Interactive comment on "Assessing changes on urban flood vulnerability through mapping land use from historical information" by M. Boudou et al.

We thank the three referees for their useful comments. The text has been reviewed according to the different comments. We added information on the state of art and on hydrological characteristics of the two flood events. We used a more precise vocabulary on vulnerability and multidisciplinarity.

About 20 additional references have been added plus an auxiliary material, with a detailed list of archives sources used to describe the two flood events.

The 9 figures have been corrected and a new figure has been added on the evolution of the number of inhabitants during the 20th century on the two cities.

Anonymous Referee #1

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General comment

The paper focuses on two flood events that, with a span of twenty years (1910 and 1930), hit two cities in France. The authors analyze how the vulnerability of these towns has changed since then, using detailed maps drawn from historical information. The authors have interesting historical documents. With these they try to define the new vulnerability of the two towns as if a similar event as 1910 and 1930 would arise again today. The study is interesting, pleasant, and definitely improvable. The paper follows the classic pattern: Introduction, General Settings, Methodology, Results, Conclusion, even if the authors do not use these specific terms.

In the paper a number of errors and inaccuracies have been noticed, some grammar ones, others due to distraction. In the introduction it is possible to point out misuse of verbs (use of the present perfect in place of simple past / errors on the paradigm of irregular verbs and use of); in the paragraphs 3.1 and 3.2 some blunders concerning the adverbs; in the paragraphs 3.4 and 4.1, unfamiliarity in the use of conjunctions and verbs again; 4.3 a mix-up in the relative pronouns ("Which return period" should be, instead, "Whose return period"). In the conclusions I also read "the age of population age", that I cannot understand ... The quality is really poor and the result is a very elementary grammar level. I think that a paper written for a French journal and later translated into English.

The English has been checked by an English native teacher, Michael Carpenter, professional translator

In the paper: there is a lack: a paragraph in which the authors analyze similar papers published worldwide. Papers in which other authors have: a) Underlined the importance of the historical data as a tool for risk assessment (Glade et al, 2001; Luino, 2002; Tropeano and Turconi, 2004; Coeur and Lang, 2010 and many other papers) b) Compared floods of the past with the future (also by means of hydraulic modeling) in order to assess the hazard, the risk, and vulnerability. This paragraph is not present and the authors should fill in the void.

A new paragraph has been added (introduction)

I would suggest that the authors, after analyzing the vulnerability, could hint at the forms of insurance provided in France. The calculation of the vulnerability necessarily leads to the conclusion of stipulating some kind of insurance.

The aim of the paper is rather to demonstrate the interest of historical information on land use to better understand the vulnerability conditions during past floods than to go in detail with the recent evolution of vulnerability conditions. We expect these second topic is more in relation with the insurance prospects. Meanwhile, we add in conclusion some perspectives on the interest of vulnerability analysis for the insurance system.

NOTES IN THE TEXT

Page 6152 *LINE 1: The term "diachronic" puzzles me: even if it is used in geology, I would like that the authors would use were using some other term.*

Corrected

LINE 5: "the XXth century–" ADD "– as a function of certain parameters such as the intensity and severity of the flood and spatial extension of damage".

Corrected

LINE 25: Add at least two other references (De Bruijn, K.M., 2005; Schanze, 2006; Cardona et al, 2012).

Added

Page 6153 *To lead, led, led. . . not LEADED.*

Corrected 4 times

Page 6155 *LINE 11 and 23: please, at the end of the sentence insert the estimated damage in French Franc (1910) with today currency revaluation of today (example = 2.5 million of euros).*

Corrected

Page 6156 *LINE 1: for the "accumulation of pieces of wood" the authors can utilize the term "jam log", commonly used for the flood.*

Corrected

LINE 4: which work? Reference.

Added (end of section 2.2)

LINE 17: indicate the source who estimated the damage.

Added

Page 6157 *LINE 6: NOT hundreds! But hundred.*

Corrected

The question is "All the structures and infrastructures realized after the Second World War how are influencing the study area? A new railway embankment or some large commercial centers, or a new bridge how could change the dynamic of the flood?". The authors have considered that?

Corrected in last sentence of section 5

Page 6158 *Line 9: "efforts" can be substituted with "work".*

Corrected

Page 6159 *Line 18: insert the website (http://www.eea.europa.eu/data-and-maps/data/urban-atlas)*

Added

Page 6162 *LINE 10: insert new reference Luino et al. (2012).*

Added

Page 6163 *LINE 9: "Ancient" is good for the "Ancient Greece, ancient Rome". I propose: "..by two floods occurred in January 1910 and.."*

Corrected

LINE 14: "Qualitative information (pictures, technical reports, national and local newspaper articles, paintings, marble plaques, etc.)..". It should be better to list all qualitative information we commonly use. . . besides the maps.

Added

Page 6168 *Figure 1: On the right: it is not clear the method adopted. It should be better a short explanation. . . here or in the text. What is the meaning of/what does it mean 3.5 to 14? 3 to 12? 2 to 8? I have found the definition "remarkability score" in the paper "Characterization of remarkable floods in France, a transdisciplinary approach applied on generalized floods of January 1930" (EGU 2014). In addition, in another one "Assessing changes on urban flood vulnerability through mapping land use from historical information" (2015).*

Addition in section 2.1 of the ranges of the three criteria + 1 reference of Boudou et al. (2015)

I suggest changing it in "criticality level", used in many scientific fields.

Caption. I suggest: "..9 most remarkable French floodings selected.."

Legend: NOT 3,5 but 3.5.

Fig. 1 corrected

Page 6172 *In the figure the blue circles are not well distinguishable. Please, use different tone of blue (pale, medium, dark). There are 5 different size circles in the map. Please, check them.*

Fig. 5 corrected. We checked the different 5 size circles, proportional to the number of fatalities and didn't see any error.

Caption: in the figure 4 there is not the date of the event, the year only. Erase "3 March" for uniformity with the previous figure.

Fig. 4 corrected. As the day of the flood is an important information when dealing with the flood chronology, we prefer to add the day on figure 4

Page 6177 *Figure 10: Why the figures in the upper part are cut at the level of the railway. For uniformity with figures 9 it should be better to enlarge them (or cut the figures 9).*

Fig. 10 corrected

Caption: NOT 1910, but 1930.

Corrected

References

De Bruijn, K.M. (2005) - "Resilience and flood risk management: a systems approach applied to lowland rivers".

Luino F., Turconi L., Petrea C., Nigrelli G. (2012) - "Uncorrected land-use planning highlighted by flooding: the Alba case study (Piedmont, Italy)".

Schanze J. (2006) - "Flood risk management – A basic framework"

Tropeano D. & Turconi L. (2004) - Using Historical Documents for Landslide, Debris Flow and Stream Flood Prevention. Applications in Northern Italy. www.eea.europa.eu/dataand- maps/data/urban-atlas

Added

Maria-Carmen Llasat

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This paper offers an interesting approach to the analysis of the changes that could be produced in the flood exposure and vulnerability as a consequence of the changes in land uses, demography and buildings. To this end the authors compare two catastrophic flood events produced in 1910 and 1930 in two little French cities. The main interest of the work would be its application to adaptation and mitigation strategies, and its reproduction in other cases study is revealed as useful for the flood community. For this reason, and although the paper seems to be based in a very rigorous work (the PhD of M. Boudou) I would recommend some minor changes before to be published in order to facilitate to the reader, the criteria and methodology applied.

General Comments

One of the main problems is the concept associated to the expressions flood vulnerability and flood exposure that should be clearly defined in the Introduction. This last is too much short and due credit to other works in the same matter has not been made. I would suggest developing a little more the Introduction, coping with the concepts of vulnerability and exposure (there are a notable controversy between the different authors and administrations about them) and any previous literature on the topic of this paper.

We added a paragraph in the introduction in order to highlight these aspects.

Specific Comments

P. 6154, l.13. *Could you include the criteria to define a "major flood"? You say afterwards that three points are considered, but they are very general. The same in Figure 1*

We added a sentence (beginning of section 2.1) to explain how the 176 major floods in France have been selected.

P. 6154, l.20. *Which is the second level?*

We added a sentence to explain that the first level consists in ranking the 176 major floods, as the second level focusses on 9 flood events, based on a good diversity of flood types and a high position within the ranking. The paper used two case studies belonging to the sample of 9 flood events.

P. 6154, l.26. *You speak about a "evaluation grid", could you provide it?*
The main features of the evaluation grid are presented on the beginning of section 2.1. We added the reference of Boudou et al. (2015).

p. 6155, l.7. *In the figure 1, the 1910 event has not one of the "highest score".*
The rank is fifth. It has been corrected in the text

p. 6155, l.8. *Return period near 100 years, for flow or rainfall? In which river was it? The Seine? Or in Besançon?*
It is related to discharge within the Seine basin. Added to the text (section 2.2)

p. 6155, l.10-11. *What is the mean here of "indirect deaths"? How do you know that 150000 people was affected by the 1910 event in Paris?*
We added some explanation on the indirect deaths (section 2.2)

p. 6155, l.11. *1,5 billion of euros of which year? Usually damages are adjusted by changes in the gross value to a specific year near to the present. Could you indicate it? The same for l. 23, and other economic damages estimated along the paper.*
Same remark than Anonymous Referee #1. We add the estimated damage in French Franc (1910) with today currency revaluation (2015) + reference to Picard (1910)

p. 6155, l.17. *Could you introduce in a bracket the value of this maximum water level?*
We added a reference to figure 3 where the longitudinal water level profile has been reported for 3 floods (1910, 1882, 1896).

p. 6155, l.17-19. *This short meteorological explanation should be placed at the beginning or at the end of the paragraph, but not in the middle of a section focused on the impacts.*
In fact, we started section 2.2 by some sentences on the 1910 flood on the Seine basin. Then, we explained that we will focus on the Doubs basin. That is why the meteorological explanation is placed here. We added some words to explain that the meteorological genesis on Doubs basin is different from the Seine basin.

p. 6156, l.4. *Attending the description the problem was in the flood "management".*
We suspect that the remark is related to **p. 6157, l.4**
The problem was in fact twofold: surprise effect due to flash flood and dyke breaking, plus specific houses vulnerability. The text has been refined (section 2.3).

p.6156, l.13. *Could you include the flow value achieved in the Tarn? I suppose is 8000 m3/s, following your explanation, but in this case, which would be the return period? (significantly larger than 100 years could be 200 or 500…). What is the average discharge of the Tarn in Moissac?*
Additional information has been inserted in the text
The average discharge at Moissac is 230 m^3/s (section 2.3).

p.6156, l.16. *In English language is 20th century, not XX century.*
Corrected (section 2.3).

p.6158, l.5-9. *Could you indicate the historical sources of information you have used?*
Please refer to auxiliary material

p.6158, l.19-24. *Could you include a table with those "simplified descriptors"?; why you associate structural exposure with urban growth but structural vulnerability with land-uses? Usually structural vulnerability refers to the capacity of the buildings in front of the specific risk. In the following page,*

lines 16-20, it seems that you interchange the concepts because you associate structural exposure to land-use classification. The same problem is observed in p.6161, l.3, when you associate structural vulnerability to urbanized area. Figure 6 cannot help to understand it

We corrected the use of structural vulnerability and structural exposure and decided to use the terms of susceptibility and exposure with regards to the state of arts available on this question.

p. 6159, l.4. *How many historical maps? For which years?*

We added the number of historical maps and aerial photograph used and their complete description is available in the auxiliary materials (3rd paragraph of section 3.3).

p. 6160, l.13. *How do you know the building height? Does Equation 1 explain the volumetric method?*

The building height is provided by the BD Topo data set. A phrase has been added to explain this fact.

p. 6161, l.21-23. *When you represent the flood extension in 2013, do you consider the existence of new structural flood protection measures like the river channeling or new dikes?*

In section 4.2 we reported the 1930 flood extent on two maps representing the land use in 1930 and in 2013. We finish the paper (end of section 5) by the mention of a future possible work on the mapping of flood extent of past floods, accounting for the morphological changes of the river, river engineering work and settlements within the flood plain, from the past to today. A sentence has been added at the end of section 5

p. 6162, l.12. *Why the flood risk vulnerability decreased since 1910?*

The sentence has been corrected (section 4.3)

Anonymous Referee #3

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General Comments

The topic of Boudou et al.'s article is perfectly suited to the thematic issue of HESS entitled "Floods and their changes in historical times - a European perspective". It combines in an interesting way data from historical archives, an original cartographic analysis together with flood management issues in urban areas and research policy from different perspectives. I think, it can be published in this issue. However, several paragraphs require modifications, supplementary informations and important clarifications.

