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Article

# How Exceptional Was the 2023–2024 Flood Sequence in the Charente River (Aquitania, South-West France)? A Geohistorical Perspective on Clustered Floods

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**Abstract:** During winter 2023–2024, the Charente River experienced four successive flood events in six months, including one major flood and three moderate ones. These grouped floods affected a huge territory in the Charente valley, in particular the Territoire à Risque d'Inondation Important (TRI, i.e., Major Flood Risk Area) between Angoulême and Saintes (46 municipalities). Although they produced little immediate damage due to their slow kinematics and low flow speeds, they had a major impact on the functioning of the territory through prolonged house flooding and infrastructure disruption. This repeated flood sequence is all the more remarkable in that it occurs after the February 2021 extreme flood and a backdrop of severe and prolonged drought initiating in 2019. This article proposes to analyze grouped floods, a complex and little-studied hydrological phenomenon, from a geohistorical perspective in order to demonstrate that they are not emergent events and to look for historical precedents that show that these particular events have already occurred in the past but have been neglected or underestimated until now. Among past grouped flood sequences extending back to 1700, a significant similarity arises with the 1859–1860 flood sequence. In both cases, the first annual flood occurred early in the year in response to an early storm season and followed an uncommon hot and dry summer. Although the floods of 2023–2024 are well documented through both meteorological and hydrological data, as well as the surrounding context, the floods of 1859–1860 remain poorly constrained. By gathering a wide range of documentary sources and instrumental data, we try to better understand the context and the course of this past sequence of grouped floods, with particular emphasis on the first annual flood, the November 1859 flood. The analysis of similarities and divergences between sequences of past and recent grouped floods makes it possible to improve knowledge of their formation and course in order to better anticipate these particular events in the context of climate change.

**Keywords:** floods; historical hydrology; geohistorical data; extreme floods; flood chronology; clustered flood; low-energy rivers; Charente River

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Received: 4 December 2024
Revised: 10 January 2025
Accepted: 13 January 2025
Published: 17 January 2025

**Citation:** Duquesne, A.; Carozza, J.-M. How Exceptional Was the 2023–2024 Flood Sequence in the Charente River (Aquitania, South-West France)? A Geohistorical Perspective on Clustered Floods. *GeoHazards* **2025**, *6*, 3. https://doi.org/10.3390/geohazards6010003



## 1. Introduction

During the past three decades, Europe was affected by repeated high-intensity floods: October/November 2000 and July 2007 in the United Kingdom [1–4], August 2002, March-April 2006, June 2013, and June 2024 in Central Europe [5–8], July 2021 and November 2023 in North-Western Europe [9–13]. These disastrous events have demonstrated the high level of vulnerability of European societies and the need for flood risk reassessment based on historical data review. In this context, historical hydrology works have multiplied [14] in order to support future flood risk management and prevention strategies in Europe, for example, in the United Kingdom [15], Czech Republic [16], and Germany [17], and to enhance statistical and modeling approaches, in particular the reconstruction of historic flood discharges corresponding to high return periods to construct effective flood defenses, for example, in France [18], Germany [19], and the Netherlands [20].

Previous works on historical floods have focused on the long-term flood chronologies reconstruction from various historical and/or field sources [21–24] but also on reconstructing historic flood discharges, better understanding the temporal and spatial hydrometeorology of the flood events, reconstructing maps of the spatial extent of past flooding for comparison with risk mapping, analyzing the long-term trends of floods, including their frequency, magnitude, and seasonality, and improving statistical models to better predict future flood events. Knowledge on historical floods is crucial to anticipate the impacts of climate change on flood regimes and help to enhance the memory of floods and risk culture. Studies have been both European [23–25] and regional in scale, such as in the United Kingdom [26–29], Czech Republic [14,16,30–32], Germany [33–37], Netherlands [38], Switzerland [39,40], Spain [41–45], and Norway [46–48]. However, few studies have focused on the occurrence of repeated grouped floods at a sub-annual time scale.

Since the late 2000s, these works have also increased in number in France but remain focused on large, high-energy rivers with major human, material, functional, and patrimonial issues. This is the case for the Seine River [49], the Loire River [50–52], the Rhône River [53,54], or the Rhine River [20,36,55]. Small mountain rivers affected by flash floods have also received special attention because of their potentially destructive impact in the Languedoc [56–59], the Pyrenees [60–62], the Alps [63–66], the Massif Central [67,68], and the Vosges [69–73].

Small, low-energy rivers have received more limited attention to date, even though they are common in the plains of western and northern France, although these “ordinary rivers” [74] experience uncommon floods like during winter 2023. This is also the case with the Charente River [75]. The low level of attention by scholarly works can be explained by the unspectacular nature of these floods, causing little damage to people as a result of slow flood dynamics (water rises over several days, low flow velocities, moderate flood discharges). Floods in the Charente River are rarely deadly, and warning systems help evacuate the most threatened areas in advance. In addition, the repeated occurrence of floods of moderate intensity (return frequency between 2 and 5 years), the rarity of extreme floods, and the low human mortality and damage are not conducive to the production of documentary archives enabling the reconstruction of past floods. The scarcity of the historical sources available has severely limited the number of historical hydrology studies on these “ordinary rivers” and has consequently led to a lack of knowledge about past floods.

As they concern a large part of the territory, the knowledge on hydrometeorological background of the floods, their spatial extent, the reconstitution of the higher level they reach, the estimation of pic flow, and their return frequencies, as well as the reconstitution of long-term chronologies and trend analysis, including frequency, intensity, and seasonality, are crucial to better manage risks in the future. Indeed, climate change represents a major challenge for these ordinary rivers [76]. Rising temperatures, combined with increased precipitation, are expected to lead to more frequent and intense floods [77,78] and to major social, economic, and political impacts. The current frequency of floods in Europe is already exceptional compared to the last 500 years [24].

This year (2023–2024), the Charente River has experienced an unusual succession of four repeated floods in six months, including one major flood and three moderate ones. These events are all the more remarkable in that they come barely two years after the major flood in February 2021 and succeeds a severe and prolonged drought beginning in 2019.

This phenomenon of grouped floods remains yet little studied, both from the point of view of their causes and their hydrological organization, and constitutes a risk that is often underestimated and unknown, particularly in urban areas. The understanding of these complex hydrological phenomena is a major issue for risk management in the context of climate change, where such events could multiply, leading to significant material damage and major disruption, particularly on low-energy rivers such as the Charente River, where flood durations are long (from a few days to several weeks).

This article proposes to analyze grouped floods, a rare (or scarcely studied) complex hydrological phenomenon, through a geohistorical approach. The main objectives are to demonstrate that repeated floods, such as those observed in 2023–2024 on the Charente River, are not isolated events and to search for historical precedents that show this type of event has occurred in the past but has been neglected or underestimated until now. The analysis of grouped flood sequences, whether past or recent, allows for the identification of both similarities and differences, providing better insight into the potential occurrence of future events in the context of climate change. However, this comparative approach has its limits, as these particular events occurred under different climatic conditions, data collection contexts, and societal vulnerability levels.

## 2. Study Area

### *2.1. The Charente River*

Located on the Atlantic coast in southwest France, the Charente River is a low-energy (10 $W \cdot m^{-2}$) and low-gradient river (0.00086 $m \cdot m^{-1}$) (Figure 1). The watershed drains 10,550 $km^2$. The river has its source in Chéronnac (296 m a.s.l.) and flows for 365 km before reaching the Atlantic Ocean at Port-des-Barques, where it forms a wide estuary (3 m a.s.l.). In the upper section, between Mansle and Angoulême, the Charente River adopts a complex anastomosed channel pattern [79] in the sense defined by Nanson [80]. Downstream of Angoulême, the fluvial pattern evolves towards a simplified anastomosing pattern and then switches to a meandering style with reduced lateral mobility downstream of Cognac [81–83].

The Charente River basin is composed of three major geological domains [84]. The first domain comprises metamorphic and granitic complexes from the Massif Central located in the upstream section. The second domain is characterized by monoclinal Jurassic limestone situated in the north of a line connecting Angoulême and Rochefort. The latter domain corresponds to folded anticline-syncline structures within Cretaceous sandy-clay detritic deposits to the south of this line. These deposits are overlapped by Holocene fluvio-marine deposits in the lower part of the catchment [85]. The impermeable clay-loam soils encourage water runoff. Infiltration potential is therefore limited, with the exception of the Angoumois karstic zone, including the Tardoire, Bonnieure, and Touvre basins. The Charente River basin shows a temperate oceanic climate classified as Cfb in the Köppen climate classification system. It is characterized by cool winters with a mean temperature of 6 °C in January and moderately warm summers with a mean temperature of 20 °C in July. Precipitation ranges between 700 mm in the coastal part and over 1000 mm in the eastern part, with an annual average rainfall of 800 mm [86].

