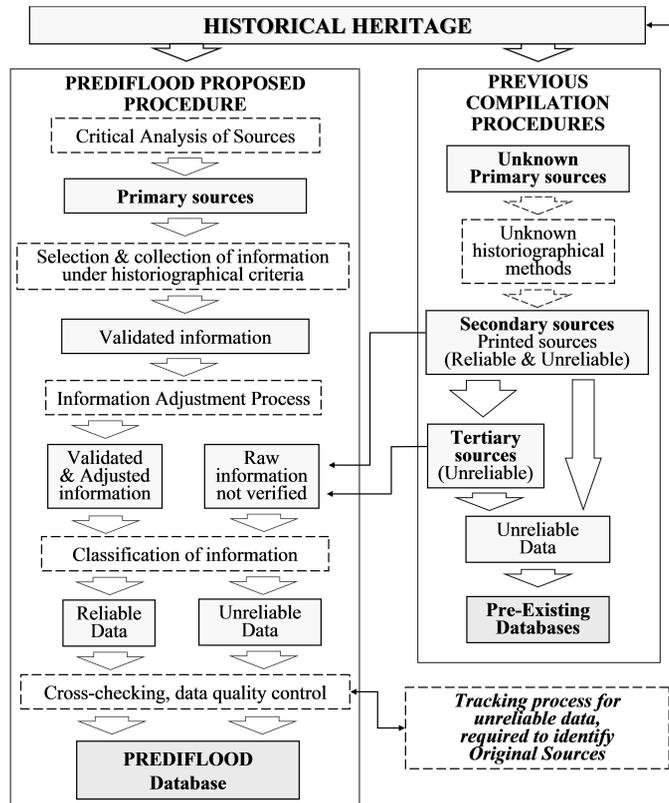
**Figure 1.** Location of Catalonia within Europe **(a)** and the Iberian Peninsula **(b)**, and map of Catalonia **(c)**. Own elaboration from a map Copyright © 2009 National Geographic Society, Washington, DC.

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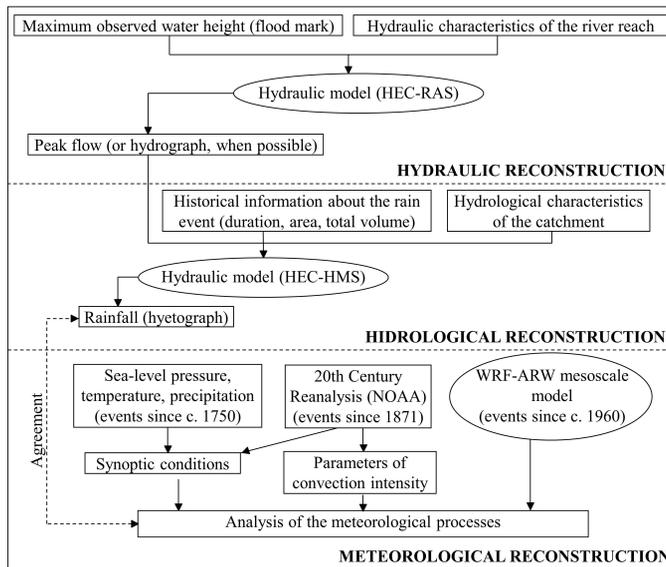
**Figure 3.** Overview of the methodological procedure of historical floods data collection (own elaboration).

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

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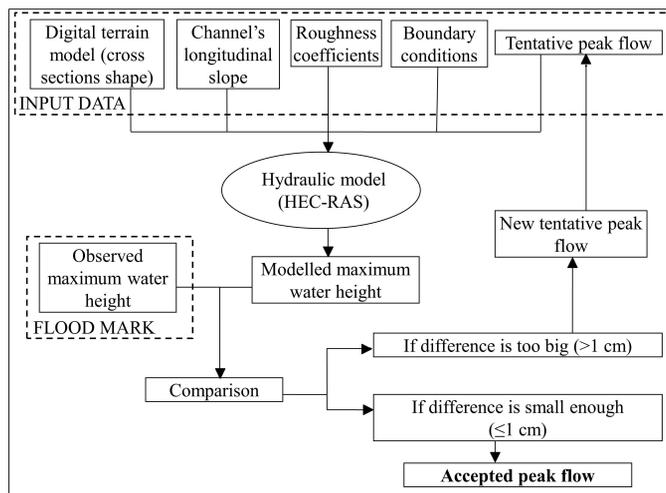
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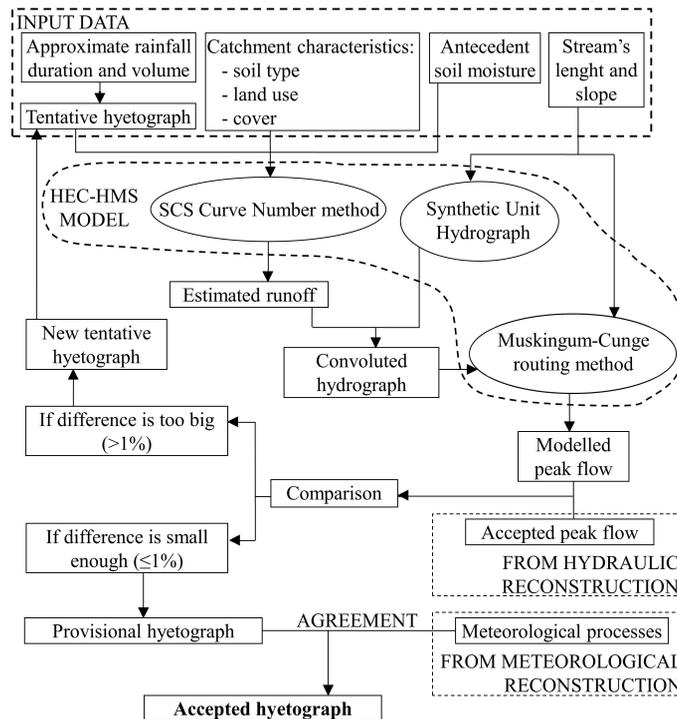
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**Figure 5.** Iterative procedure used in the hydraulic reconstruction of peak flows (own elaboration).

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**Figure 6.** Iterative procedure used in the hydrological reconstruction of hyetographs (own elaboration).

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