

Editor Decision: Reconsider after major revisions (20 Jul 2020) by Andrea Kiss

Authors reply (23 October 2020)

Comments to the Author:

Dear Authors,

thank you for the very interesting and useful work you submitted. The authors present their result regarding a rather unique source that provides an exceptionally detailed inside view to a significant drought episode and the societal (institutional) responses of an urban community. However, the paper in its present form needs further revision. In agreement with the referees' comments, I suggest a number of changes and a slight transformation of the paper that makes it suitable to be published in the present journal.

Authors: Thanks for the opportunity for revising the article. We have made our best to address the revisions suggested.

First of all, I kindly ask you to follow the structural requirements of the journal, with clearly differentiating an "Introduction" chapter (this you already have), "Sources, methodology" chapter (or separate two chapters; it is up to you), "Results" chapter, a "Discussion" chapter and a "Conclusions" chapter (this last one you already have). Currently, the information provided in your main chapters are a mixture of Results, Source (Methodology) and Discussion chapters. Please, check other papers of the journal (e.g. papers in the current special issue provide you adequate guidelines). This also means that, for example, in the "Discussion" chapter you could extend your analysis, for example, with comparisons in space (in Spain, Mediterranean or elsewhere) and time (e.g. same period in other places, or with totally different historical periods), with comparing this drought period and societal response to those of other periods, highlight particular years of importance etc. Furthermore, for example, the modern implications (conclusions and comparisons to recent drought situations and forms of societal/institutional response) of your findings, and what lessons early modern societal response on droughts may teach us, would be also rather interesting and worth to discuss briefly (for example; these are just ideas, recommendations). This means, in general, that you need to transform the currently more descriptive, historical style of the paper (especially the parts regarding societal response) to a paper with a more concise, dynamic and comparative natural scientific approach. While this approach is present in discussing the intensity of the drought anomaly and the discussion of droughts in the last 500 years, the text turns to a different style in the chapters regarding the socio-economic response. These later chapters need a thorough and major revision, and also a division of content into the appropriate major chapters based on the structural requirements of the journal.

Authors: In the revised version of the paper we have completely rearranged the article to follow the structural requirements. The revised manuscript includes the following sections: "Introduction", "Methodology and Sources" (with subsections for "Drought reconstruction" and for "Institutional response"), "Results" (with the same subsections as before), "Discussion" (with three subsections) and "Conclusions".

By adopting this new structure, we have also managed to reduce the information provided about societal response, avoiding repetitions, and clarify the novelty of the results presented in relation to drought reconstruction.

Although based on the authors' responses, many of the suggestions have already been successfully incorporated into the manuscript, some of the suggestions are worth to be highlighted and consider more carefully. Following the recommendation of Referee No. 1, please, underline more within the

text which part of your work presented here has been already discussed elsewhere, and which part is a novelty and presented here for the first time.

Authors: We have carefully revised the paper and made an effort to underline what work had been discussed elsewhere and what is presented here for the first time. Introducing a section for “Methodology and sources” and “Results” made this task easier. To be sure, several times in the paper we refer to the new figures as “previously unpublished” work. We hope the new version of the article clarifies this point.

Moreover, Referee 1 provided a number of useful comments worth for reconsideration even if you did not agree with some; in these comments, I would particularly further highlight the comment regarding the application of more figures. Either as a timeline diagram or a flow chart (or any other), it would make your results regarding societal response more plausible if you insert an overview/concluding figure on these responses (e.g. can you connect any of the major changes to particular drought years? I am sure you can....). A timeline diagram you also offered (together with a map that helps the reader to understand the text spatially better) “if needed”: yes, please, you do need at least one overview diagram on societal responses (so as a map: you are, after all, presenting your results in a natural scientific/environmental journal).

Authors: Thanks for pointing this to us and insisting on the reviewer’s comment. We produced two diagrams (Figure 7 and Figure 8) that summarise the diverse institutional responses to drought during the more significant periods identified (1626-1635 and 1643-1650). The institutional strategies presented are connected to specific years. Moreover, readers can draw their own connections by comparing the information on these diagrams to Figure 6 (“Monthly drought rogations levels in Barcelona, 1601-1650”), which is presented immediately before. In the end, producing these two diagrams has been of great help to systematise the results presented about institutional responses and refer to them at the discussion section.

We have also added a map which reflects part of the information on water infrastructure that is found in the Book of Fountains (Figure 9). We have included this map in the section “Results”, subsection “Institutional response”, because the map is a way of presenting the results of the analysis of the Book of Fountains.