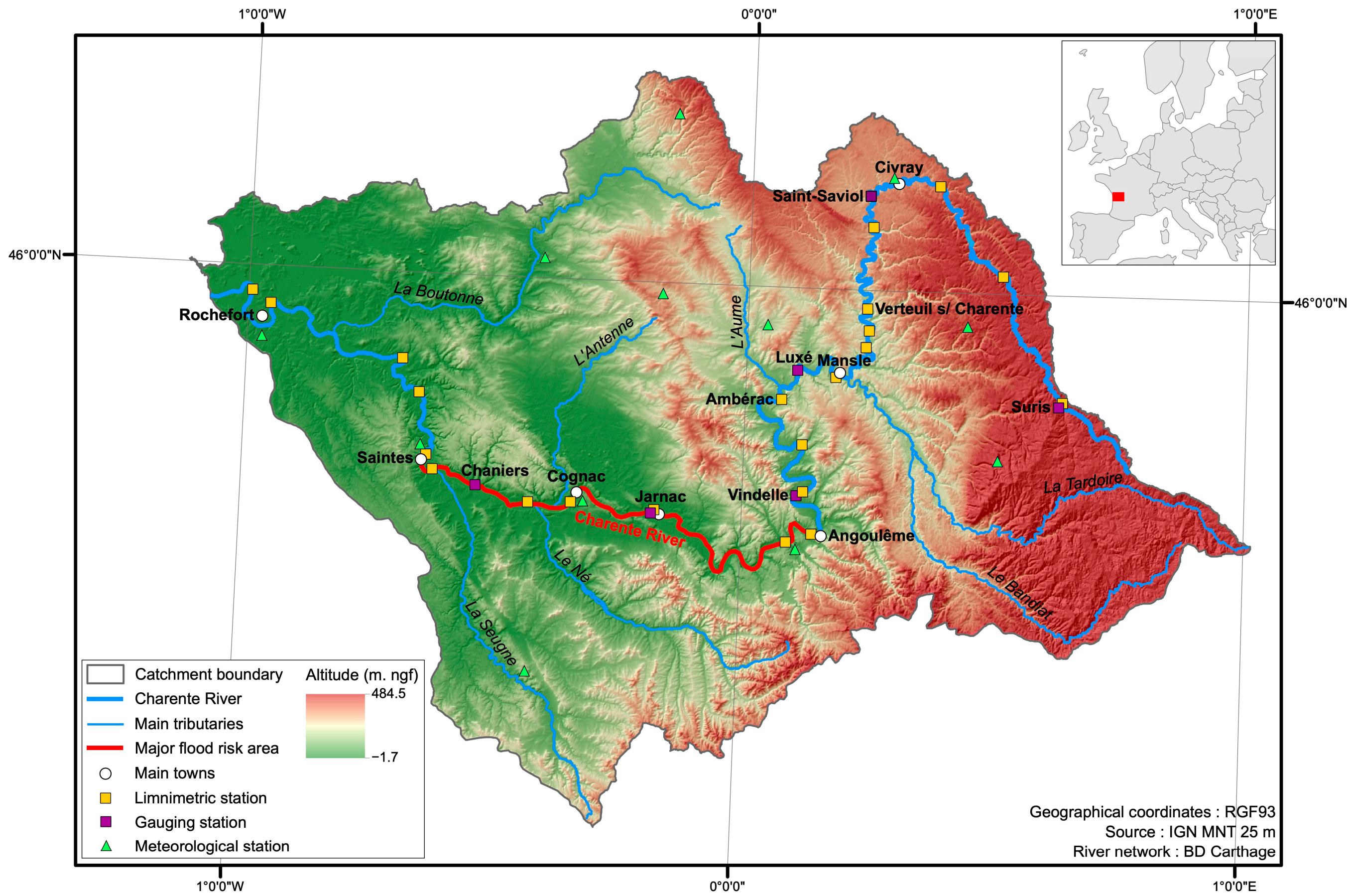



**Figure 1.** The Charente River catchment in France.

## 2.2. The Charente River Floods Regime

The Charente River features a rain-evaporation regime representative of Atlantic lowland rivers. The flow regime can be described from the Chaniers gauging station [87] located in the middle Charente River (Figure 1). The high-water stage occurs from December to March with a maximum mean discharge in February (147 $m^3 \cdot s^{-1}$) and the low-water stage extends from July to October with a minimum mean discharge in September (17 $m^3 \cdot s^{-1}$) (Figure 2). The mean annual discharge is 66 $m^3 \cdot s^{-1}$ and two-year flood reach 283 $m^3 \cdot s^{-1}$. The highest discharge is 550 $m^3 \cdot s^{-1}$ and was recorded on 8 February 2021 and corresponds to a 20-year flood.

The floods of the Charente River mostly occur in winter, particularly between December and February, generated by prolonged and/or intense precipitation from westerly lows, the second flood season being spring [75]. Autumn floods are much rarer and occur after heavy rainfall in October. Two flood types are documented in the Charente River related to the characteristics of rainfall events (i.e., duration and intensity).

The first type concerns floods generated by short (a few days) but intense rainfall events at the basin scale. The flood wave is brief but often intense and particularly concerns the upper part of the watershed. When the flood wave propagates downstream, it is attenuated by overflows over the floodplain. Water levels are higher in Angoulême but more moderate in Saintes, as the contribution of downstream tributaries is weaker. The 1962 March-April flood is representative of this flood type. In the space of four days (25, 27–29 March), 105 mm of precipitation fell at the Saintes meteorological station, equivalent to 71% of the monthly total. The event was characterized by a short and intense water level in the upper watershed. The maximum water level reached 5.50 m on 1 April 1962 at Angoulême and 5.78 m on 5 April 1962 at Saintes.

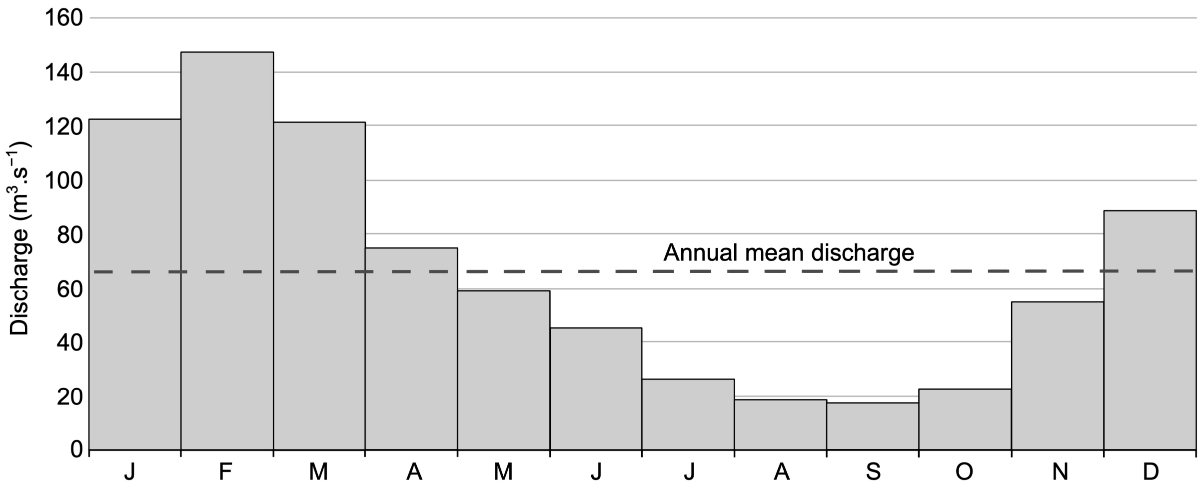



**Figure 2.** Hydrogram of the Charente River at the Chaniers gauging station on the calculated period 2004–2024 (from: HydroPortail [87]).

The second type results from persistent rainfall events (one week or more). The flood wave lasts several days and intensifies downstream as a combination of persistent rainfall in the upper watershed and the contribution of tributaries (e.g., Antenne River, Né River, and Seugne River). Water levels are more moderate at Angoulême and higher at Saintes. The 1982 December flood corresponds to this type. In 1982, October and November were very rainy. In December, however, rainfall was abundant and continued for 17 days. The mean rainfall was 243 mm on the Charente, three times more than normal. The December 1982 100-year flood reached 5.57 m (620 $m^3 \cdot s^{-1}$) on December 22 at Angoulême and 6.84 m (815 $m^3 \cdot s^{-1}$) on 24 December at Saintes (Table 1).

**Table 1.** Water discharges at the main gauging stations on the Charente River (from: HydroPortail [87], TRI Angoulême-Saintes [88], and PPRI Saintes [89]).

| Gauging Station | Suris | Vindelle | Angoulême | Jarnac | Chaniers | Saintes |
|---|---|---|---|---|---|---|
| Surface ($km^2$) | 111 | 3722 | - | 4669 | 7412 | 7220 |
| Mean annual discharge ($m^3 \cdot s^{-1}$) | 14 | 30 | - | 64 | 65 | - |
| 2-year flood ($m^3 \cdot s^{-1}$) | 10 | 188 | - | 215 | 303 | 320 |
| 5-year flood ($m^3 \cdot s^{-1}$) | 17 | 289 | - | 273 | 448 | 450 |
| 10-year flood ($m^3 \cdot s^{-1}$) | 22 | 356 | 440 | 310 | 545 | 535 |
| 20-year flood ($m^3 \cdot s^{-1}$) | 26 | 420 | - | 343 | 637 | 620 |
| 50-year flood ($m^3 \cdot s^{-1}$) | 32 | 503 | 560 | - | - | 750 |
| 100-year flood ($m^3 \cdot s^{-1}$) | - | - | 645 | - | - | 815 |
| Calculation Period | 1991–2024 | 1977–2020 | - | 1990–2021 | 2004–2024 | - |

The floods of the Charente River are characterized by slow kinematics and extend over a wide floodplain up to three km in width (Figure 3). The water level rises very slowly and lasts from a few days to one week or more. The maximum flood wave spreads in 24 h from Mansle to Angoulême and in 48 to 72 h from Angoulême to Saintes. Water level decrease is even slower and ranges between 10 and 30 days. Flood periods are consequently very long (from a few days to several weeks).

(**a**)

(**b**)

**Figure 3.** The February 2021 flood: (**a**) Flooding upstream of La Baine (Chaniers); (**b**) Flooding downstream of La Baine (Chaniers).

Despite the intensity and duration of the floods, flow velocities are low. These floods are not life-threatening. However, they can cause significant damage and major disruption (roads cut off, houses flooded, damage to engineering structures, degradation of electricity, gas, and water supply networks, water pollution from waste, etc.) because the river flows through several towns, including Angoulême, Jarnac, Cognac, Saintes, and Rochefort.

The flood dynamics in the Charente River are a consequence of the river's very low gradient, particularly in the downstream section as far as the estuary (i.e., ~0.00004 $m \cdot m^{-1}$), the weak width of the mean water channel, and the reduction in the floodplain (wooded areas, pastoral areas, etc.) by urbanization. The presence of bottlenecks in the floodplain also contributes to increased flood levels upstream and slows down the free flow of water during floods, particularly at Saintes, where the floodplain is abruptly reduced from 1 km to 40 m. The rising tide associated with high tidal coefficients can slow the evacuation of floodwaters and amplify the flood event in the downstream section of the river, at least as far as Saintes.

### 2.3. The 2023–2024 Floods Sequence

#### 2.3.1. The November 2023 Flood

The November 2023 flood forms in the Upper Charente watershed, upstream of Mansle, after the first rainfall episode generated by storm Céline (27–30 October). This flood lasts between three and four weeks over the Charente watershed. The Charente River reaches a first flood peak of 1.50 m on 7 November at Mansle, 4.15 m on 8 November at Angoulême, 7.08 m on 10 November at Cognac, and 5.42 m on 12 November at Saintes (Figure 4). As the waters began to fall in the upper section, further heavy rainfall from storms Elisa (9–11 November) and Frédérico (14–16 November) generated a second distinct flood peak on the Upper Charente River and a period of relative calm between the two flood peaks on the Lower Charente River. The Charente River records a second peak of 1.49 m on 16 November at Mansle, 4.06 m on 18 November at Angoulême, 6.96 m on 19 November at Cognac, and 5.45 m on 17 November at Saintes. The November 2023 flood is associated with a 4-year flood on the Charente watershed.