First, with regards to the poor English level of the paper, I agree with the first anonymous reviewer's comment. The full manuscript (text, figures and legends) should be proofread carefully and corrected for spelling, grammar, and content by a native English speaker because the standard of English does not reach the required scientific level of a journal like HESS. In some cases authors need to choose more appropriate expressions and to avoid invented words (see the following proposals for text and figures). You frequently use inappropriate terms in many of your sentences. Some expressions don't exist in English. . . or you use them in wrong place sometimes (awkward turns of phrase)! Authors should use more accurately the existing English vocabulary especially about hydrological and geomorphological questions. Punctuation should also be checked and adjusted. For now, the result is sloppy and quite unpleasant to read. And, from this point of view, it should be redone neatly.

The English has been checked by an English native teacher, Michael Carpenter, professional translator

I agree with the other reviewer about the lack of a paragraph in which the authors analyze similar papers published worldwide. A brief panorama dealing about main floods for both cities throughout their respective histories is also lacking, it's the leading subject of this thematic issue of HESS... (between 4 and 5 lignes for each city). Such addendum seems needful in paragraphs 2.3 and 2.2. (quoting, for example, Champion (1858-1864) and Alexandre (1987) but also local existing bibliography referring to historical floods). About this aspect, authors have to complete their bibliography which is too sketchy.

A new paragraph has been added in introduction with references of works using historical information for a better risk management. Additional references have been added about the hydrological characteristics of the two events (sections 2.2 and 2.3)

Much more detailed explanations are needed about these rainfall events (January 1910 flood and March 1930 flood): intensity, duration, quantity, etc. The maximum flood peak discharges reached during these two events are also required (more the annual mean discharges and the 10/100/1000-year flood peak discharges, if available). Does it exist recent explanations about origin of these phenomena? How were they related to known specific critical meteorological mechanisms? For example, the St. Mary Magdalene's flood, the largest recorded flood in central Europe in July 1342, was attributed to the well-known Genoa Cyclogenesis, Ligurian Depression (or V(5)-track cyclone). Maybe, is this the case for these two unusual climate events?

Additional information is now available about the hydrological characteristics of the two events (sections 2.2 and 2.3)

Have you considered the evolution/variation of the floor elevation in each city over time and riverbeds' elevation (aggradation or incision)?

The main subject of the paper is to compare the flood vulnerability, when the flood occurred (e.g. in 1910 or 1930) and today. So, we didn't account on changes about flood hazard. The last sentence in section 5. Conclusion leaves open this question for future work.

You must also add informations about physical and geographical characteristics of both studied catchments (local floodplain topography) but also dimensions of the runoff area upstream from Besançon and Moissac (including the number of tributaries). All these informations should be summarized in a large table then set in a file for the additional material.

We added the catchment area of Doubs and Tarn rivers (resp. at Besançon and Moissac). The detailed presentation of the catchments is already available in Lang and Coeur (2014).

Moreover, a detailed checklist of each document from archives (reference numbers, databases) together with their exact locations (Municipal, District or National archives) must be given. This is a minimum requirement in a work mainly based on historical written/cartographic archives!

We added an auxiliary material including the main sources exploited and their location. A foot note has been inserted at the end of section 2.1

In the paragraph named "Census of the exposed population within the flood extent" (3.4) it would be interesting to describe at length data involved in analysis (equation) that you mention in your article (additional material) but also to present numerical results used to draw various maps shown in figures.

Please refer to auxiliary material

A graph showing evolution of the population for both cities since the early XXth century would also be very welcome.

A new figure 7 has been added + corresponding text (first paragraph of section 3.4)

What kind of solutions/measures was found by both cities (or by local societies) to cope with floods throughout the twentieth century?

Such point has been addressed in section 4.3. At Besançon, the reference flood is larger than the 1910 flood, and some engineering works are in process to close the free postern-gates , which allowed in 1910 to have water inlets within the old city centre. At Moissac, building quality has been improved and flood warning efficiency has been largely improved.

At last, the conclusion paragraph is too short, especially the "perspectives" part, it should be improved by highlighting more clearly implications of obtained results in (urban) river flood risk management policies (local, national or transnational). So, the Xynthia storm was not a good example because dramatic floods and their resulting damages which have occurred didn't originate in a flooded river. . ., it exist many other relevant examples in France and Europe.

See additional sentences in section 5

Instead, unlike what is stated in the report of the first anonymous reviewer, the term "diachronic" don't bother me. Indeed, it is frequently used in environmental history, in landscape ecology or in paleoecology.

The term "diachronic" has been removed

But conversely, the notion of "transdisciplinarity" appears more problematic. "Transdisciplinary" generally refers to "a paradigm or vision that transcends narrow disciplinary worldviews through overarching synthesis", it's the last level - the ultimate degree of coordination - in integrative research approaches. You surely use data from various academic disciplines (e.g. "interdisciplinarity") but do you combine this interdisciplinarity with a participatory approach? I'm not sure that your work (Ph.D) was really a participatory research! "Transdisciplinary research is projects that involve academic researchers from different unrelated disciplines as well as nonacademic participants, such as land managers, user groups and the general public, to create new knowledge and theory and research a common question (Tress et al., 2005)". This junction between various academic disciplines/scholarly research and non-academic participants, towards a common goal to overcome the split between science and society, is specific to transdisciplinarity but unfortunately its implementation is uncommon In research practice (disputes between academic scholars, supremacy of the hard sciences over the Humanities and Social Sciences or trouble of communication between paradigms because of a problem of translation -> the famous "Thomas Kuhn theory", etc.). I suggest you read specific and relevant articles of Tress & Tress (2001) and Tress et al. (2005) summarizing pluridisciplinarity, interdisciplinarity and transdisciplinarity research concepts. After having read these articles you could redefine your view of "transdisciplinarity".

In fact, the use of "transdisciplinary" term was excessive. It has been changes (2 times) by "multidisciplinary".

Proposals of corrections to the original text

- PAGE 6152: ligne 2 *"two ancient floods" -> "TWO PAST FLOODS"*
Corrected (abstract)

- PAGE 6155 : ligne 11 *"There were a relatively small number of fatalities (4 direct + 11 indirect deaths), but the impact within the Paris region was extremely high, with 150 000 affected people and about 1.5 billion of euros of damages" -> (A REFERENCE PLEASE ?)*
Reference to Picard (1910) has been added

- PAGE 6157: ligne 7 *"vulnerable to water crushing forces"-> "VULNERABLE TO FLOOD-INDUCED FORCES (SUCH AS FLOTATION, LATERAL PRESSURES, OR MOVING WATER)"*
Sentence has been reworded (end of section 2.3)

- PAGE 6157: ligne 8 "*damaging process"-> "DESTRUCTION PROCESS"*

Sentence has been reworded (end of section 2.3)

- **PAGE 6159: ligne 27** *"for ancient time" -> "EARLIER HISTORICAL PERIODS" or "EARLIER TIMES"*
Corrected (end of section 3.3)

- **PAGE 6161: ligne 16** *"(reduction of inhabitants per building)" -> "(A DECLINE IN THE NUMBER OF INHABITANTS PER BUILDING)"*
Corrected (end of section 4.1)

- PAGE 6161 : ligne 20 *"surface areas spread by" -> "INCREASE" or "EXPANDE"*
Corrected (end of section 4.2)

- PAGE 6163: ligne 2 *"especially due to progress in flood warning and population evacuation by the civil protection services" -> "DUE TO PROGRESS IN BOTH FLOOD WARNING DECISION-MAKING AND EMERGENCY POPULATIONEVACUATION SCHEME BY THE CIVIL PROTECTION SERVICES"*
Corrected (end of section 4.3)

- PAGE 6163: ligne 5 *"is considered as the reference flood hazard in the local regulatory document of flood risk" -> "IS CONSIDERED AS THE REFERENCE FLOOD HAZARD BOTH FOR THE LOCAL FLOOD RISK MANAGEMENT STRATEGY AND PLANNING AND DEVELOPMENT DOCUMENTS".*
Corrected (end of section 4.3)

- PAGE 6163: ligne 9 *"ancient floods" -> "PAST FLOOD EVENTS"*
Corrected (section 5)

- PAGE 6163: ligne 17 *"as well from ancient censuses" -> "AS WELL FROM OLD CENSUSES"*
Corrected (section 5)

- PAGE 6164: ligne 5 *"taking into account modifications of the river and flood topography and hydraulic works (dikes, weir, dams . . .)" -> "TAKING INTO ACCOUNT CHANGES IN RIVERBED ELEVATIONS AND FLOODPLAIN TOPOGRAPHY BUT ALSO IMPACTS OF HYDRAULIC INFRASTRUCTURES (LIKE DIKES, WEIR, DAMS, ETC...)"*
Corrected (end of section 5)

Proposals of corrections to the original figures and legends:

Presentation and layout of maps and figures must be exactly the same (e.g. shape and color of symbols, north arrows, please select always the same location for copyrights and authors, kilometers in English not Kilomètres in French, etc.).
Corrected

- FIGURE 1 : *"Hydrographic districts" -> "HYDROGAPHIC BASINS" or "DRAINAGE BASINS"*
Corrected

- FIGURE 2: *"catchement area studied"-> "CATCHEMENT STUDIED"*
Corrected

- FIGURE 3: *"longitudinal profile" -> "LONG PROFILE OF THE DOUBS RIVER"*

"Longitudinal profile of the Doubs River and flood inter-comparison" -> LONG PROFILE OF THE DOUBS RIVER AND WHAT IS THE PRINTING DATE OF THE ORIGINAL PROFIL (ARCHIVE NUMBER) ? FROM THE SERVICE HYDRAULIQUE OF THE DOUBS DISTRICT? IN WHICH PART OF THE RIVER BASIN THIS LONG PROFILE IS LOCATED? AND, HOW FAR FROM THE CITY OF BEANÇON ? IN MY OPINION THIS FIGURE IS NOT RELEVANT FOR THIS ARTICLE. ITS REMOVAL MUST BE DISCUSSED.

In fact, this figure gives a very interesting information on specific energy losses in the center of the city, that explains why the water level was so high despite the discharge was not extreme. We added some cross-reference with figure 4 that helps to locate the bridges and the complete source of the document).

- FIGURE 4 : *"water entries" -> "WATER INLETS"*
Corrected

- FIGURE 5: *"City center" or "city centRE" ?*

Both are possible. We choose the following naming convention "City centre" (fig. 4, 5)

- FIGURE 7 : *"Land use classification" -> "LAND-USE TYPE CLASSIFICATION"*

"Land use and occupation within the 1910 flood extent in Besançon: (a) in 1910; (b) in 2013" -> "LAND-USE TYPES AND SOIL OCCUPATION WITHIN THE 1910 FLOOD EXTENT IN BESANÇON: (A) IN 1910; (B) IN 2013"

Continous urban fabric -> "HIGH DENSITY URBAN AREA"

Discontinuous urban fabric -> "MEDIUM DENSITY RESIDENTIAL

" parking -> "PARKING LOT"

Economic activity building -> "INDUSTRIAL, BUSINESS PARK, RETAIL CENTER"

Garrison/barrack -> "MILITARY LAND"

Education -> "EDUCATIONAL"

Administrative, cultural, religious or health building -> "INSTITUTIONAL, PUBLIC FACILITY, OFFICE,..."
Corrected

- FIGURE 8 : *"Estimated population per building within 1910 flood extent in Besançon: (a) in 1910; (b) in 2013" -> "ESTIMATED NUMBER OF INHABITANTS PER BUILDING WITHIN THE 1910 FLOOD EXTENT AREA IN BESANÇON (A) IN 1910; (B) IN 2013"*

THERE IS A PROBLEM IN THIS FIGURE: 1910 OR 1911?