As in your paper there is a particular focus on one book, it is also advisable to provide at least a sample page (and/or title page) of this source. Your audience in this journal is primarily coming from natural sciences, but even to historians you would need to introduce this source more explicitly in your “Source” chapter (i.e. what it is, how it is structured, who wrote it why, what systematic information is included there etc). Seeing your responses, many of the specific smaller suggestions you have answered and did make some changes according to the recommendation of the Referee. Nevertheless, please, also make the changes regarding major comments (e.g. regarding the presentation style what Referee 1 also suggested).

Authors: We provided the title page of the Book of Fountains in the section “Methodology and Sources”, along with the title page of another of the sources used (Figures 2 and 3). We introduce and describe the source in the subsection of “Methodology and Sources” devoted to “Institutional responses”. We have tried to differentiate between the description of the source (included in the “Methodology and Sources” section) and the results we obtain from our analysis of it (included in the “Results” section). Regarding the presentation style, we have made an effort to adopt a more analytic tone. The reorganization of the sections and figures has helped us doing this.

Regarding the comments of Referee No. 2: the referee raises a number of very useful questions: while some can be answered in the other chapters (as also the recommended by the Referee), most of these questions would be (sub)topics for the “Discussion” chapter, and I encourage the authors to use these excellent recommendations there, too. Reflecting on suggestions that are rather useful but may fall out of the scope of the paper (e.g. “Why do you interpret the writing of the book as an appropriation of knowledge and not making (private or family) knowledge public?”): even if the topic is out of the scope of the paper, you still have the possibility to reflect on this question in a sentence, referring to

its importance. When explaining to the referees (in the response), the authors actually provide a lot of useful information which, even if only with some words mentioned in the text, would easily clarify why no more details are included in the paper in the questions the referee reflected on.

Authors: Thanks for pushing us with this. This comment helped us structuring the “Discussion” section. In the revised manuscript, you will find that the “Discussion” includes three subsections. Two of those are connected to the exchanges with reviewer 2.

1 **Human responseControlling water infrastructure,**
2 **codifying water knowledge. Institutional responses to**
3 **severe drought in Early Modern Catalonia. The case**
4 **the city of Barcelona, Western Mediterranean (1620-1650)**
5

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12

13

14 **1. Introduction** 3

15 **2. Methodology and Sources** 6

16 **2.1 Drought reconstruction** 6

17 **2.2 Institutional response** 9

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20 **3.2 Institutional response** 15

21 **4. Discussion**..... 20

22 **4.1 Drought stress and political tensions** 20

23 **4.2 Knowledge transmission and adaptation** 25

24 **4.3 Enforcing control over water infrastructure**..... 27

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31

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33

34 **ABSTRACT:** Combining historical climatology and environmental history, this article
35 examines the diverse range of strategies deployed by the city government of Barcelona
36 (Catalonia, NE Spain) to confront the recurrent drought episodes experienced between
37 1626 and 1650. ~~First, our~~ Our reconstruction of drought ~~episodes in Barcelona~~ for the
38 period 1525-1821, based on *pro pluvia* rogations as documentary proxy data, identifies
39 the years ~~1625~~1626-1635 and ~~1640-1650~~1640s as the most ~~significative~~significant
40 drought events of the ~~period 1521-1825~~series (highest ~~Drought Frequency Weighted~~
41 ~~Index of the series~~). Throughout the article, we ~~drought frequency weighted index and~~
42 ~~drought duration index~~). We then focus on ~~human~~the period 1601-1650 providing a
43 ~~timeline that visualises rain rogation levels in Barcelona at a monthly resolution.~~
44 ~~Against this backdrop, we examine institutional~~ responses to drought and discuss how
45 water scarcity was perceived and confronted by Barcelona city authorities. ~~We~~Among
46 ~~the several measures implemented, we~~ present the ambitious water supply projects
47 launched by the city government, together with the construction of windmills as an
48 alternative to watermills ~~in order to mill grain, as attempts to cope with diminishing~~
49 ~~water flows. The context was aggravated by political instability, related first to the~~
50 ~~tensions between the centralising efforts of the Spanish King Philip IV and later to the~~
51 ~~impact of the Thirty Years' War in the border region between the French and Spanish~~
52 ~~Crowns (1635-1659). Finally, we interpret the efforts of the city government to codify~~
53 ~~and appropriate, in order to cope with diminishing water flows. We pay special attention~~
54 ~~to the institutional efforts to codify the knowledge about Barcelona's water supply,~~
55 ~~which in 1650 materialised in the Book of Fountains of the City of Barcelona (*Llibre de*~~
56 ~~*les Fonts de la Ciutat de Barcelona*). This manual of urban water supply, written by the~~
57 ~~water city officer after three decades of experience in his post, constitutes a rare and~~
58 ~~valuable source to study water management history but also includes significant~~
59 ~~information to interpret historical climate. We analyse the elaboration of this manual in~~
60 ~~the context of three decades marked by recurrent episodes of severe drought. We~~
61 ~~interpret the city government aspiration to codify~~ knowledge about urban water supply
62 as an attempt to systematise historical information on infrastructure to improve
63 institutional capacities to cope with ~~water scarcity in the future. These efforts~~
64 ~~materialised in the elaboration of the *Llibre de les Fonts de la Ciutat de Barcelona*~~
65 ~~("Book of Fountains of the City of Barcelona"), a manual compiling the knowledge of~~
66 ~~Barcelona's water supply from source to tap, written by the Barcelona water city officer~~
67 ~~in 1650, after three decades of experience in his post~~future water scarcities.
68