#### 2.3.2. The December 2023 Flood

The December 2023 flood is a generalized event affecting the Charente River and its tributaries. It begins towards the end of the first decade of December and lasts about two weeks over the Charente watershed. The Charente River shows one flood peak (Figure 4). The Upper Charente River reaches 2.05 m on 13 December at Mansle and 4.76 m on 14 December at Angoulême. As the waters begin to fall in the upstream section, the flood wave continues to propagate downstream of Angoulême and increases downstream of Cognac due to significant inflows from the Né and Seugne Rivers. The Charente River features a flood peak of 7.58 m on 16 December at Cognac and 6.08 m on 17 December at Saintes. The December 2023 flood corresponds to a 7-year flood on the Upper Charente River and a 10-year flood on the Lower Charente River.

#### 2.3.3. The February–March 2024 Flood

The February–March 2024 flood begins at the end of the last decade of February and lasts almost a month on the Charente watershed. The Charente River reaches a first flood peak of 1.61 m on 28 February at Mansle, 4.16 m on 29 February at Angoulême, and 6.98 m on 3 March at Cognac (Figure 4). In response to a new rainfall episode, the Upper Charente River reacts by forming a second, very distinct flood peak. The river records 1.52 m on 4 March at Mansle, 4.15 m on March 6 at Angoulême, and 7.01 m on 7 March at Cognac. Downstream, because of the rapid propagation of the second flood wave, the Charente River features one flood peak, spread out over time. At Saintes, the maximum reaches 5.54 m on 5 March. The February–March 2024 corresponds to a 4-year flood.

#### 2.3.4. The March–April 2024 Flood

The March–April 2024 flood ends this hydrological sequence (Figure 4). The flood occurs in the Upper Charente basin, upstream of Mansle, and lasts about two weeks. The Charente River records one flood peak. The Upper Charente River reaches a maximum of 1.60 m on 31 March at Mansle, 4.12 m on 2 April at Angoulême, 6.87 m on 4 April at Cognac, and 5 m on 6 April at Saintes. The March–April 2024 flood is associated with a 3-year flood in the Charente basin.

This succession of closely spaced, early floods is a situation that river managers have described as unprecedented and related to the changes in precipitation patterns resulting from climate change. We therefore looked at the flood chronology on the Charente River to see if there were any similar patterns and their meteorological context.

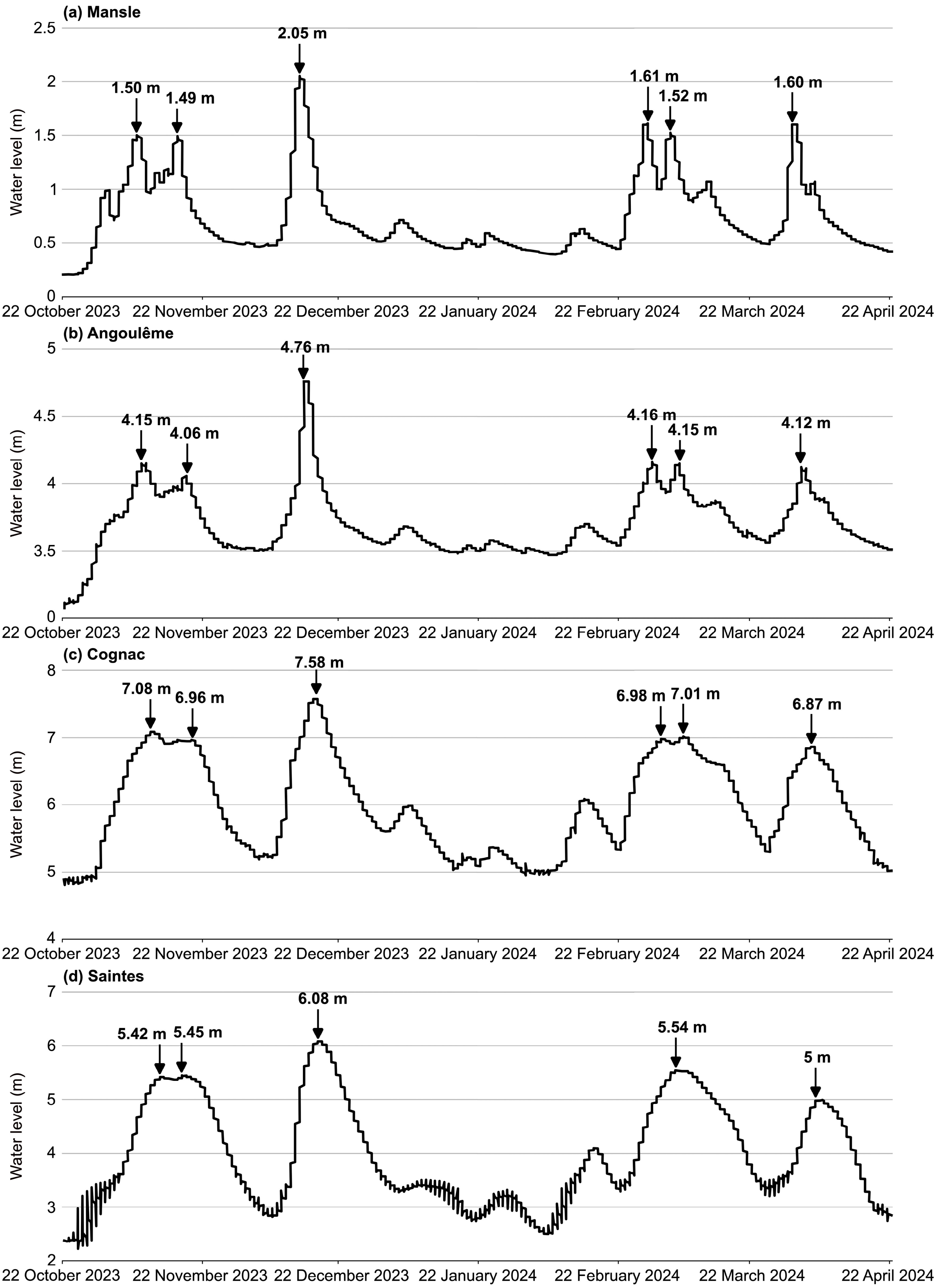



**Figure 4.** The 2023–2024 floods sequence limnigram on the Charente River at several limnimetric stations: (**a**) Mansle; (**b**) Angoulême; (**c**) Cognac; (**d**) Saintes (from: website e-crue [90]). Note that data in the Saintes gauging station are influenced by the tide at low water level.

## 3. Materials and Methods

### 3.1. Meteorological Data

For the 20th and 21st centuries, annual, monthly, and daily precipitation and temperature data were gathered from several meteorological stations managed by Météo-France [91] located throughout the Charente watershed (Figure 1 and Table 2). For the 19th century, annual and monthly precipitation data were collected at two rainfall stations located in the Charente watershed (Rochefort and Saint-Jean-d'Angély). Temperature data were recovered at the La Rochelle meteorological station, situated outside the watershed. The pressure data and associated maps were obtained from Wetterzentrale [92] based on version 3 of the 20th Century Reanalysis system supported by the National Oceanic and Atmospheric Administration (NOAA), the Cooperative Institute for Research in Environmental Sciences (CIRES), and the Department of Energy (DOE) [93]. These data were used to analyze and describe the annual and seasonal weather conditions and individual weather events that precede each flood.

**Table 2.** Current meteorological stations on the Charente watershed used in this study and located in Figure 1.

| Meteorological Station | Latitude | Longitude | Altitude | Systematic Measurements |
|---|---|---|---|---|
| Cognac | 45.665000 | −0.315833 | 30 | 1946–2024 |
| La Couronne | 45.627833 | 0.099833 | 58 | 1976–2024 |
| Montemboeuf | 45.787167 | 0.543000 | 247 | 1990–2024 |
| Tusson | 45.949000 | 0.062167 | 88 | 1986–2024 |
| Le Vieux Cérier | 45.967500 | 0.442000 | 162 | 1990–2024 |
| Nuaillé-sur-Boutonne | 46.019833 | −0.406667 | 36 | 1933–2024 |
| Saint-Germain-de-Lusignan | 45.458333 | −0.409667 | 71 | 1969–2024 |
| Saintes | 45.761167 | −0.652000 | 38 | 1916–2024 |
| Villiers-Couture | 45.987500 | −0.152000 | 106 | 1962–2024 |
| Civray | 46.160333 | 0.298667 | 143 | 1990–2024 |
| Melle | 46.235000 | −0.151333 | 136 | 1989–2024 |

### 3.2. Hydrological Data

Water level measurements were collected from the website Vigie-crue [90] for several hydrological stations located on the Charente River (Figure 1 and Table 3) to reconstruct the course of the four floods of the 2023–2024 winter period. Historical water level data were retrieved from the archives of the Ponts-et-Chaussées engineering corps (1843–1916), the *Service d'Annonce des Crues* (1916–1987), and the *Direction Régionale de l'Environnement, de l'Aménagement et du Logement de la Nouvelle-Aquitaine* (1988–Actual) in order to place these recent events in the long flood chronology. A chronicle of water levels was reconstructed at Saintes at the limnimetric scale located upstream of the Pont Palissy during the 1875–2024 period as it presents the oldest data (Figure 5). Floods higher than the 4 m warning level at Saintes (n.b. 4.20 m today) were included. Water levels reached by floods before 1875 were added to this chronicle. Hydrological measurements between 1843 and 1875 were provided by a Ponts-et-Chaussées sub-engineer to the Société des Archives Historiques [94]. They must be considered with a degree of caution, as they were recorded at the level of the old bridge (January 1843 flood) or the hanging bridge, now Pont Palissy (November 1859, December 1872, January and March 1873 floods). This chronicle of water levels at Saintes is currently the most exhaustive on the Charente River.