"Estimation of the population living in the building" -> "ESTIMATED NUMBER OF INHABITANTS PER BUILDING"
Corrected

- FIGURE 9 : *Land use classification -> "LAND-USE TYPE CLASSIFICATION"*

Residential discontinuous sparse building -> "SMALL LOT RESIDENTIAL"

Residential discontinous building -> "MEDIUM DENSITY RESIDENTIAL"

Residential continous building -> "HIGH DENSITY RESIDENTIAL"

Economic activity building -> "INDUSTRIAL, BUSINESS PARK, RETAIL CENTER"

Education -> "EDUCATIONAL"

Parking -> "PARKING LOT"

Administrative, cultural, religious,... -> "INSTITUTIONAL, PUBLIC FACILITY, OFFICE,..."

FOR THE "BUILT-UP AREA" MAYBE YOU COULD USE THE SAME CLASSIFICATION AS FOR THE WHOLE CITY?

Corrected

In fact, the built-up area does correspond to the locations outside the flooded area

- Figure 10: "*Estimation of the population in the building" -> "ESTIMATED NUMBER OF INHABITANTS PER BUILDING"*

Estimated population per building within 1930 flood extent in Moissac: (a) in 1910; (b) in 2013" -> "ESTIMATED NUMBER OF INHABITANTS PER BUILDING WITHIN THE 1930 FLOOD EXTENT AREA IN MOISSAC (A) IN 1910; (B) IN 2013."

THERE IS A PROBLEM IN THIS FIGURE : 1910 OR 1930?

Corrected

Assessing changes ~~o~~n urban flood vulnerability through mapping land use from historical information

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Abstract

This paper presents an ~~diachronic~~ appraisal of the temporal evolution of flood vulnerability of two French cities, Besançon and Moissac, which were~~have been~~ largely impacted by ~~two past~~ floods in January 1910 and March 1930, respectively. Both flood events figure~~d~~ among the most significant events recorded in France during the ~~XXth~~ 20th century, ~~as a function~~ in terms of certain parameters such as the intensity and severity of the flood and spatial extension of the damage. An analysis of historical sources allows the mapping of land use and occupation within the ~~flood~~ areas affected by~~extent of~~ the two ~~historical~~ floods, both in past and present contexts, providing~~. It gives~~ an insight of the complexity of flood risk evolution~~,~~ at a local scale.

1 Introduction

Directive 2007/60/EC on the assessment and management of flood risks draws up a new framework for the promotion of historical information. It aims to reduce and ~~to~~ manage the risks that floods pose to human health, the environment, cultural heritage and economic activity. The Directive requires Member States to first ~~first~~ carry out a preliminary assessment by 2011 to identify the ~~the~~ river basins and then the associated coastal areas which are at risk of flooding. For such zones, ~~the following~~ subsequent steps would ~~consist in~~involve drawing up flood risk maps by 2013 and establishing flood risk management plans focused on prevention, protection and preparedness by 2015. The Directive applies to inland waters as well as all coastal waters across the whole territory of the EU. In France, a national Historical Database ~~on floods~~ (http://bdhi.fr/), ~~has been opened to the public in 2015,~~ based on the inventory of major floods, ~~in France produced~~was produced in 2011 within the framework of

the EU Flood Directive (Lang and Coeur, 2014;Lang et al., 2012) and was made available to the public in 2015. It contains a description of 176 “remarkable” flood events from 1770 to 2011.

A key issue of the Flood Directive is the ~~to~~ accurate~~ly~~ assessment of ~~the~~ flood risk. A commonly accepted definition of flood risk is the combination ~~between~~ of a flood hazard and the vulnerability of the assets that are exposed (~~–~~de Bruijn, K.M., 2005; Schanze, 2006; Cardona et al., 2012). ~~In suit with~~Following this definition, the French Government distinguished two main steps for flood risk assessment. A first step consist~~sed~~ of~~in~~ mapping the potential flood extent to ~~in order to~~ evaluate the number of infrastructure assets exposed. Starting from this data, a second step consists of determining~~ed in~~ ~~censing~~ the ~~asset~~ exposure and vulnerability of the asset. For this purpose, some indicators have~~d~~ been adopted, according to the potential impacts on human health, economic activity, the environment and cultural heritage within the potential flood extent. To mention just ~~name~~ a few, ~~they are for instance~~these indicators include the number of inhabitants affected~~population exposed~~, the number of single-~~one~~ storey buildings, the number of employed persons~~ments~~, the number of nuclear power stations, the area of remarkable built heritage, etc. Following this approach, ~~the~~ flood risk assessment ~~drew up~~leads to a contrasted overview of the actual flood risk. The results indicate a strong and unequal ~~assets~~ exposure of assets over the French territory, and raise some concerns in a context of increasing flood damage~~s~~ (SwissRe, 2015) and global change.

The term “vulnerability” has long been a subject of debate in the scientific literature, being covered by several definitions (Birkmann, 2006; Wisner *et al.*, 1994). A commonly used definition of vulnerability is the likelihood of the elements at risk to produce damage. Based on that definition, assessing the vulnerability and its evolution can be broken down into two main steps: firstly, assessing the exposure by listing the elements at risk and secondly, assessing the susceptibility of the elements at risk (Merz et al., 2007). To carry out these two steps, we identify a series of indicators adapted for a retrospective analysis.

On the one hand, the exposure analysis is supported by quantifying the number of buildings and inhabitants at risk. On the other hand, the susceptibility analysis is based on identifying the building use type, providing some keys for understanding the kind of damage to be expected during floods (Barroca et al., 2006). For example, some building types are especially likely to trigger major damage (industrial or commercial activities) or cause disturbances for

society (e.g. public infrastructures such as hospitals or schools), thus requiring special attention from risk managers (Merz et al., 2007).

Many authors have already highlighted the importance of historical data as a tool for risk assessment (Glade *et al.*, 2001; Brazdil *et al.*, 2006; Coeur and Lang, 2008; Kjeldsen *et al.*, 2014). A general survey of flood mapping techniques in Europe by de Moel et al. (2009) provides evidence that flood maps are available in almost all countries, based on historical floods or design-basis floods. As an example, Barnikel (2004), Tropeano and Turconi (2004) or Luino *et al.* (2012) reported past flood extents in relation to present-day land use, which allows the development of prospective analyses of flood risk.

Assessing flood impacts and understanding the past vulnerability of a territory is an essential step towards a long- ~~–~~term mitigation strategy (Changnon *et al.*, 2000). Firstly, it allows a better understanding of the circumstances that lead~~d~~ to a disaster. ~~And s~~Secondly, it helps to shed ~~the~~ light on the actual~~actual~~ state of ~~the~~ vulnerability within a territory. This vulnerability (especially visible through the exposure of ~~the~~ assets) ~~has to~~should be seen as the result of a complex historical evolution, partly related to the occurrence of ~~past~~ damaging flood events in the past (Barrera *et al.*, 2006).

~~In order t~~To take account of~~consider~~ a potential increase in~~of~~ flood risk, the Flood Directive assessment has to be considered in terms of a~~t a~~ long time~~arge temporal~~ scale. The indicators developed during the preliminary phase are in fact closely correlated with~~to~~ the present-day~~actual~~ situation and raise some questions about the past situation of vulnerability. How do we assess the vulnerability and exposure situations ~~during~~ for past flood events based on~~with~~ uncertain and sparse historical sources? Can we ~~confirm~~ validate an increase in the~~of~~ exposure and vulnerability of stakeholders ~~'s exposure and vulnerability~~ based on a temporal analysis of past disasters? Are these disasters still relevant and easily integrated into risk management policies as indicated in the Flood Directive text?

To address~~carry out~~ these issues, the present study ~~this paper proposes to~~ sets out to highlight the ~~interest~~ importance of historical information ~~through~~ by applying a ~~transdisciplinary~~multidisciplinary and mapping approach (Danière, 2014). Our~~The~~ study is based on the set of 176 major ~~French~~ floods in France, which offers an opportunity to explore the vulnerability associated with past flood events ~~vulnerability~~. We apply~~ied~~ thi~~se~~ methodology to~~on~~ two case studies selected for their "remarkability": the January 1910 flood event (generalized over~~to~~ all the North-East of France) and the March 1930 flood event

(concentratedfocused on the Tarn River valley). We focused the our analysis on two cities, Besançon and Moissac, which were each one largely affected by the floods of 1910 and 1930, respectivelyone of these two events. After a brief presentation of the two flood events (section 2), we present the methodological framework used for mapping the the vulnerability (section 3). It This approach ishas been applied toon the two case studies (section 4), illustrating the past and present vulnerability situations in the two cities. Finally, some key pointss are given (section 5) about concerning the interest importance of historical information for assessing vulnerability changes during the XXth 20th century.

2 Case studies

2.1 Selection of two remarkable flood events

During the inventory work carried out for the Flood Directive in 2011, we selected a total of 176 major floods in France since 1770 (see Lang and Coeur, 2014) based on the following considerations: diversity of flood types, strong flood hazard or spatial extent, important socio-economic impacts, in addition to reference events used in planning documents (flood mapping area) or last significant flood in living memory. Using a ransdisciplinarymultidisciplinary methodology, we established an evaluation grid based on three main features was established (Boudou *et al.*, 2015): 1/ flood intensity (score between 3.5 to 14) according to several criteria (return period of the maximum peak discharge; duration of submersion; dyike breaches or log jams); 2/ flood severity(score between 3 to 12), with two main indicators,: flood damages (number of fatalities, economic loss) and social, media or political impacts of the event (establishing a new risk policy, calling for international solidarity to face the crisis, etc…); 3/ spatial extentsion of damages (score between 2 to 8). This grid allowed usIt allowed to rank the 176 major floods (Boudou, 2015). Then, a second level of selection ledselection led us to focus on the nine9 events showned in Fig. 1 (Jan. 1910, March 1930, Oct. 1940, Dec. 1947 / Jan. 1948, Dec. 1959, Jan. 1980, Nov. 1999 and, Dec. 2000 / April 2001). These flood events cover all flood typologies (oceanic/snowmelt/Mediterranean floods, marine storm submersionsurges, cyclones, dam breachingeaking) and are considered as some of the most remarkable in accordance with the evaluation grid. Lang *et al.* (2012) presented the main characteristics of these nine events (except for the 1947-48 flood).