69 **1. Introduction**

70

71 In July 1650, during ~~onean intense episode of the hardest droughts remembered~~drought
72 in Barcelona, ~~Francese Socies~~, the city water officer (“mestre de les fonts”); ~~Francesc~~
73 ~~Socies~~ started writing a book that described in great detail the water supply and
74 distribution system of the city: ~~the *Llibre de les Fonts de la Ciutat de Barcelona*~~
75 ~~(“Book of Fountains of the City of Barcelona”)~~. At the time, Socies had been in his
76 post for over thirty years, overseeing the city’s fountains and water supply, and was
77 approaching retirement. ~~He was a crucial actor and a unique witness of the turbulent~~
78 ~~times that the water supply of the main city of Catalonia was going through, marked by~~
79 ~~recurrent droughts since the mid 1620s. In 1627 he had taken part in the ambitious—~~
80 ~~and eventually unsuccessful— project to build a water canal from the Llobregat River to~~
81 ~~Barcelona. In 1634, he had been excommunicated by the Cathedral’s Chapter of~~
82 ~~Barcelona after cutting its water supply following the orders of the city government—~~
83 ~~the Consell de Cent. During the 1640s he left no stone unturned to find the origin of the~~
84 ~~water losses that affected one of the main fountains of the city and worked hard to~~
85 ~~increase the sources of the urban water supply system. With three~~After decades of
86 ~~experience behind him, he was growing old~~coping with no successor in sight. Suffering
87 ~~the impacts of drought almost every year~~drought very frequently, and well-aware of the
88 precious ~~knowledge that experienced gathered by~~Francesc Socies ~~embodied~~, the city
89 government ~~approached him with a proposal. They had~~ asked ~~the city water officer to~~
90 ~~write a book compiling all~~him to compile his knowledge about Barcelona’s water
91 supply system, ~~from source to tap. This. The resulting book would~~should perpetually be
92 kept in the city archives, ~~in order to illuminate~~shed light on the work of future water city
93 officers and improve ~~urban~~water management. ~~Socies took months to reply, but finally~~
94 ~~accepted under the condition of receiving a lifetime pension. On~~In November 1650, he
95 delivered what became known as the *Llibre de les Fonts de la Ciutat de Barcelona*
96 (“Book of Fountains ~~of the City of Barcelona~~”) (Archival source AS1).

97 This article focuses on the three decades (1620-1650) leading to the codification of
98 Barcelona water knowledge into the Book of Fountains and examines them from the
99 perspective of historical climatology and environmental history. ~~This period coincides~~
100 ~~with the years of Francese Socies as city water officer. Key to the relevance of our case~~
101 ~~study, a systematic analysis of 165 tree-ring series in the Mediterranean for the last 500~~
102 ~~years~~The period 1625-1635 in Catalonia has already been identified in the historical
103 ~~climatology literature as severely dry (Díaz, 1984; Martín-Vide and Barriendos, 1995;~~
104 ~~Rodrigo and Barriendos, 2008). These results are coherent with a systematic analysis of~~
105 ~~165 tree-ring series in the Mediterranean for the last 500 years, which~~ points to an acute
106 period of drought between 1620 and 1640, an episode that affected the whole Western
107 Mediterranean (Nicault *et al.*, 2008). ~~Our analysis of documentary sources for the city~~
108 ~~of Barcelona, drawing on *pro pluvia* rogations as proxy data, confirms this assessment.~~
109 ~~We document how the severe droughts experienced in the city during 1625-1635 and~~
110 ~~1640-1650 stand out within the period covered by *pro pluvia* rogations (1521-1825).~~
111 ~~While the period 1625-1635 had already been identified by research on historical~~
112 ~~climatology as severely dry in Catalonia (Díaz, 1984; Martín-Vide and Barriendos,~~
113 ~~1995; Rodrigo and Barriendos, 2008), in this paper we establish that Barcelona suffered~~
114 ~~the most significant drought event of the period 1521-1825 during these years (highest~~
115 ~~Drought Frequency-Weighted Index of the series).~~Drawing on *pro pluvia* rogations (rain
116 ~~rogations) as proxy data and focusing on Barcelona, in this article we establish that the~~
117 ~~years 1626-1635 and 1640s constitute the most significant drought events that occurred~~