**Table 3.** Current hydrological stations on the Charente River consulted in this study and located in Figure 1.

| Hydrological Station | River | Latitude | Longitude | Systematic Measurements |
|---|---|---|---|---|
| Mansle | Charente | 45.87736732 | 0.17996101 | 2005–2024 |
| Angoulême | Charente | 45.65311030 | 0.15309785 | 1916−2024 |
| Cognac | Charente | 45.68964247 | −0.33987427 | 1993−2024 |
| Saintes | Charente | 45.74707976 | −0.62972709 | 1875−2024 |


**Figure 5.** Limnimetric scale and flood marks at the Palissy Bridge in Saintes.

### 3.3. Documentary Sources

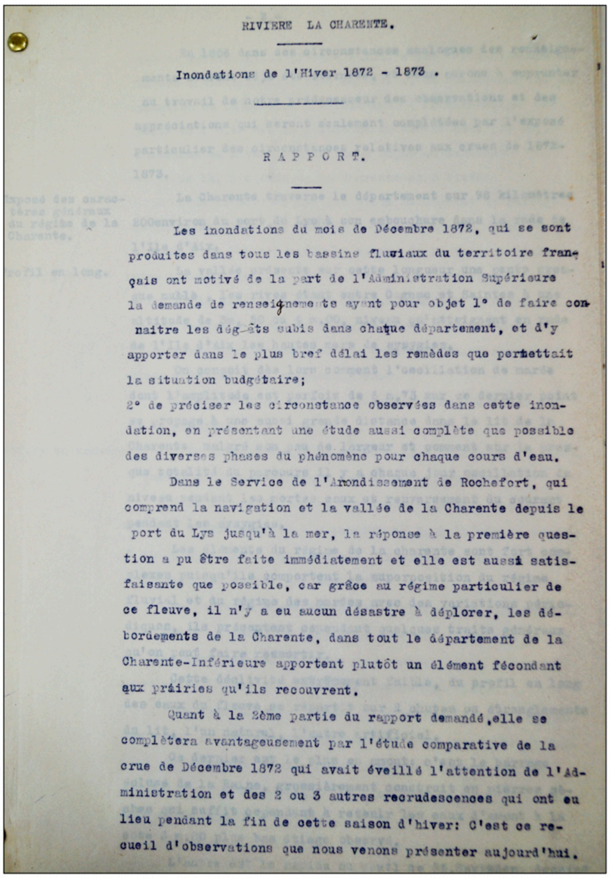
For the pre-instrumental period, the data on the historical floods was compiled from various documentary sources, using the historical collection method proposed by Brázdil et al. [14] and Barriendos et al. [21]: secondary sources, historical archives, local newspapers, iconographic documents, and epigraphic records. These historical records, most dating from the 19th century, made it possible to document the number of annual floods as well as the seasonality and severity of the events when the hydrological data are incomplete or missing.

#### 3.3.1. Secondary Sources

Secondary sources were first consulted but are very limited. Some historical floods affecting the Charente River during the 18th and 19th centuries are mentioned, notably in Champion [95]. This research is detailed and occasionally refers to the sources consulted (newspapers, books, etc.). However, this chronology of past floods is not exhaustive. Only catastrophic flood events were reported. Low-intensity floods are not considered noteworthy, due to their repeated frequency and limited material damage. Only floods attested by other sources have been included in this work.

#### 3.3.2. Historical Archives

The research was carried out on four archival collections: the archives of the *Département de la Charente*, the archives of the *Département de la Charente-Maritime*, the municipal archives of Saintes, and the *fonds régional et ancien des médiathèques* de Saintes. The modern archives (documents from the 18th to early 20th centuries) were mainly produced by the Ponts-et-Chaussées engineer corps, responsible for the maintenance of rivers and fluvial infrastructures related to commercial navigation, river crossing, water mills, floods, etc. The engineers' written reports provide several valuable pieces of information, including the date of the events, weather conditions, course of flood, location and type of material damage, level reached by water, reconstruction plans, and engineering works built against the floods (Figure 6). The contemporary archives (documents starting from 1940) are composed of documents deposited by the *Etablissement Public Territorial du Bassin Charente* and the *Service d'Hydrologie Maritime of the Direction Départementale de la Charente-Maritime*. These documents refer in particular to flood prevention and protection measures planned or implemented following the December 1982 and January 1994 floods.



RIVIERE LA CHARENTE.

Inondations de l'Hiver 1872 - 1873 .

R A P P O R T.

Les inondations du mois de Décembre 1872, qui se sont produites dans tous les bassins fluviaux du territoire français ont motivé de la part de l'Administration Supérieure la demande de renseignements ayant pour objet 1° de faire connaitre les dégâts subis dans chaque département, et d'y apporter dans le plus bref délai les remèdes que permettait la situation budgétaire;
2° de préciser les circonstance observées dans cette inondation, en présentant une étude aussi complète que possible des diverses phases du phénomène pour chaque cours d'eau.

Dans le Service de l'Arondissement de Rochefort, qui comprend la navigation et la vallée de la Charente depuis le port du Lys jusqu'à la mer, la réponse à la première question a pu être faite immédiatement et elle est aussi satisfaisante que possible, car grâce au régime particulier de ce fleuve, il n'y a eu aucun désastre à déplorer, les débordements de la Charente, dans tout le département de la Charente-Inférieure apportent plutôt un élément fécondant aux prairies qu'ils recouvrent.

Quant à la 2ème partie du rapport demandé, elle se complètera avantageusement par l'étude comparative de la crue de Décembre 1872 qui avait éveillé l'attention de l'Administration et des 2 ou 3 autres recrudescences qui ont eu lieu pendant la fin de cette saison d'hiver: C'est ce recueil d'observations que nous venons présenter aujourd'hui.

The Charente River

1872-1873 Winter Floods

Report

The December 1872 floods, which occurred in all the river basins of France, prompted the Superior Administration to request information with the aim of 1) reporting on the damage suffered in each department, and remedying the situation as quickly as possible ;
2) detail the circumstances surrounding this flood, presenting as complete a study as possible of the various phases of the phenomenon for each river.
In the Service de l'Arrondissement de Rochefort, which covers the navigation and valley of the Charente from the Port du Lys to the sea, the answer to the first question could be given immediately, and it is as satisfactory as possible, because thanks to the river's particular regime, there are no disasters to be deplored, and the flodds of the Charente River throughout the Charente-Inférieure department bring a fertilizing element to the meadows they cover.
As for the second part of the report, it will be completed by a comparative study of the December 1872 flood, which had alerted the Administration, and the two or three other floods that occurred at the end of the winter season. It is this collection of observations that we have come to present today.

**Figure 6.** Documentary record example: Report on the 1872–1873 floods by a Ponts-et-Chaussées engineer (from: Archives of the *département de la Charente-Maritime*, S6571).

Municipal archives of Saintes feature various documents, including complaints from residents of the river. These complaints provide information on the extent and damage of the flood. However, a degree of caution must be applied to these particular documents, as they can occasionally exaggerate the number of floods and their damage in order to obtain greater compensation.

### 3.3.3. Newspapers

From the first half of the 19th century, the floods on the Charente River are mentioned in local newspapers, particularly in the *Echo Rochelais* (1829–1941), the *Charentais* (1834–1895), the *Indicateur de Cognac* (1837–1944), the *Tablette des Deux-Charentes* (1843–1944), the *Indépendant de la Charente-Inférieure* (1848–1944), the *Ère Nouvelle des Charentes* (1871–1940), the *Charente* (1883–1940), and *Sud-Ouest Charente-Maritime* (from 1944 to date). Newspapers were consulted on the press websites of the *Bibliothèque Nationale de France "retronews"* [96] and the *Département de la Charente "La Source"* [97]. When newspapers were not available on the press websites (e.g., the *Tablette des Deux-Charentes* and the *Indicateur de Cognac*), these documents were consulted in the archival collections.

The exhaustive reading of the local newspapers made it possible to complete the chronology with previously unidentified floods on the Charente River. It also improves knowledge of past floods by providing information on previous floods, material damages, human losses, rescue operations, water level measurements, and actions taken by authorities during and/or after the flood event (Figure 7). News reported by local newspapers should be treated with caution: partial or misleading information, subjectivity of the author, excessive catastrophism, exaggeration of damage, and spatial inequality of information. Indeed, on this last point, the flood accounts pay significant attention to the consequences of the flood on the major cities crossed by the Charente River (Angoulême, Cognac, Saintes), where the issues are high; conversely, the small villages and rural areas are almost never mentioned.

**FAITS DIVERS.**

Depuis quinze jours, la Charente, ordinairement si paisible, est sortie de son lit, et ses eaux débordées ont atteint une hauteur considérable. Il faut remonter aux années 1842 et 1843 pour trouver une crue semblable. Toutes les prairies qui bordent la rivière sont inondées. Dans la nuit de mercredi à jeudi, les eaux se sont élevées de 40 centimètres, et depuis elles n'ont cessé de monter d'une vingtaine de centimètres par douze heures.

La Charente s'est répandue sur plusieurs points de la ville, notamment au Pont-des-Monards, au quai Palissy, sur les quais Reverseaux, des Frères, la rue de l'Ormeau, etc. Le rez-de-chaussée de plusieurs maisons est inondé : on y mesure 30 à 40 centimètres d'eau environ.

Jusqu'à présent, aucun accident grave n'est parvenu à notre connaissance, sauf quelques dégradations occasionnées aux bains Gaudet et à la maison de M. Cartron, occupée par M. Massiou, aubergiste, Route-Neuve, et dont les murs intérieurs se sont affaissés.

**NEWS**

For the past fifteen days, the Charente River, usually so peaceful, has been rising out of its banks, and its overflowing waters have reached a considerable height. It's only in 1842 and 1843 that a similar flood has occurred. All the meadows bordering the river were flooded. During the night of Wednesday to Thursday, the water rose by 40 centimeters, and since then it has continued to rise by about 20 centimeters per twelve hours.

The Charente River flooded several points in the city, including Pont-des-Monards, Quai Palissy, Quais Reverseaux, Quais des Frères, Rue de l'Ormeau, etc. The first floors of several houses were flooded, with water levels of around 30 to 40 centimetres.

To date, no serious accidents have been reported, with the exception of some damage to the Gaudet's baths and Mr Cartron's house, occupied by Mr Massiou, innkeeper, Route-Neuve, whose interior walls have collapsed

**Figure 7.** Newspaper example about the Charente River. Article of the November 1859 flood from the *Indépendant de la Charente-Inférieure* of 5 November 1859 (from: website *"retronews"* [96]).

### 3.3.4. Iconography

Postcards of past floods and pictures of recent ones were also used (Figure 8). They immortalize the remarkable nature of these extreme events and maintain the memory of the floods. These documents provide valuable information on the spatial extent, water level, and material damage of the flood. However, they are used with caution, as they reflect the experience and perception of their author and are dependent on technical advances in photography.