In this study,~~paper~~ we ~~will~~ investigate the two oldest selected events, ~~respectively~~ which took place in January 1910 and March 1930, focusing on the urban situation in ~~Besancon~~Besançon and Moissac (Fig. 2). The aim is to focus on two cities that~~which~~ have been significantly flooded in the past and to understand how their vulnerability to flooding has changed ~~until now~~up to the present day. A detailed inventory of documentary sources on these two events can be found in the online material.[1]

2.2 The January 1910 flood event in ~~Besancon~~Besançon (Doubs River catchment)

~~,~~The flood of January 1910 ranks ~~fifth among~~fifth among the 9 floods selected as remarkable according to the evaluation grid (Fig. 1). This flood event is mostly known for being the most significant flood ~~that~~ affecting~~ed~~ the city of Paris, with a return period of about one hundred years for several rivers of the Seine basin. After a very wet end to the year 1909 (450 mm of rainfall in 3 months), the Seine basin received a large amount of rain and snow in January 1910 (about 300 mm in the upper part, 110 mm in the central part and 280 mm in the downstream part). The water level at Paris-Austerlitz was 8.66 m, the second highest historical level after the flood of February 1658 (8.80 m) (Champion, 1858-1864; Goubet, 1997). There were a relatively small number of direct fatalities (7 deaths) plus 9 indirect deaths (several cavity collapses), but the impact within the Paris region was extremely high, with 150 000 persons affected ~~people~~ and economic losses of about 400 million gold francs ~~or~~ (1.5 billion euros, 2015) (Picard, 1910). Despite the fact that a large part of ~~the N~~northern France~~ench~~ ~~territory~~ was also affected, most of the attention of society and recollections~~the memory~~ of this event have been focused on Paris. ~~In order t~~To demonstrate the remarkability of this event, not only for the Seine catchment area but also for more rural regions, we ~~then decided to focus~~ concentrate our study on the Doubs basin where the flood of January 1910 remains one of the most significant historical floods, with ~~and~~ the highest water level being recorded in the city of Besançon (see fig. 3, e.g. Z = 245.55 m at “Poterne, Place la Revolution”). While ~~As~~ the flood event across~~on~~ the Seine basin was~~is~~ characterized by a clustering of several oceanic rainfall events, the flood event in~~on~~ the Doubs basin was triggered by an episode of ~~a~~ heavy rainfall ~~event~~ from ~~the~~ 18 to 21~~st of~~ January (between 150 and 250 mm), plus the presence of ~~a~~extensive ~~large~~ snow cover after a wet winter which led

[1] Auxiliary material is available in the html. doi:XXX

to ~~to a~~ significant snow melting. A large part of the old city of ~~Besancon~~Besançon was flooded, with huge damage~~s~~. Many shops, houses and their basements were inundated, causing important losses of furniture. The streets ~~of the town~~ were also particularly badly affected~~suffered~~ due to the high flow velocity. In total, the cost of the flood~~ing~~ at Besançon is estimated at around 2 million francs (DREAL Franche-Comté *et al.*, 2010), ~~actually~~ representing 7.7 million euros ~~2015~~in present-day money.

According to several documentary sources (Allard, 1910; Ministère de l'Ecologie, 2011), it appears that the hydro-meteorological conditions of the event (peak discharge at Besançon of about 1750 m^3/s, with a return period of about 100 years; catchment area of 4379 km^2) cannot explain why the flood level was so high throughout the old city. Such exceptional water levels in the city centre were~~is~~ the consequence of energy losses at~~along~~ the bridges of the town. These energy losses were larger than usual (cf. Fig. 3, in comparison with the 1882 and 1896 flood events) due to a ~~jam~~ log jam (about 35 000 m^3), resulting from the ~~submersion~~ inundation of a paper factory a few kilometres upstream of~~to~~ ~~Besancon~~Besançon, contributing significantly to a ~~the~~ rais~~inge~~ of the water level.

Archive sources (especially administrative reports produced by the Chief Engineer of the Ponts-et-Chaussées, Serial S, Doubs departmental archives) also reveal~~ed~~ some major failures of ~~the~~ flood warning during the event. Surprised both by the ~~flood~~ arrival and the~~its~~ intensity of the flood, the local authorities did not succeed in~~to~~ ~~establish~~ setting up temporary protecti~~veng~~ structures at the different open~~ed~~ city gates ("postern gates"), which ~~and~~ directly contributed to the inundation~~submersion~~ of the city (Fig. 4)

2.3 The March 1930 flood in Moissac (Tarn River catchment)

At the end of February 1930, an intense ~~large~~ Mediterranean rainfall event occurred in the South-West of France, with hot and moist air from the Mediterranean Sea penetrating deep into the Massif Central highlands. From 25 February to 4 March, a large area was affected by heavy rainfall (e.g. more than 200 mm over 6000 km^2 during 4 days), with a maximum of 694 mm in 7 days at Saint-Gervais-sur-Mare (spring of the Orb river). The very serious adverse consequences of this rainfall event can be explained by at least two factors. From October 1929 to February 1930, high rainfall totals were observed (e.g. 1 177 mm at Lodève, 840 mm at Florac), thus favouring a strong reaction of the basins which were already saturated.

Moreover, a warming in temperature associated with intense rainfall was causing a large amount of snow melting (20 to 100 cm) above 600 m.

Due to its intensity and ~~its~~ unusual date of occurrence ~~date~~ (at the end of a wet winter) the rainfall event triggered ~~to~~ an exceptional flood event (Pardé, 1930). The following flood hazard intensity can be judged exceptional for the downstream part of the Tarn catchment (8000 m^3/s at Moissac, 15 400 km^2; mean annual discharge 230 m^3/s), with a return period of about 250-300 years (Dreal Midi-Pyrénées, 2014). Between 210 and 230 fatalities were recorded during thise Tarn River flood ~~event~~ (resp. Bichambis, 1930 and Boudou, 2015), ~~leading to~~which represents one of the most destructive~~amaging~~ flood events ever recorded in France and surely the most significant during~~for~~ the ~~XXth~~ 20th ~~th~~ century. The economic loss for the entire surrounding ~~all~~ region ~~around~~ was estimated at~~is estimating~~ around 1 billion francs, which ~~represents~~ corresponds to 570 million euros 2015 (Journal Officiel de la République Française, 1930).

One of the striking features~~issues~~ of the disaster can be found in the concentration of ~~the~~ damage~~s~~ in the town ~~city~~ of Moissac (120 deaths out of~~for~~ a total of 210). Reconstructing and mapping the flood chronology using historical sources provides us with~~enhances~~ a better understanding of the circumstances of the disaster (Fig. 5). On~~The~~ 3 ~~rd of~~ March 1930, the flood arrived in the town. Before 18:30 the Tarn River was already overflowing the main channel, ~~both~~ on both the south ~~left~~ and north~~right~~ banks~~sides~~. Fortunately, the town~~city~~ centre was protected by three main dy~~i~~kes and the ~~embankment of the~~ railway line embankment. From 18:30 to 23:00, the water level rose~~aised~~ and the flood extent covered the area between the main dikes at the eastern part of the town~~city~~. Around 23:00, at the time of maximum discharge ~~value~~ (estimated at around 8000 m^3/s), three breaches suddenly appeared along the ~~embankment~~ railway embankment. These ~~breaches led~~breaches led to a sudden outburst of the dy~~i~~kes and ~~to the~~ final ~~submersion~~ inundation of the town~~city~~.

According to the ~~death~~ locations of fatalities and the ~~disaster~~ feedback of information on the disaster~~s~~, the explanation of the high ~~number of fatalities~~death toll is twofold. Firstly, the rapid influx of water into~~within~~ the city due to the flash flood and dy~~i~~ke failures induced a surprise effect on~~for~~ the inhabitants of Moissac. Secondly, the collapse of more than 600 houses was~~is~~ related to the typical kind of housing in~~of~~ this region, being ~~made~~ built of ~~with~~ raw bricks especially vulnerable to flooding and sustained~~durable~~ contact with water.

3 Methodology for monitoring changes in flood vulnerability

3.1 Relevance of historical events in the present context?

One of the main requirements of the Flood Directive is to identify areas with a potential high level of flood risk, based on historical floods that would have significant adverse consequences if they occurred again. As the consequences are ~~both~~ dependent on~~ing on~~ the flood hazard as well as~~and~~ the personal, social and economic assets located in the flood risk zones, one of the main concerns is to assess the changes in~~evolution over time of~~ local vulnerability of city centres as a function of time. In~~For~~ both case studies, the main casualties and/or economic losses within the catchment were located in ~~one~~ a single municipal area~~city~~. But some aggravating factors are~~were~~ time dependea~~n~~t~~s~~, such as woody debris upstream of bridges at Besançon or dy~~i~~ke failures to~~at~~ the east of Moissac. Other aggravating factors are~~were~~ related to social vulnerability, such as failures ~~o~~of~~n~~ flood warning at Besançon or vulnerable building materials at Moissac.

~~In order~~To obtain a ~~to~~ better ~~understand~~understanding of the local disaster process, our study ~~we~~ aims to ~~will~~ monitor changes in flood vulnerability, comparing the past and ~~the~~ present situations. Several questions have to be addressed. Is it possible to assess~~correctly depict~~ correctly the changes in ~~the~~ vulnerability over time according to the available sources? Does the~~a~~ mapping of land use provide enough information to identify indicators of vulnerability? Can we establish ~~some~~ scenarios concerning ~~about~~ the impact of a future flood based on a historical flood?

After a preliminary analysis that involves~~by~~ geo-referencing historical information in the present-day context, we then ~~will~~ consider the mapping of land use and ~~the counting~~estimating ~~of~~ the numbers of the population at risk, while comparing ~~from~~ the past and the ~~to~~ present situations.

3.2 ~~A d~~D~~ynamic mapping to locate historical information~~

A preliminary step of this study~~work~~ consists of~~ed in the implement~~carrying out~~ation of a~~ dynamic mapping with a spatial display of the ~~historical information formerly~~ previously collected historical information. The historical corpus made up of various document formats and sources is~~was~~ included in a GIS by locating the information available. However, ~~S~~some

place names have ~~however~~ changed since the date of the flood event ~~date~~, ~~which required~~thus requiring ~~-~~ supplementary ~~work~~treatment of the data.

The ~~Such~~ dynamic consultation of historical information is not only of~~for~~ interest for ~~to~~ correctly locating~~e~~ the various sources of information on flood vulnerability, but~~. It~~ can also be used to develop risk awareness and risk culture on an exposed territory. As an example, the high-water mark inventory developed for~~in~~ the Seine river catchment (www.**reperesdecrues-seine.fr/carte.php**) provides ~~a~~ dynamic mapping which is easily understandable and interactive for the general public, in contrast~~contrary~~ to the maps resulting from hydraulic or hydromorphogenic modelling (de Moel *et al.*, 2009).

3.3 Evolution of land use

~~We will~~In this section, we address the exposure ~~and susceptibility~~and susceptibility to flood risk (Fig. 6) using simplified descriptors which remain consistent with the level of data availability and accuracy of historical information (Barnikel and Becht, 2003, Barnikel, 2004).

Firstly, the exposure analysis is based on the ~~evolution of the~~changes in the population living per building and provides information about the evolution of ~~for~~ built-up area~~s evolution~~. Secondly, susceptibility analysis based on land-use classification provides relevant information to evaluate the nature of buildings affected during ~~the~~ flood~~ing~~. ~~Use of h~~Historical information is required which at least describe~~s~~~~ing~~ the land cover on different dates ~~is required~~. For example, historical maps and aerial photos often depict the built-up territory for a specific year.

~~In order t~~To perform a spatial analysis of historical maps, it is necessary to integrate them~~their integration~~ into a GIS ~~was required~~. Three steps are~~were~~ executed: scanning, georeferencing and digi~~tta~~lization~~ing~~ supported by a spatial reference system~~d geometry~~ (Fig. 6a) (Rumsey and Williams, 2002, Levin *et al.*, 2010). A set of historical maps and aerial photographs produced by the French National Institute of Geographic and Forest Information (IGN) are ~~was~~ used to depict the extent of built-up areas~~urban extension~~ at the scale of a block of house~~s scale~~. A total of 7 topographic maps (from 1911 to 1988) are used for Besançon and 26 aerial photographs for Moissac (from 1947 to 1983). Aerial photographs are favoured in the case of Moissac because of the inconvenient representation of the town on topographic maps, which is split between four map plates. These raster data are then~~were~~ imported and

georeferenced. A spatial database (BD TOPO) produced by~~coming from~~ the IGN, describing the present French territory and its infrastructures, is~~was~~ used to select control points and ~~to~~ evaluate distortions during the digitizing step. During this last step, information from topographic maps is~~was~~ vectorized into a unique "historical layer". In this way, each object is given~~gets~~ a spatial reality (via the GIS representation) and a temporal reality (by associating a temporal field to indicate its existence for a specific year). Consequently, the "historical layer" ~~makes it possible~~allows us to ~~depict some~~obtain "temporal snapshots" (Langran and Chrisman, 1988, Gregory and Healey, 2007) of the urban fabric: the space is discretized based on ~~available~~ information ~~at~~available at the time of ~~event~~the event ~~period~~.