118 in the city during the period 1521-1825 (highest drought frequency weighted index and
119 drought duration index of the series). This previously unpublished drought
120 reconstruction in Barcelona is the first contribution of our work.

121 ~~Once the local and regional significance of drought during the period of study (1620-~~
122 ~~1650) has been established with biological proxies from the existing literature and with~~
123 ~~our documentary data, we move on to examine the different strategies deployed by the~~
124 ~~city to cope with drought, as well as several conflicts that broke out during this period,~~
125 ~~related to power struggles around food and water supply. Throughout the article, we~~
126 ~~combine the detailed account written by Francese Sociés in 1650 with abundant~~
127 ~~municipal and religious documents from the previous thirty years. Finally, we interpret~~
128 ~~the efforts of the city government to codify and appropriate water supply knowledge—~~
129 ~~successfully materialised in the Book of Fountains—as an attempt to systematise~~
130 ~~historical information on infrastructure to improve the institutional abilities to cope with~~
131 ~~water scarcity and manage water resources more efficiently—in other words, to better~~
132 ~~adapt to drought or other disturbances affecting water supply.~~

133 ~~Our research is the first academic analysis of the Book of Fountains, which has been~~
134 ~~kept in Barcelona city archive since it was delivered in 1650. While the book has been~~
135 ~~mentioned in the literature about Barcelona's history (Voltes Bou, 1967; Cubeles, 2011),~~
136 ~~there is no systematic analysis of Francese Sociés work. No modern editions of the~~
137 ~~Book of Fountains have ever been published, and during our research we have carried~~
138 ~~out the first complete transcription of the text. This is therefore the first article that~~
139 ~~presents the Book of Fountains and contextualises its elaboration within the historical~~
140 ~~climatology of the city of Barcelona (Western Mediterranean). As a manual of urban~~
141 ~~water supply, the Book of Fountains constitutes a rare documentary source. Although~~
142 ~~urban water supply was a common problem in the context of pre-modern Europe, we~~
143 ~~have only identified another book that shares some of its features. It is *Le Livre des*~~
144 ~~*Fontaines de Rouen*, written by Jacques Le Lieur between 1524 and 1525 (Sowina,~~
145 ~~2016).~~

146 ~~In contrast to the development of historical climatology research in Catalonia, little~~
147 ~~work has been done on the human response to drought beyond acknowledging~~
148 ~~addition, following the pioneering research on the social dimensions of past climate~~
149 ~~variability (Pfister, Brázdil and Glaser, 1999) and recent environmental history~~
150 ~~monographs that have incorporated historical climatology (White, 2011; Degroot, 2018),~~
151 ~~we examine the diverse range of strategies deployed by the Barcelona city government~~
152 ~~to confront the recurrent drought episodes experienced during these years. In contrast to~~
153 ~~the development of historical climatology in Catalonia, research on the human~~
154 ~~dimensions of climate variability is still scarce. The work ~~that climate conditions in the~~~~
155 ~~17th century accentuated the agricultural, social and political crisis (Serra i Puig and~~
156 ~~Ardit, 2008). The research of Antoni Simon i Tarrés, who highlighted the importance of~~
157 ~~drought among the complex interaction of factors that ~~led to triggered~~ social unrest in~~
158 ~~Barcelona and Catalonia during the late 1620s and 1630s stands out among the few~~
159 ~~existing publications on the topic (Simon i Tarrés, 1981, 1992). Others have underlined~~
160 ~~that climate conditions in the 17th century accentuated the agricultural, social and~~
161 ~~political crisis (Serra i Puig and Ardit, 2008). The relevance of the climatic factor in the~~
162 ~~Spanish context during the 17th century has also been underlined by Geoffrey Parker,~~
163 ~~who pointed out that during the reign of Philip IV Spain “suffered extreme weather~~
164 ~~without parallel in other periods, particularly in 1630–2 and 1640–3” (Parker 2013:289)~~
165 ~~and examined the revolt of Catalonia against the Spanish King (1640-1651) in this~~
166 ~~context.~~