**Figure 8.** Postcards on the Charente River: (**a**) The February 1904 flood in Faubourg L'Houmeau at Angoulême (from: Archives of the *Département de la Charente*, 26 Fi 202); (**b**) The February 1904 flood in Quai des Frères at Saintes (from: *Fonds Ancien et Régional des Médiathèques de Saintes*, 3231 CP); (**c**) The 1907 flood in Rue du Gond at Angoulême (from: Archives of the *Département de la Charente*, 11 Fi15/281).

#### 3.3.5. Epigraphic Records

The water levels reached during the past and most recent extreme floods were marked on buildings, bridges, or doors in the form of carved marks, painted marks, or specific plaques (Figure 5). These flood marks provide a visual representation of the flood event in the immediate environment in terms of spatial extent and water level. A total of 334 flood marks were identified in the Charente watershed [98]. In many cases, the only proof of a historical flood is a flood mark.

### *3.4. Processing of Historical Data*

#### 3.4.1. Historical Data Gathering

Historical data were collected by consulting inventories and selecting items by keywords. All available historical documents mentioning a flood, overflow, or similar event were consulted in their entirety. All events corresponding to a flood were included in the flood chronology on the Charente River. Each event was classified to one of the following zones: Upper Charente River (from its source to Angoulême), Middle Charente River (Angoulême to Saintes), Lower Charente River (downstream of Saintes to the estuary), and Charente River. This last class includes events occurring in at least two zones. An additional category was added to include flood events with no accurate location. Based on available historical data, the date of flooding, meteorological and rainfall conditions, flood dynamics (rising water level, duration of flood, decreasing water level), resulting damage and its location, water levels, and flood defense during (e.g., setting up surveillance in flooded areas) or after (e.g., project to build a canal to facilitate floodwater runoff) the flood were documented for each event. Finally, seasonality was analyzed on the basis of the season of occurrence of the flood event. If a flood occurs during two consecutive months, only the first month is recorded. If a flood occurs for two months between two consecutive seasons, only the first season is considered. Seasonality was determined according to the current hydrological seasons: winter—December, January, February; spring—March, April, May; summer—June, July, August, September; autumn—October, November.

#### 3.4.2. Flood Chronology

The flood chronology on the Charente River was reconstructed since the 18th century based on documentary and instrumental data. The first version of this chronology in Duquesne and Carozza [75] was revised and completed on the basis of additional research in the local press. The flood chronology allows the analysis of the frequency, intensity, and seasonality of floods and highlight the occurrence of remarkable and complex events, in particular grouped floods.

However, this chronology is based on four major discontinuities [71]: (1) the discontinuity of the hazard attributed to changes in the hydro-sedimentary conditions of the river, climatic variations, and changes in land use; (2) the discontinuity of vulnerability of societies linked to changes in building construction techniques and materials, and to changes in the flood risk culture; (3) the discontinuity of perceptions of flood risk associated with the culture and memory of risk (intergenerational transmission, new inhabitants, instrumentalization of risk, etc.); and (4) the discontinuity of documentary sources in time and space. In fact, the flood chronology on the Charente River depends on the nature, quantity, quality, and reliability of the historical data available. The production of documentary sources is related to the damage caused by the flood and is therefore dependent on the vulnerability of societies and the perception of flood risk. While this long-term chronology references all extreme flood events accurately, it can overlook some events of low or moderate intensity, as these are not mentioned in documentary sources in the 18th and 19th centuries in the absence of significant material damage.

For older floods, chronological data are often limited, and hydrological observations are incomplete, particularly in the absence of daily flood bulletins, which makes it difficult to apply classical flood separation methods such as those proposed by Lang et al. [99] and Robson and Reed [100]. In the case of this work, only the time distance between peak flow is used as an independence criterion for past and recent flood sequences in order to apply uniform criteria. This approach overcomes the lack of continuous data.

#### 3.4.3. Classification of Flood Events

The flood classification on the Charente River was performed in order to qualify the intensity of the flood event from the documentary sources collected. The classification criteria were determined from several previous studies [14,53,64,67,69,71,101]. However, these criteria were adapted to the specificities of the low-energy hydrological dynamics of the Charente River. In fact, the classification is based on material damage (agricultural damage, damage to engineering structures, damage to private and public property) and human losses (very rare).

Four categories were defined: low (C1), medium (C2), high (C3), and extreme (C4) flood events. Their characteristics are detailed in Duquesne and Carozza [75]. A fifth level (C-1) comprises floods mentioned in several historical documents but for which little or no information is available (e.g., date, spatial extent, material damage, water level, etc.) [14]. This specific level preserves information and avoids distorting results.

Each flood was analyzed separately. The classification of some floods was facilitated by the availability of the documents, but for others, particularly the older ones, it proved more complex. There is a risk of uncertainty, with the possibility of under- or overestimating the event. The main limit of this classification is linked to the availability of sources. The lack of documentary sources may be due to the absence of damage considered significant, but also to biases in the archives (lost, destroyed, or unclassified documents).

## 4. Results

At the current time, the flood chronology on the Charente River records 211 individual floods between 1700 and 2024, based on the study of documentary sources and instrumental data (Figure 9). This inventory is an update of data from Duquesne and Carozza [75]. This flood chronology shows the irregularity of floods over time. In detail, only major floods were recorded during the 18th century, due to the lack of information in historical sources, where only extreme events are mentioned. Between 1835 and 1875, a number of unpublished floods were referenced from local newspapers, particularly small floods. Indeed, minor floods were probably not recorded in the historical archives, due to the lack of significant material damage and the absence of a flood monitoring service. Since 1875, the number of floods recorded has increased in relation to the hydrological observations carried out by the Ponts-et-Chaussés engineering corps, the creation of the *Service d'Annonce des Crues* at the beginning of the 20th century, which now records all floods, including those of low intensity, as well as the increase in the quantity and quality of available documentary sources. However, between 2002 and 2020, the number of floods decreased, which can be explained by a succession of dry periods and reduced rainfall in the watershed.

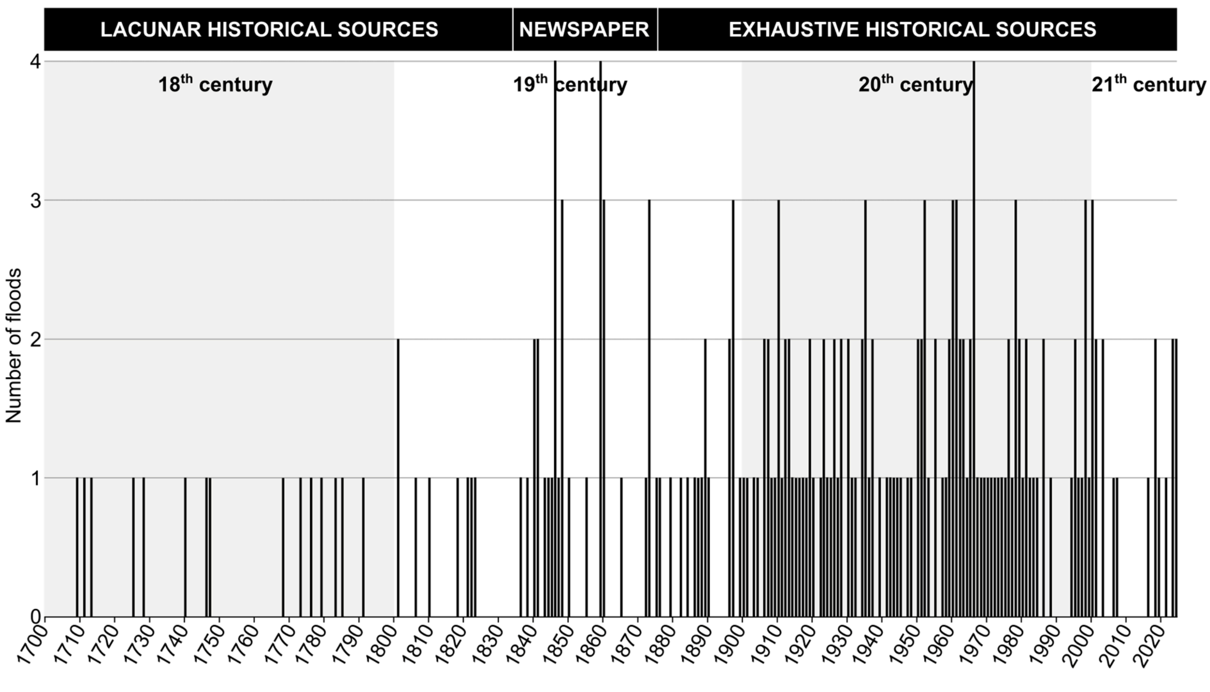



**Figure 9.** Number of floods per year (1 January to 31 December) in the Charente River between 1700 and 2024 (211 floods). Data completed from Duquesne et Carozza [75].

Grouped floods are not an emergent phenomenon on the Charente River during the hydrological winter, which extends from October to April (Figure 10). Since 1700, 38 sequences of grouped floods were recorded. However, the Charente River rarely records more than two grouped floods during this period, with 25 sequences of two clustered floods. The 2023–2024 hydrological sequence is therefore particularly remarkable, since it recorded four clustered floods in six months. Although this phenomenon is exceptional, historical records show that it has already occurred in the past. To date, only four other flood sequences feature this unusual repetitive character (i.e., four or five clustered floods): 1859–1860, 1872–1873, 1960–1961, and 1997–1998.