Subsequently, the description of "historical layer" objects provides information on the nature~~kind~~ of building exposure. A land-use classification is~~was~~ drawn up~~achieved~~ based on a nomenclature adapted from the~~an~~ Urban Atlas of the European Environment Agency (http://www.eea.europa.eu/data-and-maps/data/urban-atlas), according to historical information constraints (Fig. 6b). A first geomatic processing step is performed ~~was run~~ to discretize the residential buildings on a 0.25 hectare grid. ~~In each mesh, a~~A density criterion is~~was~~ applied in each grid cell, based on the percentage contribution to the ~~art of~~ building~~s~~ footprint, leading to a ~~partition~~ distinction between dense and sparse areas. ~~In order t~~To enhance the classification, a second processing step is carried out~~was then run,~~ using a proximity criterion for each building~~,~~ based on~~by~~ the number of buildings within a 200-m~~eters~~ radius (continuous and discontinuous buildings). Local information is then added related to the location and ~~the~~ nature~~s~~ of non-residential constructions ~~were added~~. BD TOPO data are~~were~~ used to describe the current situation~~time~~, and a point-in-time~~unctual~~ layer is~~was~~ built with our "historical corpus" information for ~~ancient time~~earlier historical periods.

3.4 Census of the exposed population within the flood extent

General information is provided by the evolution of population at the scale of the municipality. Figure 7 presents the data derived from several population censuses during the 20th century. It shows than the number of inhabitants has grown by about + 100 % at Besançon (from 57 978 to 116 914, between 1911 and 2010) and + 60 % at Moissac (from 7 814 to 12 354, between 1911 and 2006). As only part of the built-up area was affected by floods, especially in the case of Besançon, it is necessary to cross two layers of information: the number of inhabitants per small block and the spatial extent of the historical flood (1910 or 1930 floods at Besançon and Moissac, respectively).

Human exposure ~~ ~~is taken into account ~~ed for, ~~by census or an estimation of the resident population. The aim here is ~~was ~~to ~~disperse ~~distribute the~~a~~ raw demographic data throughout the blocks of houses by following its evolution at different scales (Wu *et al.*, 2008). The m~~M~~aps so produced can~~ould~~ shed ~~the ~~light on the evolution of human exposure within the area affected by the flood ~~extent~~.

To assess the current population living ~~population ~~within the flood extent, we ~~applied a formula to redistribute at block of house scale ~~make use of two demographic data sets produced by the French National Institute for Statistics and Economic Studies (INSEE) ~~demographic data sets~~, applying formula (1) to redistribute the population data at the scale of blocks of houses. ~~.~~ The first dataset~~one~~ is defined at infra-municipal scale with~~with~~ IRIS data ~~use~~ (Infra-urban statistical area). The second dataset~~one~~ is based on an estimation of the fiscal population with~~estimation ~~in a 200 x 200 m grid. These datasets are~~were~~ distributed ~~through~~ at the scale of residential blocks of houses, based on a volumetric~~tric~~ method (Lwin and Murayama, 2009), in proportion to the~~of~~ building footprint area multiplied by~~times~~ the vertical density, ~~according to~~using the building height provided by BD TOPO:

$$\text{Developped area} = \frac{\text{building height} \times \text{building floor area}}{\text{average storey height}} \quad (1)$$

Historical information, in the form of~~as an old~~ a census or ~~a ~~raw demographic data, is~~was~~ required to ~~census or to~~ estimate (Ekamper, 2010) the numbers of the population exposed ~~population ~~at the time of the disaster. General census reports are available for every French municipality (sometimes online), generally compiled every 5 years up until 1946, with some exceptions. These documents contain~~ ~~nominative information about the municipal population ~~in nominative list~~, ~~gathered ~~grouped by building and street, at~~on~~ different dates. The comparison between past and present exposed population within the flood extent should take account of ~~the~~ possible changes~~evolutions~~ of census methodology over time.

4 Change of vulnerability based on two case studies

We ~~will ~~now consider the changes of vulnerability in~~on~~ the two case studies, from past to present, using historical sources and current information.

4.1 Changes in vulnerability of Besançcon ~~vulnerability~~ with respect to ~~to~~ the January 1910 flood

Figure 8 displays the land use within the area affected by the 1910 flood ~~extent~~ in Besançon, based on the situations in 1911 and 2013 ~~contexts~~ (resp. dates of two censuses). No significant change can be seen in terms of~~on~~ vulnerability, according to the spatial extent of the ~~-~~built-up area. Since the centre of~~As Besancon~~Besançon ~~downtown~~ is located within a meander of the Doubs River, with no opportunity for~~of~~ spatial expansion or urban densification, there has been~~was~~ no increase of exposure, apart from~~or~~ the hospital area. Although~~Despite~~ the city has experienced a spatial expansion towards the~~in~~ n~~N~~orth, on the right bank, this area~~it~~ is located outside our zoning at a larger scale.

According to the land use classification, we can not~~cice~~ significant changes ~~with~~in the various activities. There has been~~was~~ a fall in military ~~function~~employment, in favour of an increase in~~of the~~ administrative and public facilities~~function~~. While ~~the~~ military areas have decreased by~~of~~ 74% between 1911 and 2013, ~~the~~ administrative areas have ~~were multiplied~~grown by a factor of 12. A reduction of human exposure is noticeable between ~~1910~~ 1911 (the census year closest to the 1910 flood) and 2013, with a 24% decrease in the city-centre~~of the downtown~~ population.

The demographic evolution is represented on Fig. 9 at the scale of a block of house~~s scale~~, reflecting the ~~household~~ decrease in household size (~~reduction~~ decline in the number of inhabitants per building) and a~~some~~ decline in~~removal of~~ residential function (reduction of inhabited buildings within the city centre~~downtown~~).

4.2 Changes in vulnerability of ~~Current~~ Moissac with respect ~~vulnerability~~ to the March 1930 flood

The flood risk mapping of Moissac ~~cartography gives~~yields an opposite diagnosi~~s~~tic~~, with an important~~ major increase of vulnerability within the area affected by the 1930 flood ~~extent~~ (Fig. 10). Built~~d~~-up ~~surface~~ areas have expanded by 122% between 1930 and 2013. Such spatial extension is explained by new residential development (mainly housing estates) and economic buildings ~~on the E~~east of the ~~downtown~~ city centre and by a progressive densification of~~n~~ the low~~-~~density area on the south~~left~~ bank flood plain.

Despite a new distribution of the population (Table 1), the human exposure ~~did~~ has not~~not change~~ significantly changed. The reduction of ~~of the downtown~~ population density in the city

centre is compensated by a spatial expansion (Fig. 11). The human exposure has mainly increased on the ~~downtown~~ east side of the city centre~~side~~, especially in the area located between the two levees. It should be noted that no general census report is~~was~~ available for Moissac in the 1930s. The~~refore, the 1930 exposed~~ population exposed to flood risk in 1930 was ~~therefore~~ estimated ~~through~~ from a raw ~~rough~~ demographic data set, obtained~~provided~~ from an internet database ~~holding~~ containing a historical population census at the~~a~~ municipality scale (http://cassini.ehess.fr/), which was~~and~~ then distributed according to~~persed based on~~ the volume-based~~tric~~ method.

4.3 A~~n a~~ppraisal of the temporal evolution of flood risk

These two case studies shed ~~the~~ light on the complexity of flood~~-~~-risk evolution. At the ~~a large scale of a country~~nation-wide scale, it is clearly acknowledged~~dmitted~~ that the increase of flood damage~~s during~~ over the last few decades is induced by a general increase in~~ing of~~ flood vulnerability (Kron, 2002, Luino *et al.* 2012, Kundzewicz *et al.*, 2014, Smith *et al.*, 2014). At a local scale, where topographic, social and economic contexts are crucial, it is necessary to have a more detailed~~n in depth~~ analysis.

In Besançon, there has been no extension of the urban area within the old city since 1910, but significant land-use changes have led to a decrease of flood vulnerability as some previously residential areas are now used as administrative buildings buildings~~flood risk vulnerability decreased since 1910, but with significant land-use changes.~~. ~~Submersion~~ The frequency of flooding has changed in the historical centre, due to the establishment of safety measures ~~establishment~~, especially with the construction of mitigation structures such as cofferdams to close the postern-gates. Some uncertainties remain for~~to~~ determining~~represent~~ the flooded area in the case of an ~~1910~~ event ~~flood~~comparable to the 1910 reference flood, since~~as~~ opposite effects come into play. The log jams at the bridges are not expected to be repeated, but additional hydraulic losses have been introduced by new hydraulic structures since 1910. Nowadays, the reference flood selected in the regulatory documents is a simulated flood larger than the January 1910 flood.

In Moissac, the ~~trajectory of the~~changes in vulnerability show~~follows~~ a more contrasted pattern~~evolution~~. As in various other French regions, the built-up areas ~~city experienced~~ have grown~~a growth~~ in spatial extent~~sion~~ since 1930, characterized by an important development of housing estates ~~development~~. One critical point is the development of one-storey buildings,

leading to a higher human ~~and structural~~ vulnerability due to the lack of a refuge floor. ~~At the~~On the other hand ~~opposite~~, building quality has improved. During the 1930 flood, the house collapses in Moissac and the consequent~~rrelated~~ fatalities were closely related to the construction materials used ~~for its construction~~. ~~In order t~~To increase ~~weakness~~ the resistance of~~in~~ the structures, new materials and ~~architecture~~ building techniques~~s~~ were ~~then~~ used during the reconstruction stage~~ep~~. Another positive ~~evolution~~ change is related to the improvement of safety measures, due to progress in ~~both~~ flood~~-~~-warning decision ~~-~~making as well as~~and~~ regards emergency population evacuation schemes implemented by the civil protection services. ~~Today, t~~The 1930 flood in Moissac, with a~~hich~~ return period ~~is~~ estimated at around 250 years, is nowadays considered as the reference flood hazard ~~both~~ for the local flood risk management strategy as well as~~nd~~ for planning and development documents. This territory ~~would~~ appears to remain vulnerable, especially to risks of d~~y~~ike failure ~~risks~~.

5 Conclusion and perspectives

This study~~paper~~ present~~sed~~ a case study on the urban vulnerability of two French cities ~~which have~~that were ~~been~~ largely impacted by ~~two~~past floods occurring~~ed~~ in January 1910 and March 1930. This approach~~It~~ gives an insight into~~of~~ the complexity of flood risk evolution, while also taking ~~with~~ local characteristics into account. Mapping historical sources can provide reliable information on the ~~past~~ flood vulnerability in the past, but this requires ~~given~~ some preliminary work. A first step is necessary to ~~correctly~~ locate and geo-reference the historical information within the present geographical reference system. Qualitative information (images~~pictures~~, technical reports, national and local newspaper articles, paintings, marble plaques, etc. ~~historicalaccounts~~…) can be interpreted as a~~to~~ complement ~~some~~ to historical maps on land use. An~~The~~ assessment of the population at risk within spatial units can be ~~deducted~~ inferred from technical documents with nominative lists of persons as well from old censuses. Historical information on past floods can therefore be useful when building scenarios on ~~the~~ future possible floods, providing a reliable reference of what might be possible in terms of water depth, flow velocity and flood extent. Additional work is needed to account for possible changes both in vulnerability and flood hazard over the past several decades (from historical floods to the present day) and for future decades (prospective studies). ~~-~~It is also important to bear~~keep~~ in mind the uncertainties associated ~~uncertainties~~ with~~on~~ historical data and to use relevant scales when mapping vulnerability indicators.

As usual, thea ~~diachronic appraisal~~temporal analysis of flood risk evolution at a local scale implies a good knowledge of the general context of the socio-economic development of territories, as well as ~~evolutions~~ changes in the ~~of risk memory~~recollection and perception of risk. According to ~~the~~ data availability, this study~~paper~~ focuse~~sd~~ ~~on~~on only a small ~~part~~ component of vulnerability. However, ~~In order t~~to ~~complete~~ carry out a comprehensive~~total~~ flood vulnerability analysis, ~~some~~ other indicators should ~~however~~ be taken into account. After the Xynthia storm surges in 2010 (41 fatalities due to floods in France), Vinet *et al.* (2012) showed ~~for instance~~ that the age of the population ~~age~~ is a key component of local vulnerability. It is clear that the insurance system may benefit from similar analyses on urban flood vulnerability over the last few decades.