167 However, ~~neither Parker nor Simon i Tarrés~~ none of these authors explicitly
168 ~~address~~ addressed the human response to climatic disturbances in Catalonia during these
169 years. More recently, Mar Grau-Satorras has ~~used~~ examined the example of the town of
170 Terrassa (Barcelona region, Catalonia) to ~~examine~~ analyse how local communities
171 combined different strategies to cope with drought, including infrastructural,
172 institutional and symbolic responses which changed throughout time (Grau-Satorras *et*
173 *al.*, 2016, 2018; Grau-Satorras, 2017). Along these lines, our research focuses on the
174 case of Barcelona as an example of Western Mediterranean urban agglomeration
175 (40,000 citizens). ~~We~~ under severe environmental stress. Among other institutional
176 strategies in response to drought and diminishing water flows, we discuss the
177 elaboration of the Book of Fountains ~~among other adaptation strategies~~, underlining the
178 relevance and novelty of the attempt of Barcelona city government to codify water
179 knowledge in the form of a book ~~as a tool~~ for future ~~water~~ managers.

180 ~~The article proceeds as follows. In the next section, we provide an overview of droughts~~
181 ~~during the period 1521-1825. Due to lack of instrumental data, we use a compilation of~~
182 ~~archival religious and municipal sources about pro-pluvia rogations (rain rogations) as~~
183 ~~proxy data for drought. In line with previous research in the field of historical~~
184 ~~climatology re-assessing traditional documentary sources or presenting innovative ones~~
185 ~~(Adamson, 2015; Veale et al., 2017), our research draws attention to the potential of~~
186 ~~urban water supply manuals as a rare but significant source to be considered to critically~~
187 ~~interpret institutional responses to droughts. While the Book of Fountains has been~~
188 ~~mentioned in the literature about Barcelona's history (Voltes Bou, 1967; Perelló Ferrer,~~
189 ~~1996; Cubeles, 2011), there is no systematic analysis of Francesc Socies work and no~~
190 ~~modern editions of the Book of Fountains have ever been published. After carrying out~~
191 ~~the first complete transcription and study of this text, this is the first article that~~
192 ~~contextualises the elaboration of the Book of Fountains within the most intense dry~~
193 ~~years of the period 1521-1825. Manuals of urban water supply constitute rare~~
194 ~~documentary sources, and we have only identified another book similar book: Le Livre~~
195 ~~des Fontaines de Rouen, written by Jacques Le Lieur between 1524 and 1525 in the city~~
196 ~~of Rouen, France (Sowina, 2016).~~

197 ~~The article proceeds as follows. In the next section, we provide an overview of the~~
198 ~~methods and sources used to reconstruct droughts during our period of study, as well as~~
199 ~~to review the institutional responses to it. In the "Results" section we present three~~
200 ~~previously unpublished figures that show the drought frequency weighted index and~~
201 ~~drought duration index for the period 1521-1825, together with a timeline that presents~~
202 ~~rain rogation levels in Barcelona between 1601 and 1650 at a monthly resolution. The~~
203 ~~results about institutional responses are presented in the form of two diagrams showing~~
204 ~~the main strategies followed by the city government and the specific years they were~~
205 ~~implemented. Next, the discussion section is subdivided in three parts. First, we~~
206 ~~examine how institutional responses to drought intertwined with urban and political~~
207 ~~conflicts. Second, we discuss the Book of Fountains as a strategy for codifying~~
208 ~~knowledge transmission and improve urban water management. Third, we analyse the~~
209 ~~Book of Fountains as a tool to enhance water infrastructure control. In the conclusions,~~
210 ~~we summarise the relevance of our local case study and point out the potential of urban~~
211 ~~water supply manuals as historical sources for both climate reconstruction and past~~
212 ~~climate adaptation.~~