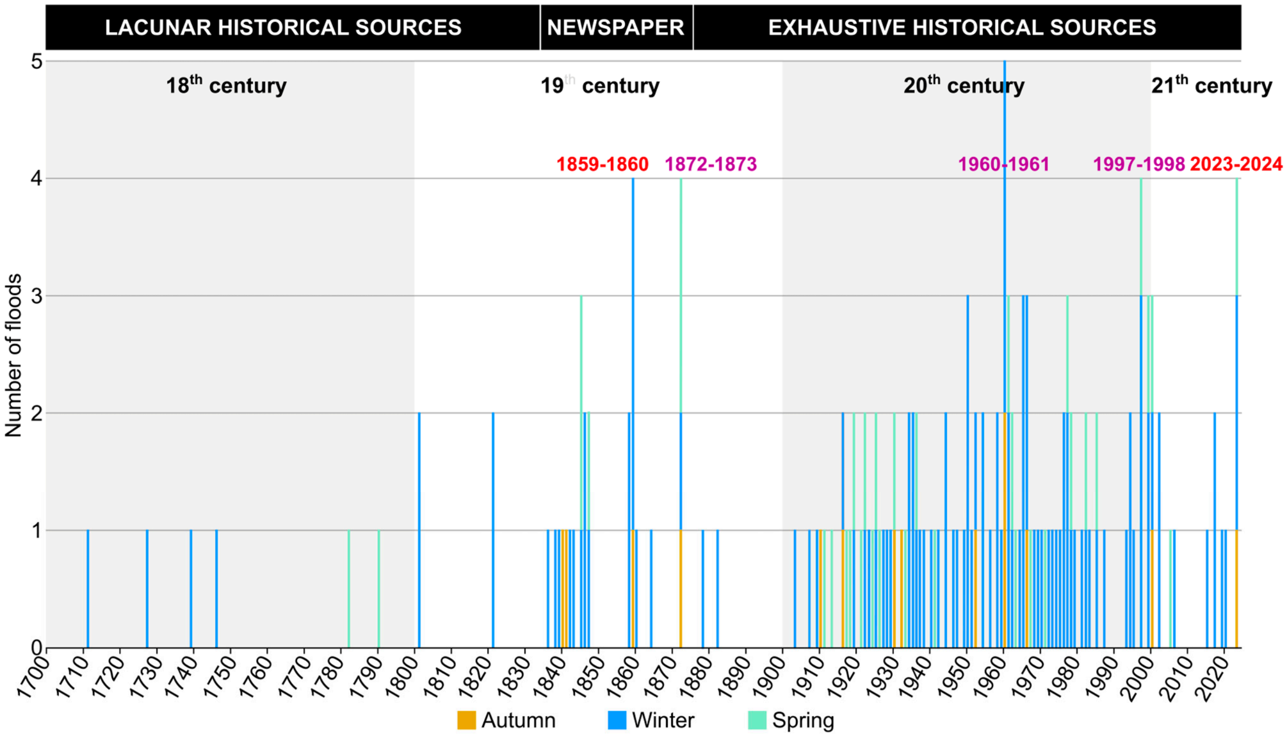



**Figure 10.** Number of grouped floods per winter period (October to April) by seasonality in the Charente River between 1700 and 2024. Only floods for which chronological data are available are shown (162 floods). Grouped floods sequences in bold are those studied in this paper.

The similarities between the grouped flood sequences of 1872–1873, 1960–1961, 1997–1998, and that of 2023–2024 are limited to the number of floods. However, these grouped flood sequences show divergences in terms of seasonality and intensity of flood events, particularly for the first annual flood (Figures 10 and 11). Indeed, the 1872–1873 hydrological sequence comprises an autumn flood, a winter flood, and two spring floods. Among these four events, the first two are classified as high floods, while the last two are of lesser magnitude. Although the first annual flood is early, it occurs in the last decade of November and extends into December, marking a break with the 2023–2024 sequence. The 1960–1961 hydrological sequence is particularly noteworthy for its five successive floods in four months, including an extreme flood (January 1961), a moderate flood (December 1960), and three low-intensity floods (two in November 1960 and one in February 1961). The November 1960 floods, one in the first decade and the other in the last, show an early start to the flood season. However, at the Saintes limnimetric station, these events are characterized by extremely modest water levels (4.26 m and 4.64 m, respectively) compared with the warning level established by the local authorities (i.e., 4.20 m). These flood events clearly distinguish from the November 2023 flood, marked by more significant water levels during the two maximums (5.42 m and 5.45 m). The 1997–1998 sequence consists of three winter floods and one spring flood of low to moderate intensity. This sequence differs from the 2023–2024 flood sequence by a late first annual flood, which begins around the last decade of December, and by the modesty of the water levels reached, which correspond to a 2- or 3-year flood.

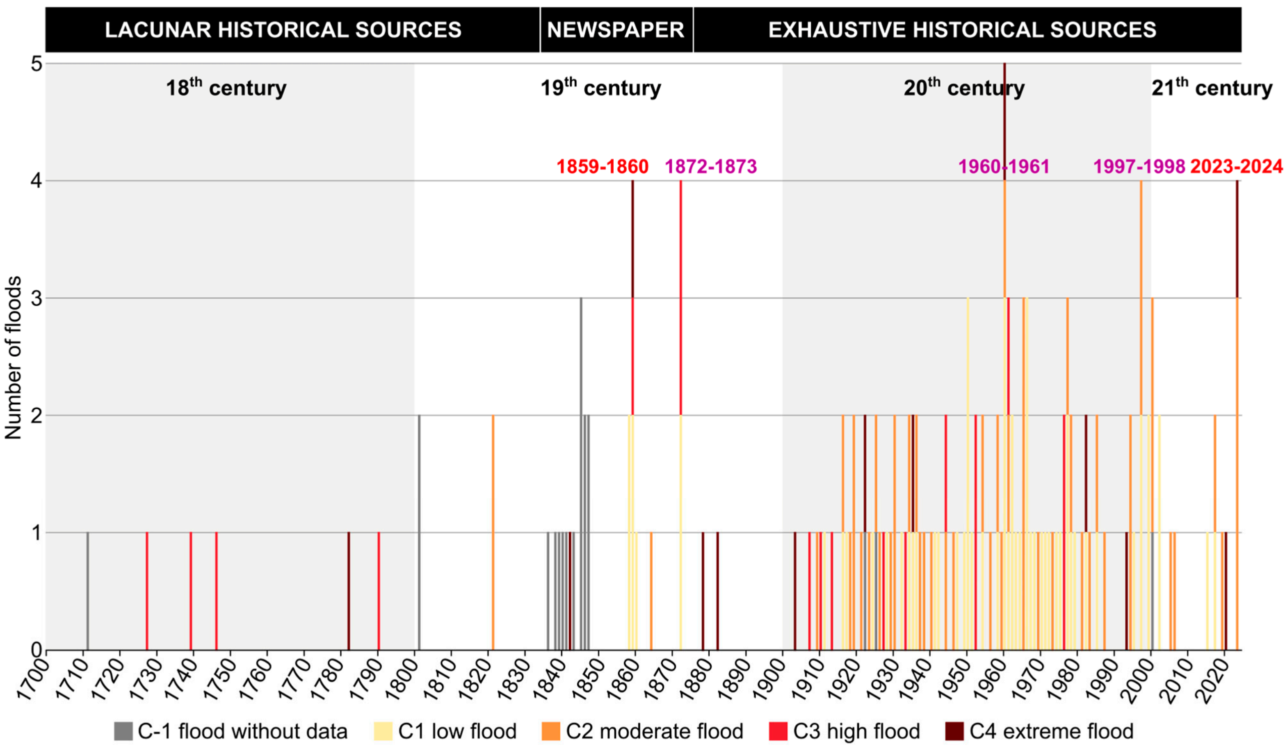



**Figure 11.** Number of grouped floods per winter period (October to April) by intensity in the Charente River between 1700 and 2024. Only floods for which chronological data are available are shown (162 floods). Grouped floods sequences in bold are those studied in this paper.

Ultimately, only the sequence of grouped floods of 1859–1860 shows significant similarities with that of 2023–2024, both in terms of the number of floods and the precocity of the first annual flood (Figure 10). The November 1859 and November 2023 autumn floods occurred early, with remarkably prolonged flood durations, approximately three to four weeks. While the November 1859 flood is classified as an extreme flood (C4) because of the high water levels and the major material damage, the November 2023 flood, of moderate intensity (C2), reaches water levels similar to a 4-year flood (Figure 11). In both cases, water levels were particularly high compared to the warning level established by local authorities, which is rare for such early events.

## 5. Discussion

The 2023–2024 grouped floods are well documented, not only because of the meteorological and hydrological data available but also because it occurs in a favorable context for the production and diffusion of information. On the other hand, the 1859–1860 grouped floods remain relatively unknown to scientists, river managers, and residents of the Charente River, while the first annual flood, that of November 1859, is notable for its earliness and severity. This lack of knowledge is mainly due to the context in which few data are produced. In this period, only two limnimetric scales are installed, at Angoulême and Saintes, and hydrometric measurements are very rare, in the absence of a flood monitoring service. Meteorological data are also limited. Two precipitation stations are operational in the Charente watershed, and no temperature measurements are taken, except at the La Rochelle meteorological station, located close but outside the study area. To reconstruct the context and course of the November 1859 flood, several documentary sources were used to supplement the limited instrumental data available. This analysis highlights the similarities between the clustered flood sequences of 1859–1860 and 2023–2024 by focusing on the first annual flood, the November 1859 and November 2023 floods.

The November 1859 and November 2023 floods occur after particularly hot and dry summers. The mean seasonal temperature is 21.9 °C in 1859 (La Rochelle meteorological station) and 21.4 °C in 2023 (Saintes meteorological station). June records high temperatures, with a mean of 20.8 °C in 1859 and 22 °C in 2023. These high temperatures continue throughout July (24.4 °C in 1859 and 20.4 °C in 2023) and August (20.6 °C in 1859 and 21.7 °C in 2023). In both cases, rainfall is near seasonal normals. Cumulative summer precipitation ranges from 125 mm at Saint-Jean-d'Angély to 182 mm at Rochefort in 1859 and 123 mm at La Couronne to 149 mm at Saintes on the Middle Charente River in 2023.

The high temperatures in 1859 and 2023 last until mid-autumn. September in both years is particularly hot, with a mean temperature of 17.3 °C in 1859 and 21.9 °C in 2023. In both cases, the AMJJAS NAO index shows a high negative value close to −1.20 in 1859 and 2023 (index baseline period: 1901–2000) [102,103]. The JJA NAO index centered on the summer months features particularly strong negative values, near −1.60 in 1859 and −2.15 in 2023 [103]. This reflects the persistence of high pressure along the Atlantic coast.

The 1859 and 2023 autumns are notable for the early onset of storms, coupled with heavy rainfall as early as the last decade of October. In 1859, cumulative autumn precipitation reaches 400 mm in La Rochelle, 396 mm in Rochefort, and 303 mm in Saint-Jean-d'Angély. In 2023, cumulative autumn rainfall is close to 418 mm in Angoulême and 517 mm in Saintes. The November 1859 and November 2023 floods occur in the context of a particularly long and intense rainfall sequence, caused by a very meridional positioning of the jet stream and a trajectory of disturbed oceanic flows from the North Atlantic. In both cases, the ONDJFM NAO index is negative [102] (index baseline period: 1901–2000), with a high negative SON NOA index of around −0.50 [103]. October shows a particularly high negative monthly NAO index, −1.14 in 1859 [104] and −2.03 in 2023 [105]. Between 24 October and 5 November 1859 and between 18 October and 18 November 2023, several storm events with heavy precipitation, which are rare at this time of year, occur at short intervals on the Charente watershed (Figures 12 and 13).