This ~~paper~~ study addresses the issue of~~focused on~~ flood vulnerability, which ~~that~~ is an important component~~part~~ of the flood risk. In ~~P~~parallel, research ~~work~~ ~~is however also necessary~~ on flood hazard is also necessary~~, in order~~ to simulate past floods in a present-day context, taking into account modifications of the river (morphological changes and river engineering) and new settlements on the flood plain.

6 Author contribution

M. Boudou established the evaluation grid used for the selection of “remarkable” flood events. He collected data on the two historical floods and produced thematic maps on flood hazard. B. Danière carried out dynamic mapping to locate historical information and thematic maps on flood vulnerability. M. Lang ~~did the~~ supervise~~dion of~~ the drafting ~~writing~~ of the paper.

7 Acknowledgements

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Tables

Table 1. Exposed population in 1930 and 2013 for each ~~submersion~~ flooded area~~zone~~ (cf. Fig. 11) in Moissac

Flooded area (Fig. 11)	1930	2013
(1)	4089	1160
(2)	1044	2880
(3)	2267	2000
Total	7400	6040

Figure captions

Figure 1. Location map of the nine~~9~~ most remarkable French flood~~ing~~ events selected in this study and table showing~~of~~ their related remarkability scores ~~related~~ (Boudou, 2015)

Figure 2: Location of the case studies: (left) Doubs basin and Besançon ~~city~~; (right) Tarn basin and Moissac ~~city~~

Figure 3. Longitudinal profile of the Doubs River within the old city of Besançon and ~~flood~~ inter-comparison of floods (sources: Ville de Besançon – Service de la voirie et des eaux : *Profil en long des crues du Doubs du 21 janvier 1910, 28 décembre 1882 et 10 mars 1896, 10 mars 1910*, Bibliothèque et archives municipales de Besançon, série 0). Locations of Republique and Battant bridges are shown on Fig. 4

Figure 4: Old Besan~~ç~~con city centre with characteristic water inlets during the flood event on 17 to 21 February 1910 ~~flood event~~

Figure 5. Flood chronology and location of fatalities during the ~~3 March 1930~~ flood event in ~~the city of~~ Moissac on 3 March 1930

Figure 6. Evolution of vulnerability: (a) exposure; (b) susceptibility (building use type)

Figure 7. Evolution of the number of inhabitants during the 20th century at Besançon and Moissac. Source: EHESS-Cassini before 1962, INSEE from 1968

Figure 8. Land use types and soil occupation within the area affected by the 1910 flood ~~extent~~ in ~~Besancon~~Besançon: a/ in 1911; b/ in 2013

Figure 9. Estimated number of inhabitants per building within the area affected by the ~~within~~ 1910 flood ~~extent area~~ in ~~Besancon~~Besançon: (a) in ~~1910~~1911; (b) in 2013. Some blocks of houses are depicted only on one of the maps~~in only one map~~, because of land-use changes. Non-residential blocks of houses are not taken into account here

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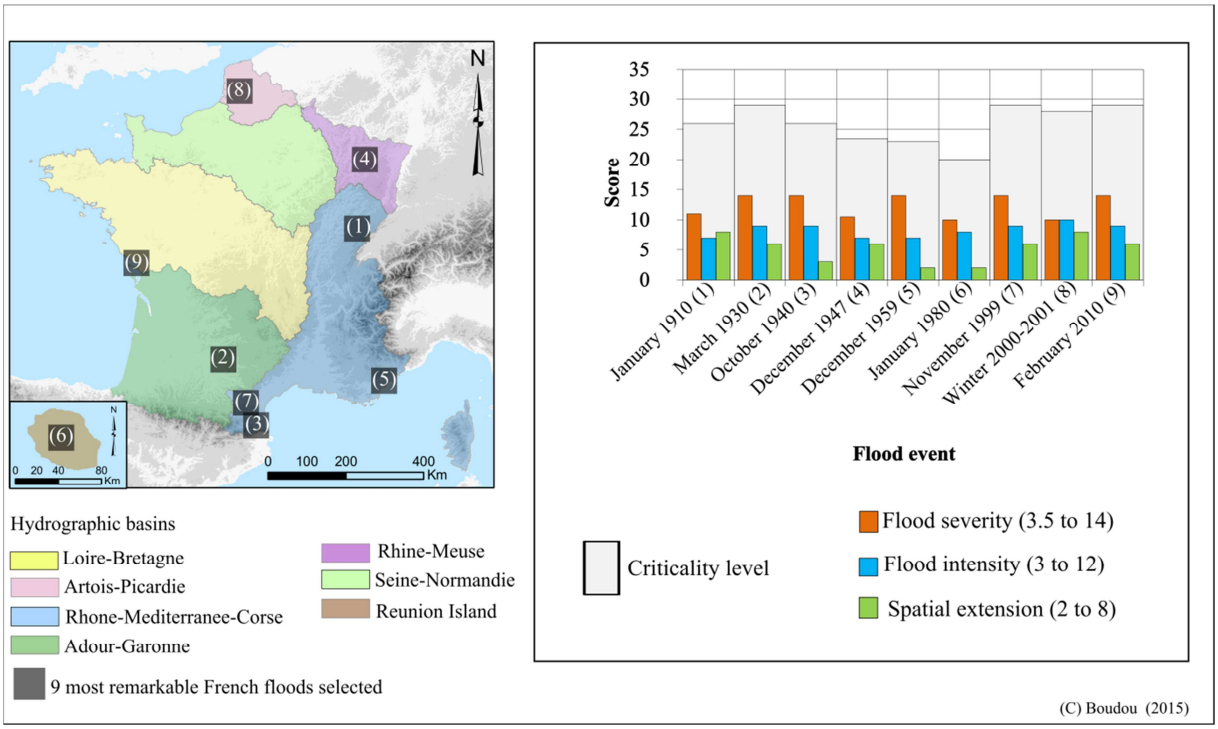
Figure 11. Estimated number of inhabitants per building within the area affected by the ~~within~~ 1930 flood ~~extent area~~ in Moissac: (a) in 1930; (b) in 2013



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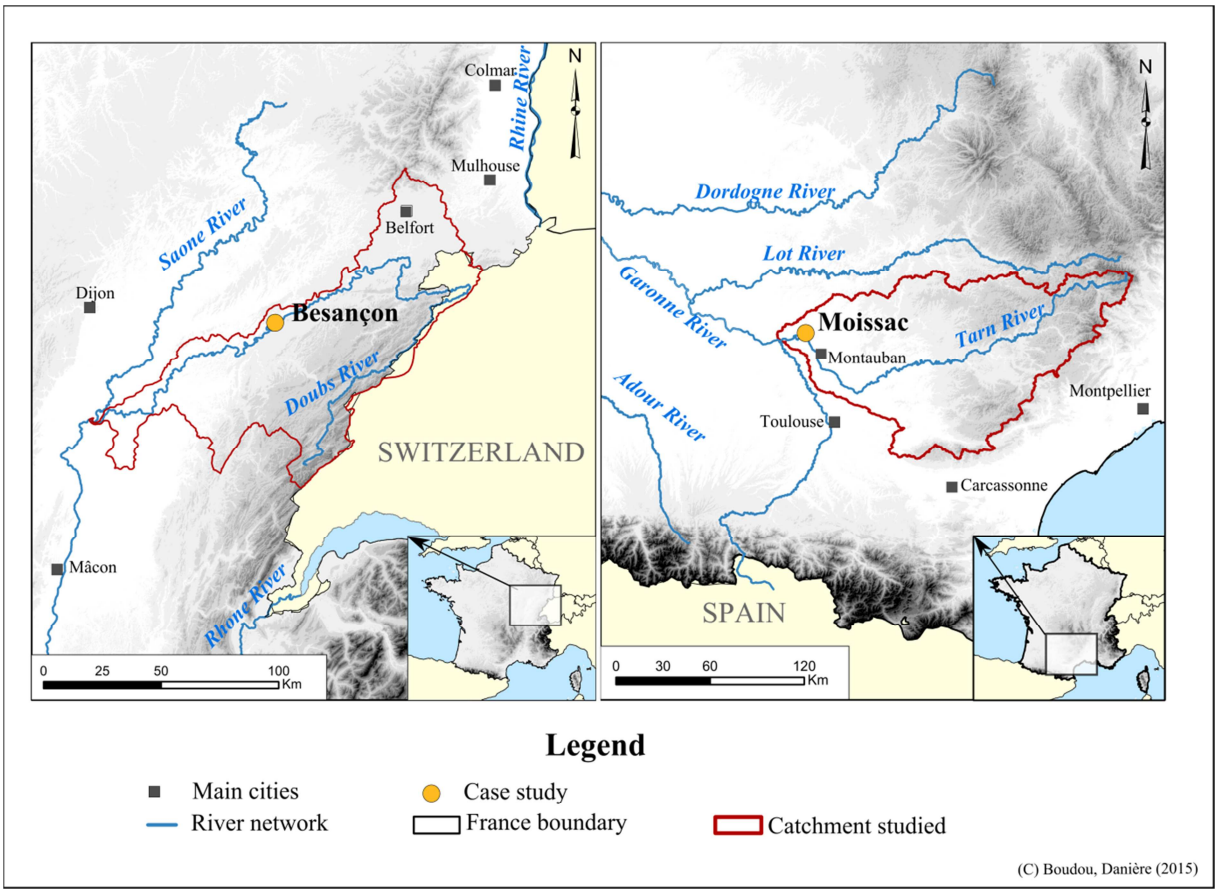

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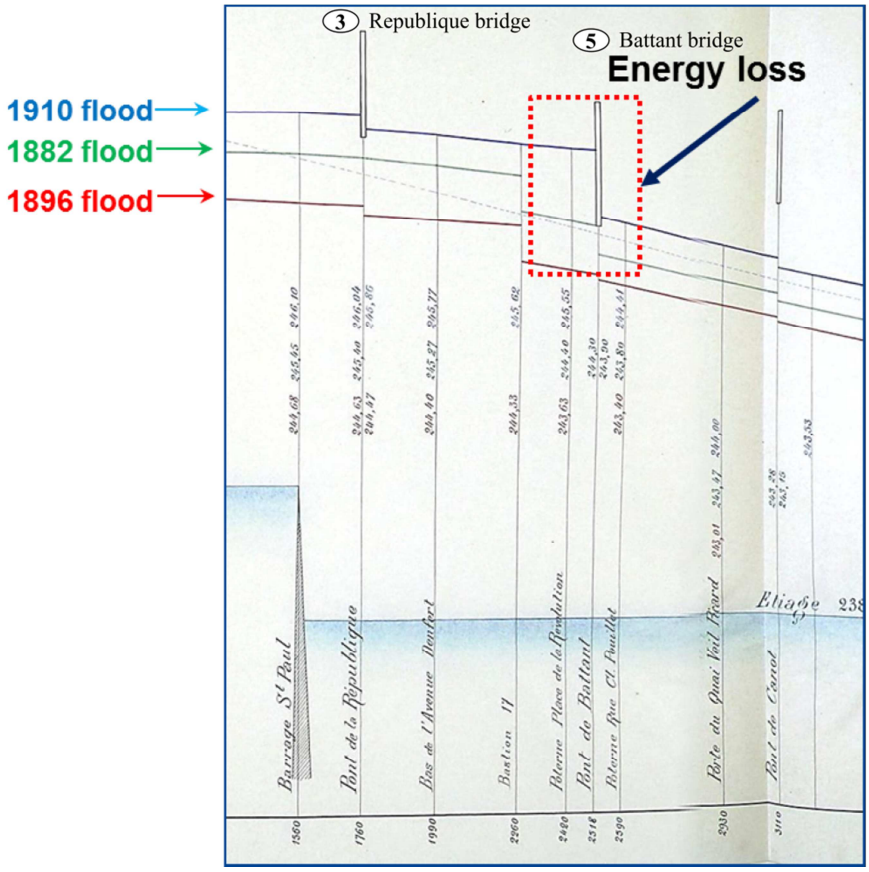