213
214

215 **2. Methodology and Sources**

216
217 **2.1 Drought reconstruction**

218 ~~(Martín Vide & Barriendos, 1995; Barriendos, 1996; Barriendos, 1997). Our work~~
219 ~~demonstrates the comparative significance of the period of study (1620-1650).~~
220 ~~Following this, in section 3, we draw on municipal sources to narrate the growing~~
221 ~~difficulties experienced by water supply in Barcelona to face the severe drought~~
222 ~~episodes that started in 1626-1627. We analyse the proposal of the city government to~~
223 ~~build a water canal from the river Llobregat under the light of the water scarcity caused~~
224 ~~by drought. Similarly, we interpret the great expansion of windmills supported by the~~
225 ~~Consell de Cent as an alternative for milling grain when there was not enough water in~~
226 ~~the city's mills' canals. Finally, we introduce the major conflict that confronted the city~~
227 ~~government with the Cathedral in 1634, leading to the excommunication of the city~~
228 ~~water officer and the members of the Consell, and relate it to the power struggles about~~
229 ~~food and water supply.~~

230 ~~In section 4, we turn our attention to the efforts that the city government carried out to~~
231 ~~increase its control of water supply and improve its management. After discussing the~~
232 ~~difficulties faced by Francese Socies to prevent water thefts during the 1640s, we focus~~
233 ~~on the proposal presented by the Consell de Cent to the city water officer. We examine~~
234 ~~the Book of Fountains as an example of codification of water knowledge of the past to~~
235 ~~prevent future problems; in other words, both as a book depository of knowledge and as~~
236 ~~a tool to improve adaptation to diminishing water flows. Finally, in the conclusions we~~
237 ~~summarise the relevance of our case study in the context of the 1620-1640 drought in~~
238 ~~the Western Mediterranean and call for interdisciplinary work that combines climate~~
239 ~~reconstruction with critical analysis of social responses to extreme climate events.~~

240
241 **2. Climatic context**

242
243 The climatic conditions during the 17th century can be considered as part of the climatic
244 episode known as the Little Ice Age (LIA). Paleoclimatic research has pointed to a
245 higher frequency and severity of cold spells during this episode (Pfister et al., 1996;
246 Pfister et al. 1998; Ogilvie 2001)(Pfister, Schwarz-Zanetti and Wegmann, 1996; Pfister
247 et al., 1998; Ogilvie and Jónsson, 2001; White, 2014). More recently it has also
248 identified and analysed a general increase in the irregularity of rainfall patterns,
249 manifested in the emergence of hydrometeorological extreme episodes with great social
250 and environmental impact. At the climatic scale, in the Spanish Mediterranean this
251 increase in the frequency and severity of extreme hydrometeorological events manifests
252 in periods of around 40 years for the case of extraordinary rainfalls leading to floods
253 (Barriendos and Martín-Vide, 1998; Llasat et al., 2005; Barriendos et al., 2019).

254 Rain rogations have been successfully used as a proxy for the reconstruction of rainfall
255 variability (Martín-Vide & Barriendos, 1995; Barriendos, 1996; Barriendos, 1997). In
256 the case of extreme drought episodes, the behaviour observed in the frequency of these type of events in
257 the coast of Catalonia Rogations were a mechanism to respond to environmental stress, in
258 this case drought. The institutions involved (agricultural guilds, city councils, cathedral
259 chapters) have left reliable and detailed records, with data at a daily resolution. In
260 Catalonia, rain rogations are classified in five levels, according to its severity. These
261 categories can be identified by the typology of religious liturgies, from simple rogations

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262 [inside the church \(low, level 1\) to pilgrimages to sanctuaries \(critical, level 5\). An](#)
263 [integrated index is obtained by weighting data according to the severity of each level of](#)
264 [rogation. This index is standardised so that it can be compared with other populations](#)
265 [and regions \(Martín-Vide and Barriendos, 1995\).](#)