Between 24 October and 5 November 1859, three major storms occur in the space of thirteen days (Figure 12). Newspaper sources report that the first storm, which occurs between 24 and 26 October, is particularly severe. It is accompanied by high gusts of wind and very heavy rainfall. Along the coast, swell and rising sea levels due to high tidal coefficients lead to local marine submersion. Tidal coefficients exceeded 90 on 25 and 26 October 1859 at Île d'Aix [106]. Inland, heavy rainfall caused small, localized floods on the Charente River. From 27 to 30 October, rainfall is intense and continuous. On 31 October and 1 November, a second storm, much stronger than the previous one, generated violent winds both on the coast and inland, but above all, heavy rainfall that caused extensive floods on the Charente River and its tributaries. Finally, on 4 and 5 November, a third storm, less violent than the previous two, generated further precipitation, amplifying the rise in water levels on the Lower Charente River.

Between 18 October and 18 November 2023, five storms with heavy rainfall occur in the space of twenty days (Figures 13 and 14). Storm Céline (27–30 October), of moderate intensity, was responsible for strong winds of 90 to 100 km/h along the Charente coast, coupled with persistent rainfall. Two days later, a violent storm named "Ciarán" hit the Charente watershed between November 1 and 3. This storm generates violent winds of 130 to 150 km/h on the coasts and 90 to 110 km/h inland, accompanied by further heavy precipitation. Two days later, storm Domingos affects the Charente watershed from 4 to 6 November. Significant but less violent than the Ciarán storm, it generates further heavy rainfall and strong winds. Wind gusts of up to 152 km/h are recorded in Cognac. On 9 and 10 November, storm Elisa causes further heavy rainfall across the watershed. In mid-November, storm Frederico (14–16 November) ends this very disturbed period.

Although much more modest than the four previous storms, it produces locally sustained rainfall, particularly over the northern part of the basin.

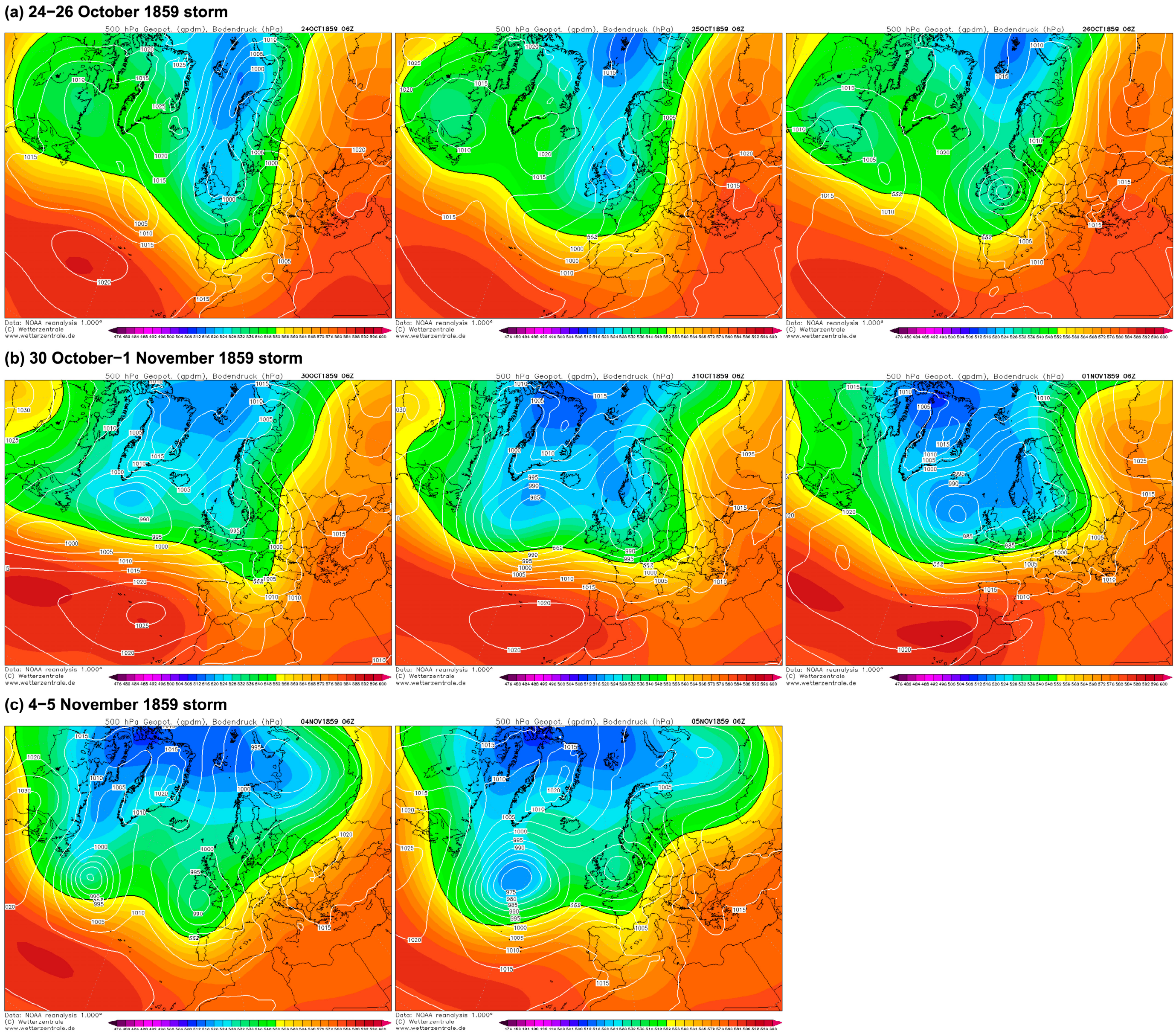



**Figure 12.** Pressure fields over Europe during each storm between 24 October and 5 November 1859 in the early morning (6 a.m.). (**a**) 24–26 October 1859 storm; (**b**) 30 October–1 November 1859 storm; (**c**) 4–5 November 1859 storm. Pressure field maps based on version 3 of the 20th Century Reanalysis system supported by the NOAA, CIRES, and DOE [93] (from: Wetterzentrale [92]).

The November 1859 and November 2023 floods begin in the last days of October for the older and the first days of November for the more recent. In both cases, the floods were particularly long, lasting around three to four weeks in the Charente watershed. In 1859, the Charente reaches a maximum of 5.31 m on 3 November at Angoulême and 6.30 m on 5 or 6 November at Saintes. These particularly high-water levels place the November 1859 flood among the extreme floods, ranking it 4th for the Upper Charente River and 8th for the Lower Charente River (Figure 15). This extreme flood event corresponds to a 50-year flood on the Upper Charente River and a 30-year flood on the Lower Charente River. Material damage is considerable in the towns along the Charente River, particularly in Angoulême and Saintes (Figure 7). Although less intense in terms of water levels and material damage, the November 2023 flood reaches water levels close to a 4-year flood, which is rare for such an early autumn flood.

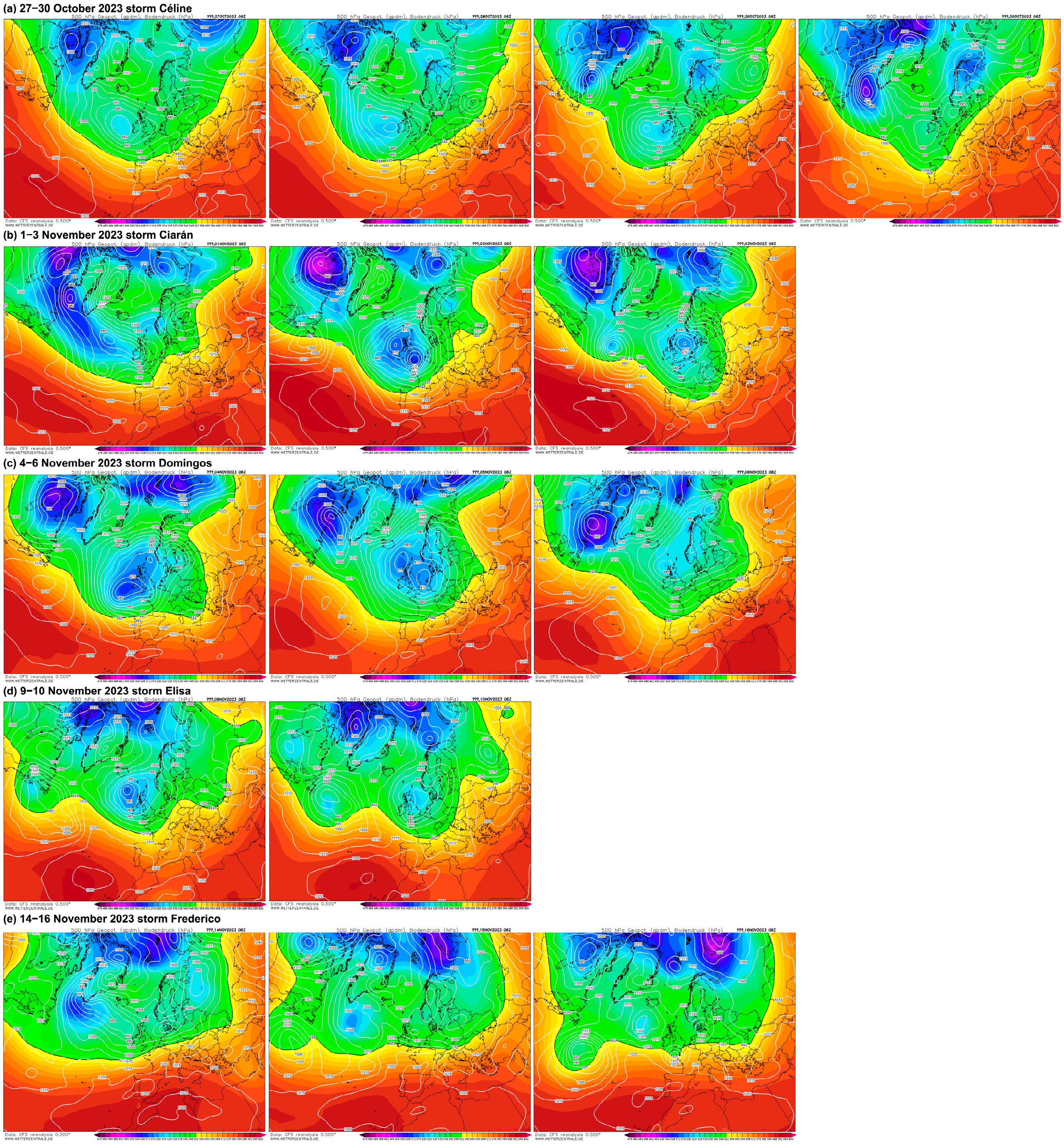



**Figure 13.** Pressure fields over Europe during each storm between 27 October and 16 November 2023 in the early morning (6 a.m.). (**a**) 27–30 October 2023 storm Céline; (**b**) 1–3 November 2023 storm Ciarán (**c**) 4–6 November 2023 storm Domingos; (**d**) 9–10 November 2023 storm Elisa; (**e**) 14–16 November 2023 storm Frederico. Pressure field maps based on version 3 of the 20th Century Reanalysis system supported by the NOAA, CIRES, and DOE [93] (from: Wetterzentrale [92]).