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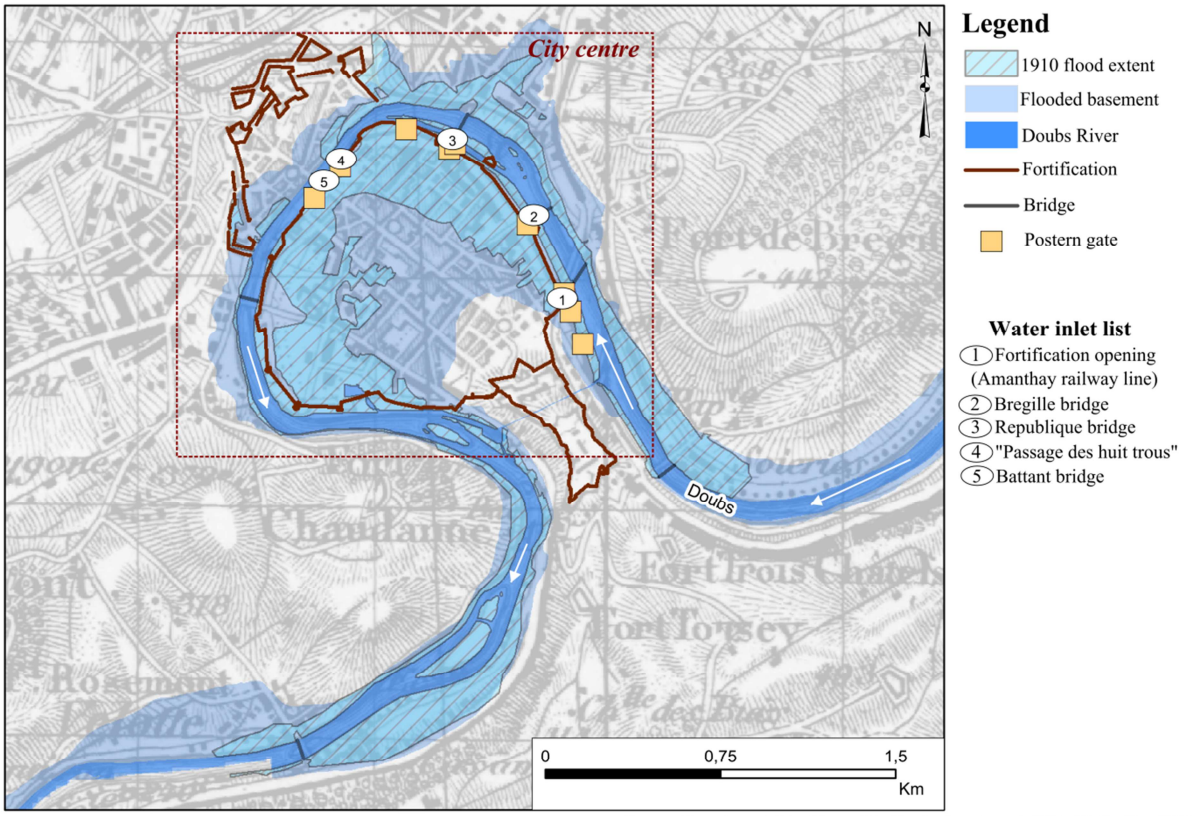

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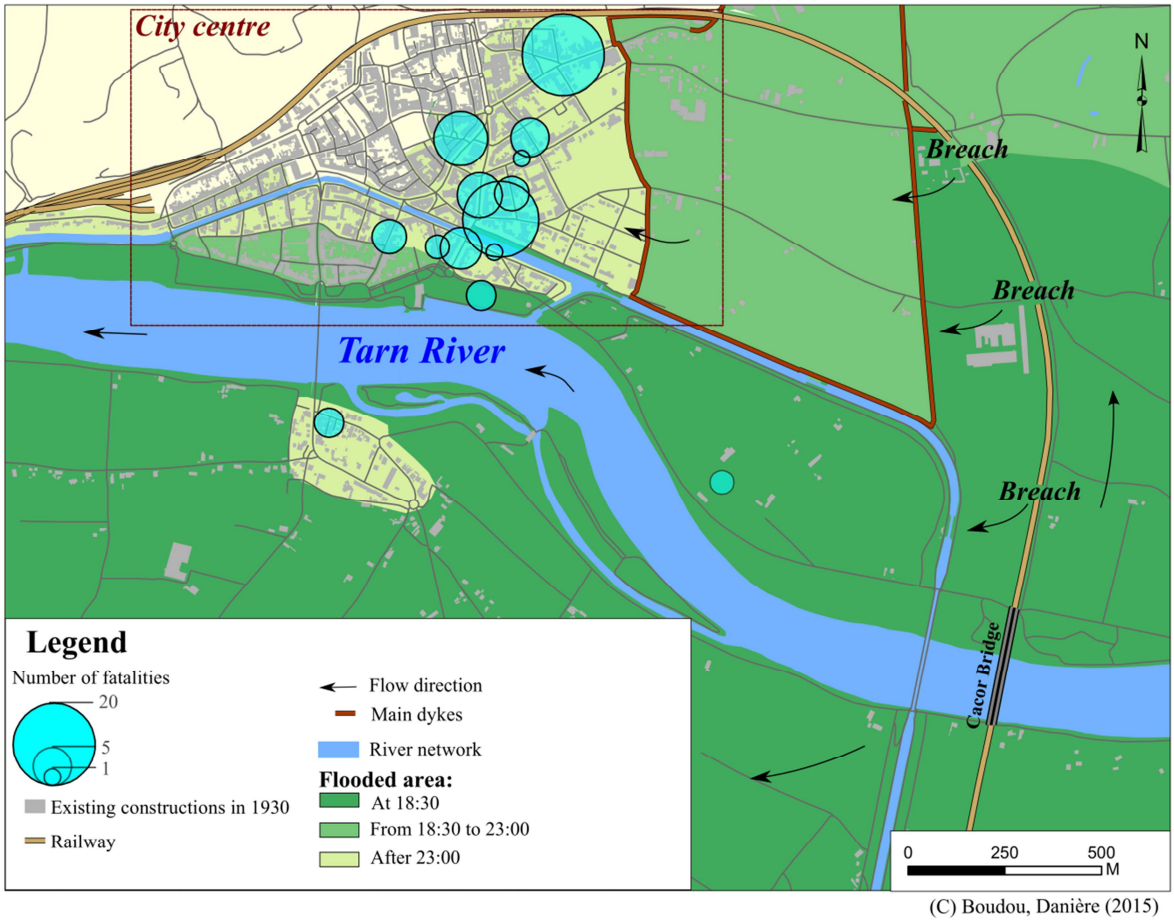

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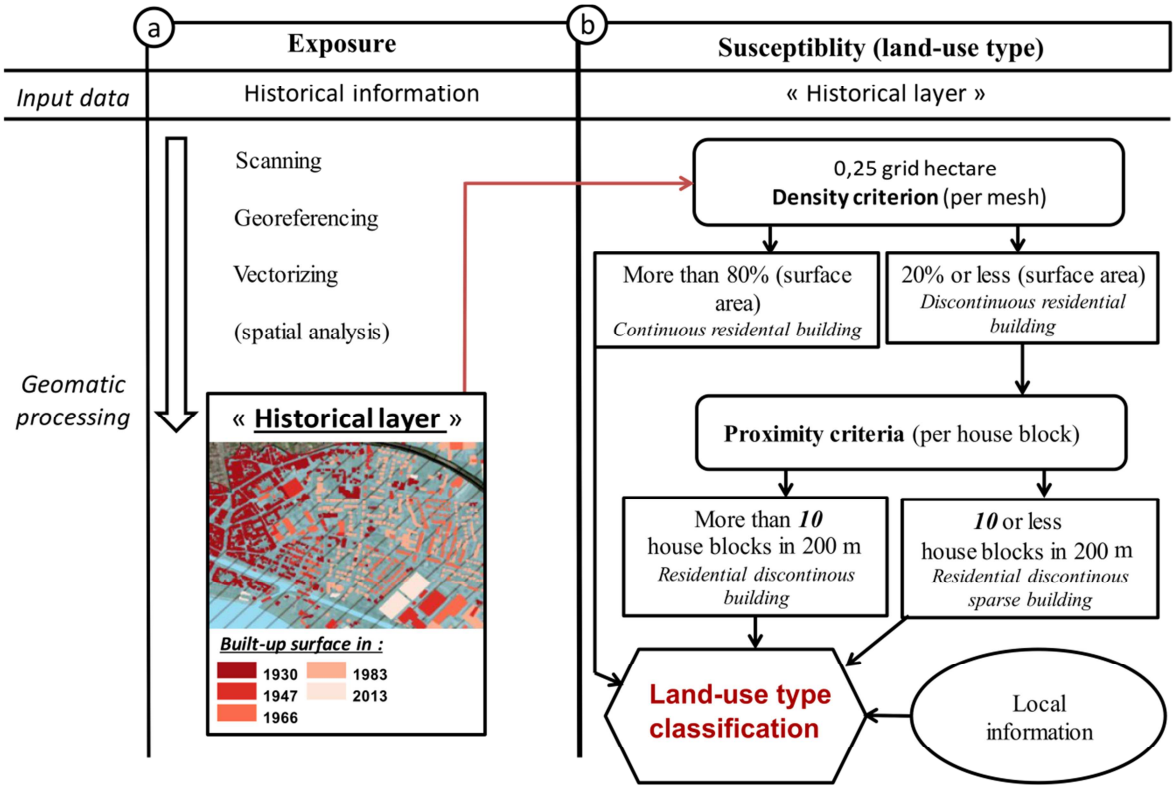

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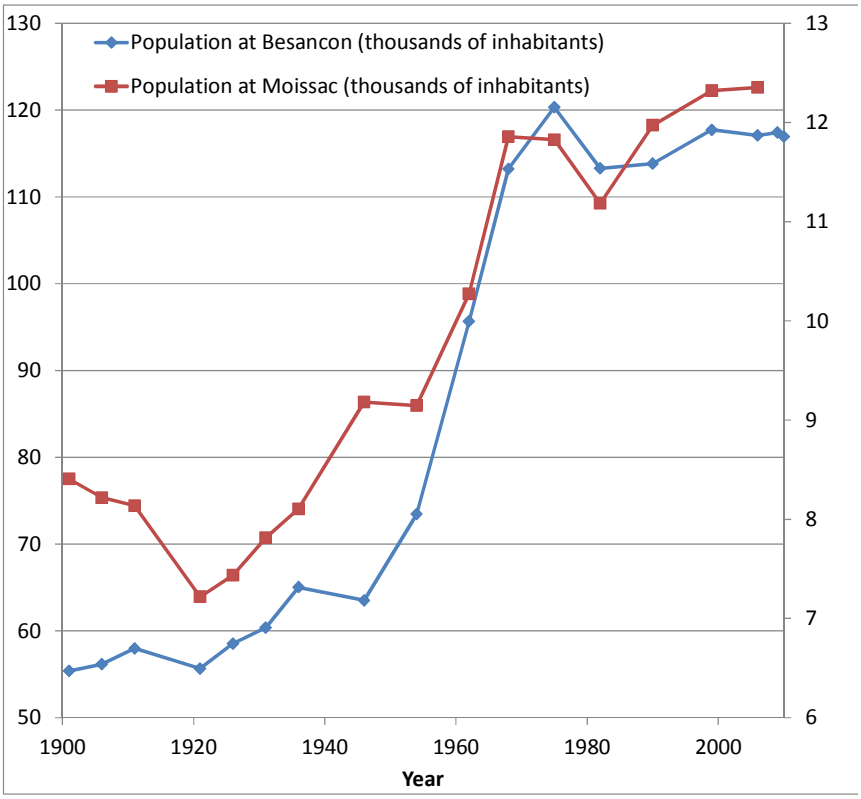