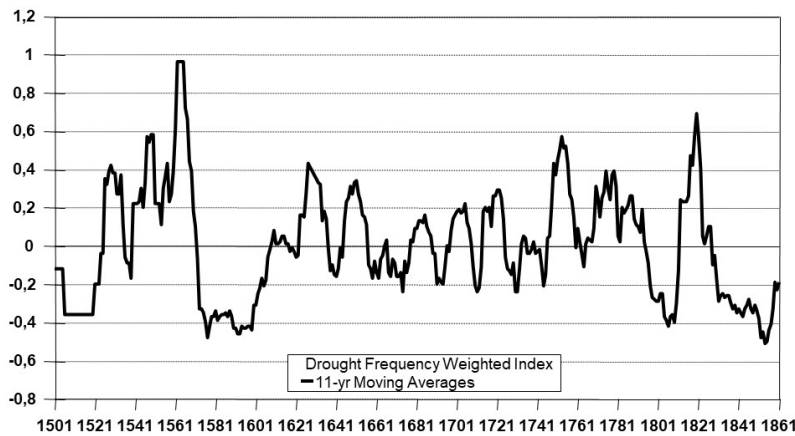
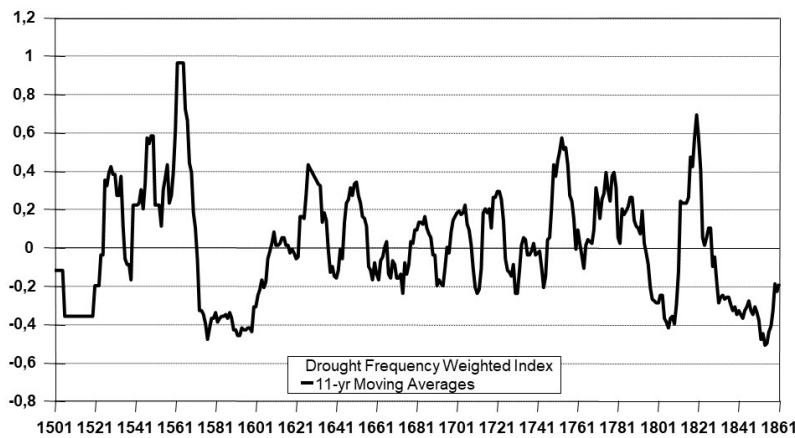
266 [Drawing on previous research based on this method and sources, Figure 1 provides a](#)
267 [general view of the frequency of extreme droughts for the period 1501-1861 with data](#)
268 [from four Catalan cities near the Mediterranean coast at a yearly resolution \(Barcelona,](#)
269 [Girona, Tarragona and Tortosa\) \(data adapted from Oliva *et al.*, 2018\). This general](#)
270 [view allows to identify many recurring events of medium intensity and some of very](#)
271 [high intensity for the Catalan cities studied \(Barcelona, Girona, Tarragona, and Tortosa, see Figure](#)
272 [1\) **coast. The relevant drought events identified are the following:** 1520s, 1540s, 1560s,](#)
273 [1620s \(c. 1625-1635\), 1750s, 1812-1824.](#)

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Con formato: Catalán

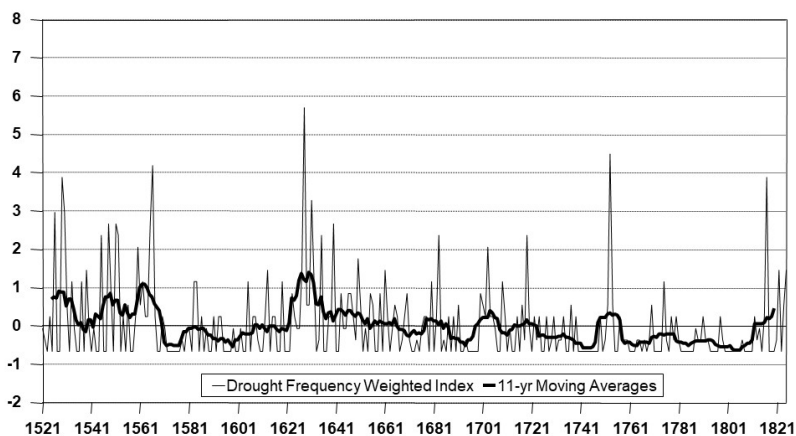


276 **Figure 1.** Drought Frequency Weighted Index- (1501-1861). Standardised values. 11 years moving
 277 averages from ~~4 locations~~ four cities: Girona, Barcelona, Tarragona and Tortosa. Data adapted from Oliva
 278 *et al.*, 2018.

279
 280 ~~Figure 1 also shows how the drought that characterises the period of study in Catalonia~~
 281 ~~extends during a significantly long period, including a lower intense drought~~
 282 ~~immediately after the 1625-1635 pulse. But in order to better interpret the impact and~~
 283 ~~perception of these drought episodes, it is crucial to set them against the very lack of~~
 284 ~~any similar experience in the previous 50 years. During most of the period 1570-1600~~
 285 ~~there are no traces of drought episodes in the Catalan coast, and the episodes of the~~
 286 ~~early 1600s were less intense and relatively brief (Figure 1).~~

287 ~~In relation to 17th century Catalonia, Figure 1 shows two pulses of drought during our~~
 288 ~~period of study (1620-1650): a higher one approximately between 1625-1635 and a~~
 289 ~~lower one immediately after. This assessment is coherent with the systematic analysis of~~
 290 ~~165 tree-ring series in the Mediterranean for the last 500 years, which point to an acute~~
 291 ~~period of drought between 1620 and 1640, an episode that affected the whole Western~~
 292 ~~Mediterranean (Nicault *et al.*, 2008).~~