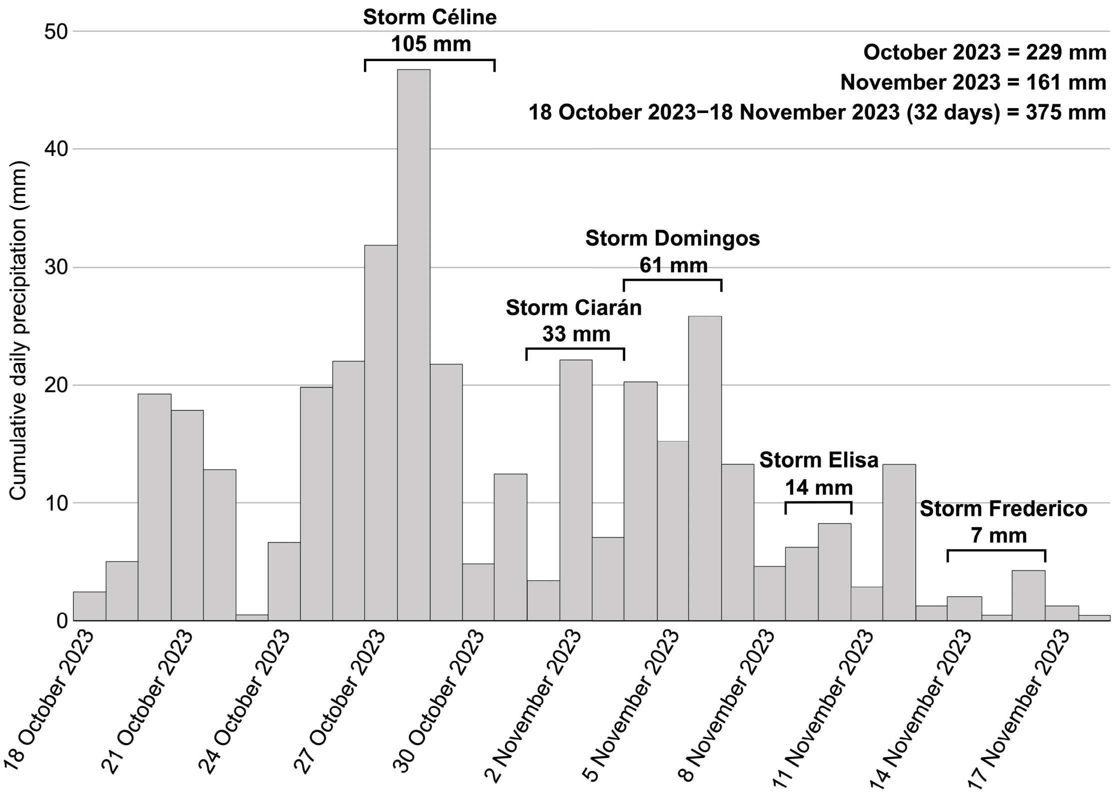



**Figure 14.** Rainfall sequence between 18 October and 18 November 2023 at the Saintes meteorological station (from: Météo-France [91]).

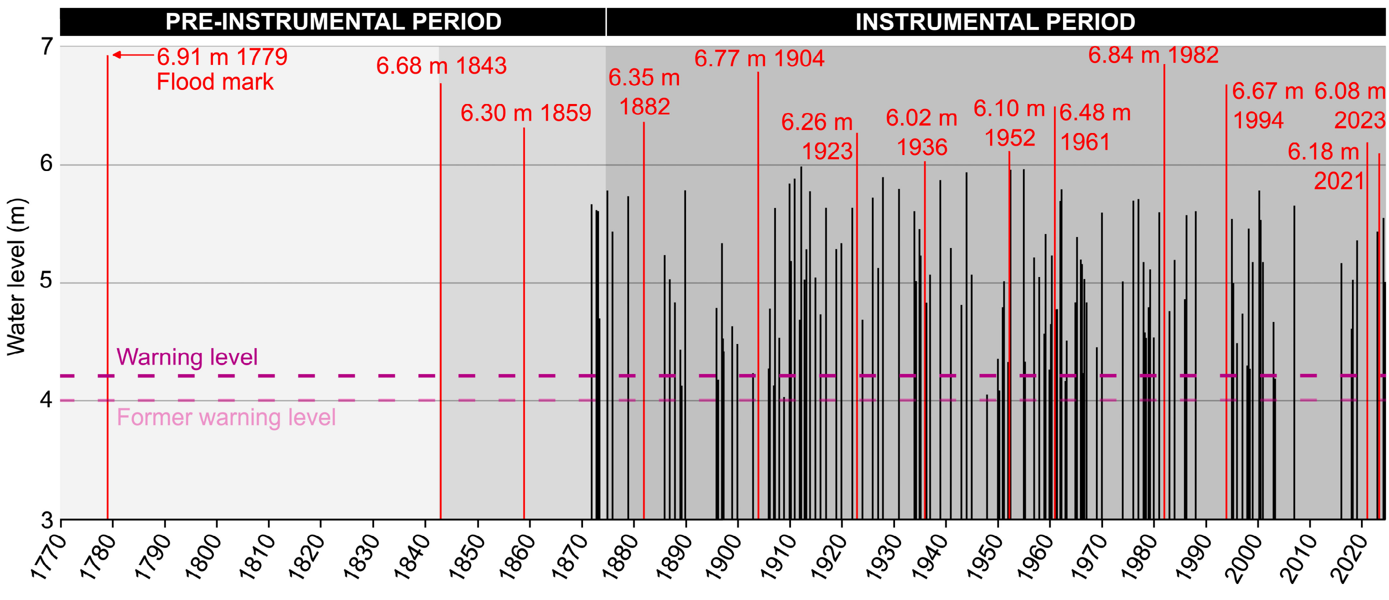



**Figure 15.** Chronicle of water levels at the upstream limnimetric scale of the Pont Palissy at Saintes. Floods with a water height of 6 m or more are considered extreme events in Saintes (in red on the figure).

## 6. Conclusions

The grouped floods of 2023–2024 on the Charente River are exceptional in terms of both the repetition of the number of floods and the precocity of the first annual flood. Although this hydrological phenomenon is rarely observed, it is not unprecedented since the 18th century. Indeed, the 2023–2024 sequence presents high similarities with the

1859–1860 sequence. In both cases, the first annual flood occurred early in the year (i.e., the November 1859 and 2023 floods), after an exceptionally hot and dry summer that prolonged into mid-autumn. An almost uninterrupted succession of storms favored by the meridional positioning of the jet stream over the near Atlantic—a rare phenomenon at this time of year—caused particularly prolonged and extensive flooding. The November 1859 and 2023 floods reached exceptional water levels for this time of year, corresponding to a 50-year flood to a 30-year flood for 1859 and a 4-year flood for 2023.

This work highlights the importance of documentary sources and instrumental data in the understanding of past grouped floods in the Charente watershed. However, data for the 18th century and most of the 19th century (up to the 1870s) remain poorly documented. Documentary sources are few and far between, and information is generally not very detailed and often unreliable. While this lack of documentation can be explained by conservation bias (lost, destroyed, and/or unclassified documents), it is mainly attributed to the specific characteristics of the Charente River floods. Despite (very) long flood durations, flow speeds are low. The floods have had a limited impact on human life, both in the past and in the present. As a result, they produced few archives until the 1870s, even though they caused major material damage and dysfunction. This is the case for the November 1859 flood. The lack of instrumental data limits our ability to reconstruct the context and course of the flood. To overcome this limitation, the extension of used sources was carried out in archive centers to retrieve daily records of rainfall, temperature, wind, and sky conditions on a regional scale in order to clarify the context of the 19th-century floods.

The 2023–2024 clustered floods on the Charente River highlight the importance of improving our understanding of these still little-studied hydrological phenomena. The analysis of historical antecedents allows us to better understand the conditions of their formation and course in order to more effectively anticipate these events and their course in the context of climate change and land use evolution. This research also highlights the value of approaching grouped floods as a hydrological phenomenon in their own right, which remains a largely underestimated risk for the time being. Particularly in the context of low-energy rivers with slow flood kinetics, grouped floods are likely to produce very long-lasting floods, with significant impacts on the territories concerned. It is therefore essential to adapt flood severity indicators to this specific geomorphological context.

**Author Contributions:** Conceptualization, A.D. and J.-M.C.; methodology, A.D. and J.-M.C.; software, A.D. and J.-M.C.; validation, A.D. and J.-M.C.; formal analysis, A.D. and J.-M.C.; investigation, A.D.; resources, A.D. and J.-M.C.; data curation, A.D. and J.-M.C.; writing—original draft preparation, A.D. and J.-M.C.; writing—review and editing, A.D. and J.-M.C.; visualization, A.D. and J.-M.C.; supervision, A.D. and J.-M.C.; project administration, A.D. and J.-M.C.; funding acquisition, A.D. and J.-M.C. All authors have read and agreed to the published version of the manuscript.

**Funding:** This research received no external funding.

**Data Availability Statement:** The original contributions presented in this study are included in the article. Further inquiries can be directed to the corresponding author.

**Acknowledgments:** We would like to thank EPTB Charente for providing us with access to the website e-crue. We acknowledge the archives of the *Département de la Charente-Maritime* for providing permission to publish Figure 6, the archives of the *Département de la Charente* for Figure 8a,c and the *fonds régional et ancien des médiathèques de Saintes* for Figure 8b. We are also grateful to Wetterzentrale for providing permission to publish Figures 14 and 15.

**Conflicts of Interest:** The authors declare no conflicts of interest.

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