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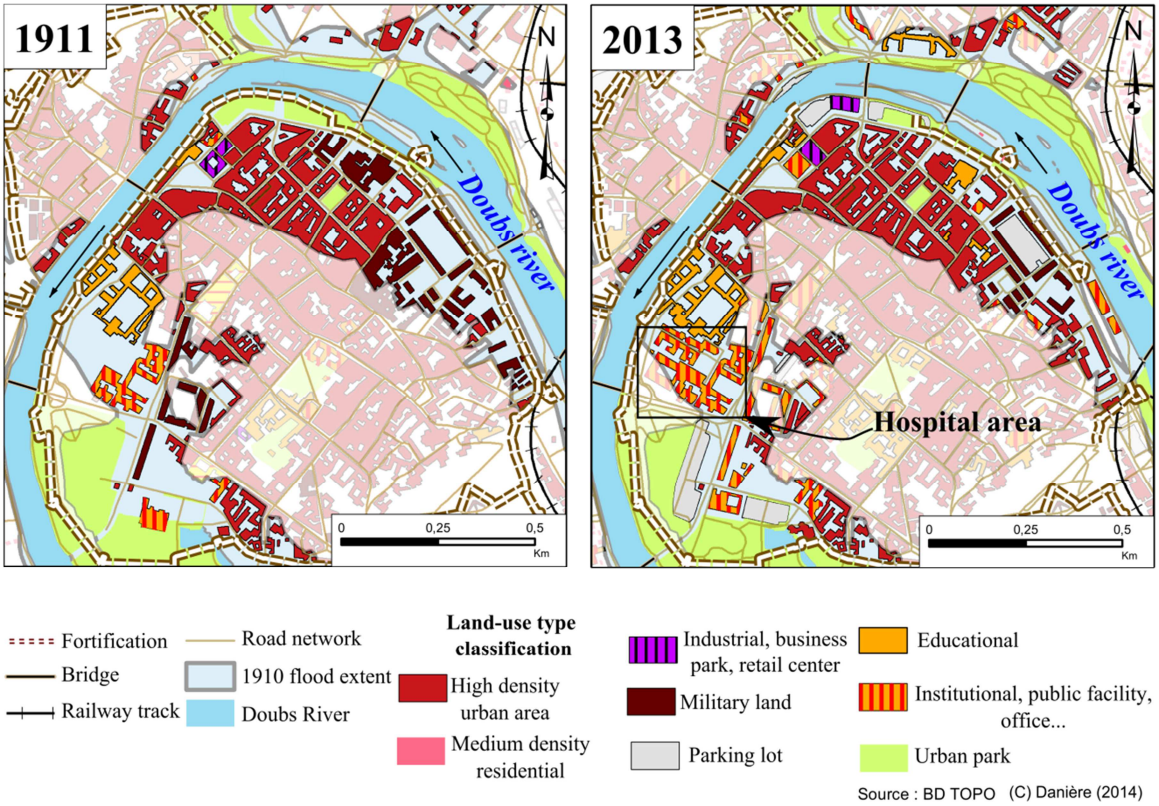
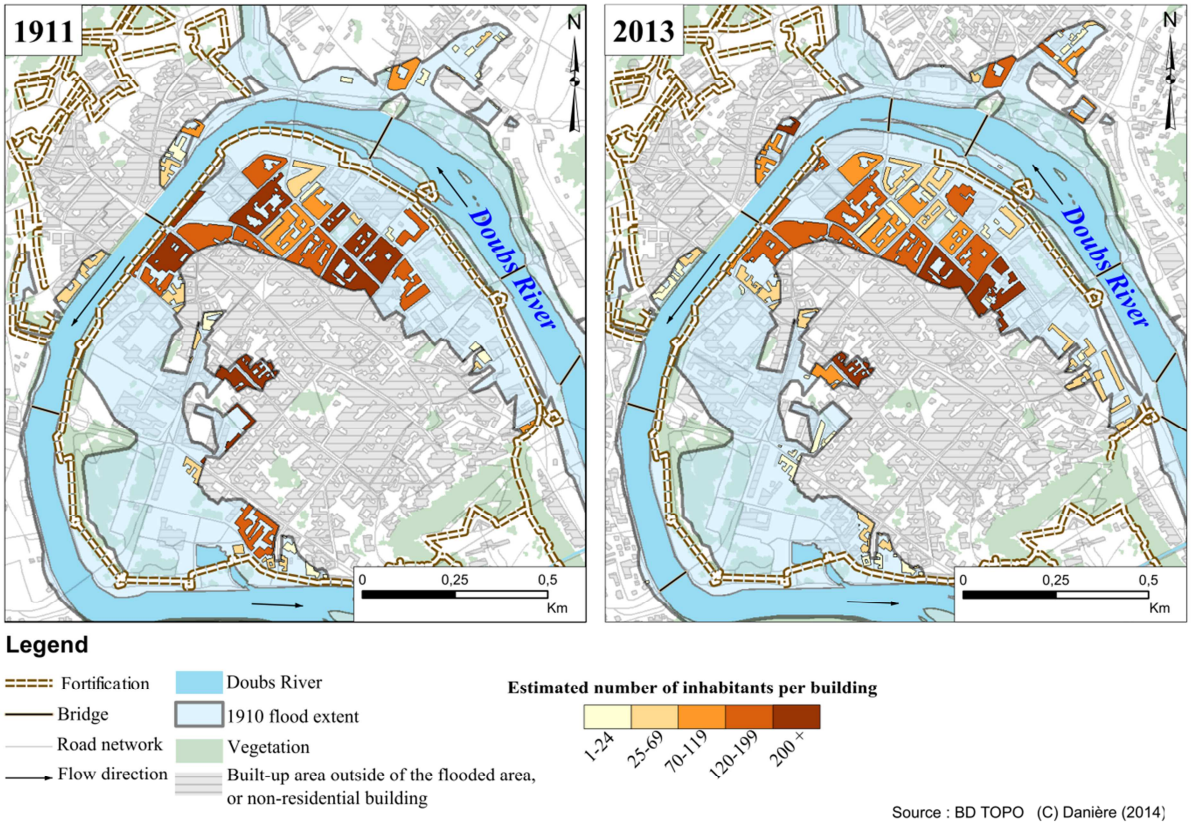


Figure 8. Land ~~use~~ use types and soil occupation within the 1910 flood extent in~~in~~ Besan~~c~~çon: a/ in 1911; b/ in 2013



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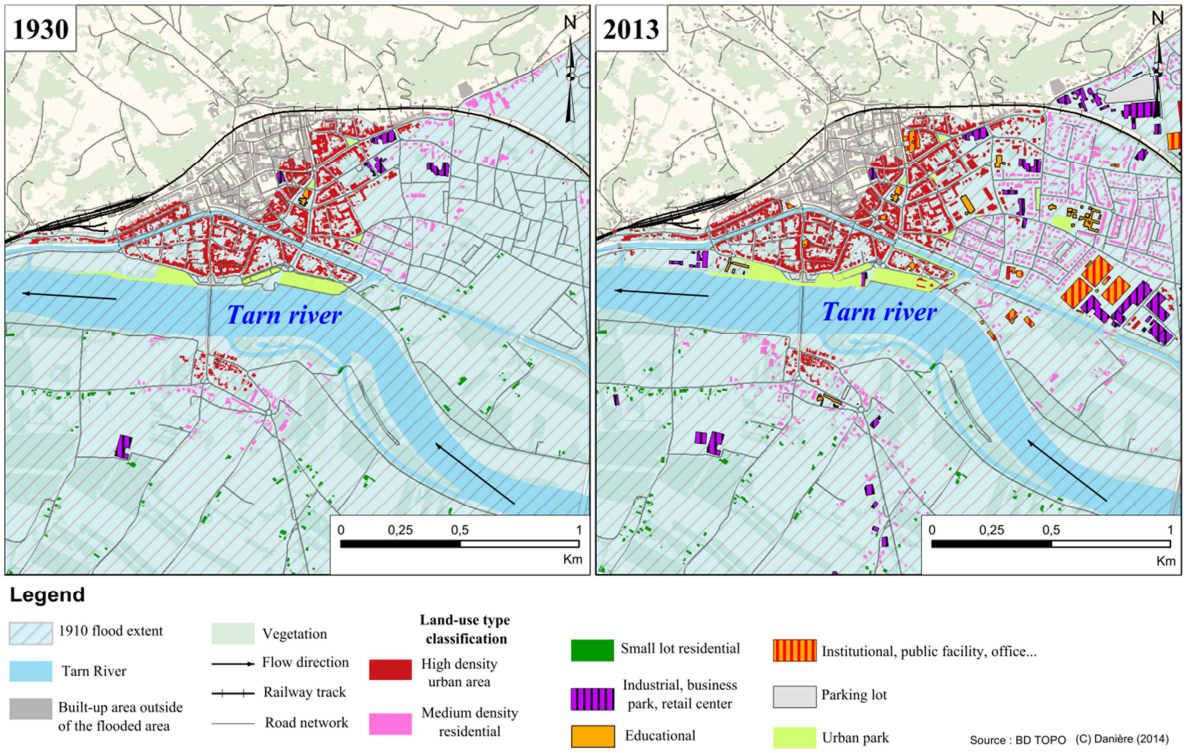
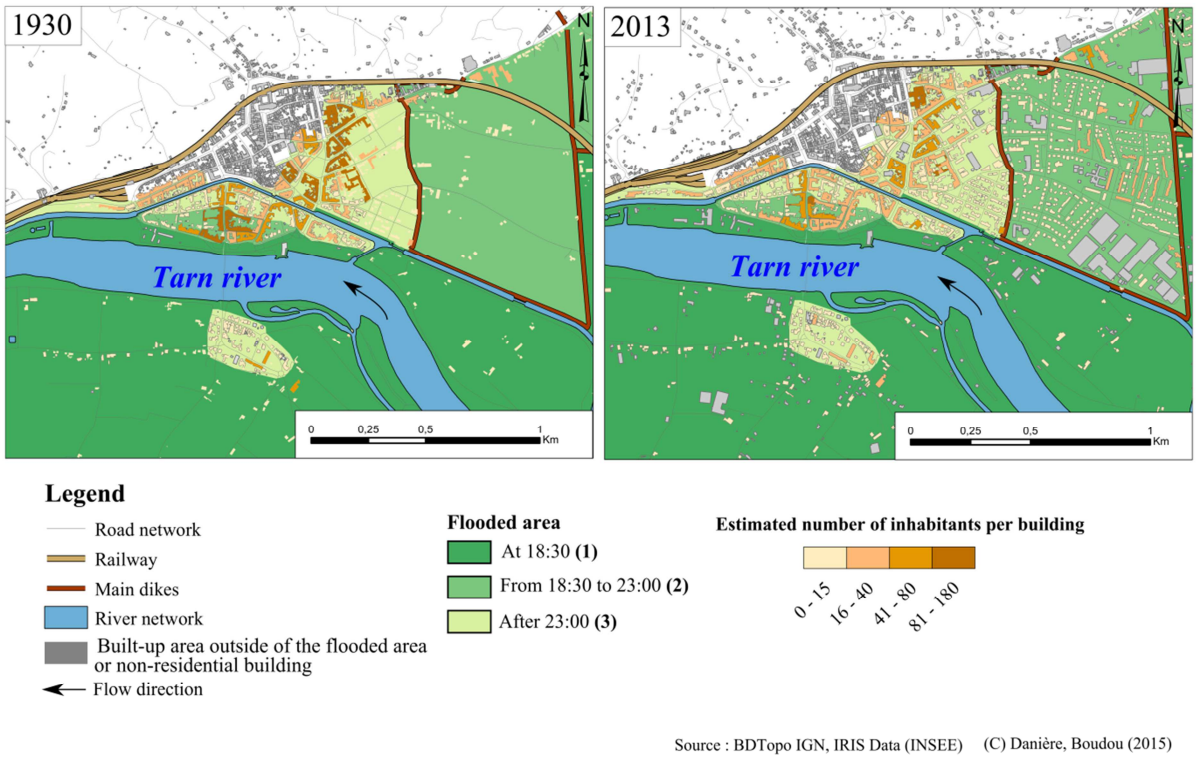


Figure 10. Land use types and soil occupation within the area affected by the 1930 flood in Moissac: (a) in 1930; (b) in 2013



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