293 ~~In order to document the impact of drought in Barcelona and the institutional measures~~
 294 ~~to adapt to it, our research delves in the Catalan capital leaving aside the other three~~
 295 ~~cities included in Figure 1. In first place, we focus in the case of Barcelona and examine~~
 296 ~~in detail the behaviour of drought drawing on the records of *pro pluvia* rogations, the~~
 297 ~~results show a distribution of frequent droughts between 1521 and 1825, with different~~
 298 ~~degrees of intensity. By using yearly apply the drought frequency weighted indexes, we~~
 299 ~~can identify the decade of 1560s and 1625-1635 as the two most significative drought~~
 300 ~~events of these three centuries in the city index displayed in Figure 1 to the local data of~~
 301 ~~Barcelona. But the latter stands out for its extreme severity (Figure 2).~~



302
 303 ~~(see Figure 24 in the section “Results”, previously unpublished). Second, we take~~
 304 ~~advantage of: Drought Frequency Weighted Index. Standardised values. City of Barcelona (1521-1825).~~

Con formato: Fuente: 12 pto, Sin Negrita

306 ~~In order to improve the characterisation of climatic events in Barcelona, there is a~~
307 ~~variable that provides useful information to understand how drought was perceived and~~
308 ~~the responses it generated assess the length of drought episodes.~~ In the case of Barcelona,
309 the level 2 of *pro pluvia* rogations involved the public exhibition of a specific relic: the
310 remains of Santa Madrona (Martín-Vide & Barriendos, 1995). The public exhibition of
311 this relic in the high altar of the Cathedral lasted until the authorities established that the
312 drought was over. In ~~this~~that moment, the urn containing the Saint's remains was taken
313 back to the Chapel of Santa Madrona in the near mountain of Montjuïc. This liturgical
314 pattern ~~allows for determining the perception of drought by the Barcelona city~~
315 ~~authorities at a daily resolution. In other words, it~~ introduces the possibility of analysing
316 the duration of drought episodes as perceived by local authorities. ~~On, something that~~
317 ~~has not been studied in this geographical context. By accounting for the amount of days~~
318 ~~per year than the level 2 of drought was active in Barcelona and standardising the result~~
319 ~~to make it comparable with other cities, we obtain an annual index of drought duration~~
320 ~~for the period 1521-1825 (see Figure 5 in the section "Results", previously unpublished).~~
321 ~~Finally, since the data allows for an analysis at a monthly resolution, we aim at~~
322 ~~elaborating a timeline to describe the behaviour of drought and the different rogation~~
323 ~~levels focused on the study period 1600-1650. This timeline (see Figure 6 in the section~~
324 ~~"Results", previously unpublished) allows to distinguish if the dry months were~~
325 ~~sporadic and irregular or appeared as a persistent anomaly for long periods.~~

326 2.2 Institutional response

328 Our analysis of the institutional response to drought focuses on the period 1620-1650.
329 We provide a qualitative analysis of the records produced by the Consell de Cent (city
330 government) in relation to water management during these years. Most of all, we
331 interpret the elaboration of the *Llibre de les Fonts* in the context of the frequent drought
332 of our period of study. This rare source, kept at the city archives, was written by the
333 water city officer Francesc Socies during the summer of 1650, at the request of the city
334 government (AS1, Figure 2; AS2). The Book of Fountains is a manual about urban
335 water supply, a text where Socies provides instructions that codify both the knowledge
336 of his profession and the experience of his job position, where he was posted between
337 1620 and 1650. The manual aimed at guiding future interventions in the supply system
338 and communicating what future water city officers should know.
339



Figure 2. First page of the *Llibre de les Fonts*, Manuscripts, L-15, Arxiu Històric de la Ciutat de Barcelona (AHCB).

Con formato: Fuente: 10 pto, Negrita, Francés (Francia)

Con formato: Centrado

Con formato: Francés (Francia)

The structure of the book follows the water distribution system and describes it as an interconnected network, from the drainage underground channels in the hills of Barcelona known as “water mines” (*qanats*) to the city fountains. The author indicates with high precision where each element is located, both for those visible and those hidden from view, underground or behind walls (water taps, pipes, water tanks or wells). In addition, throughout the book, the author provides a calendar for the system’s maintenance within a particular urban space and time. Sociés specifies where to intervene and how often, for instance in relation to the cleaning of pipes and curtailing the growth of trees’ roots that can disrupt sections of the system (e.g. every two, four or five years). Nevertheless, Sociés’ temporal specifications do not only apply to maintenance, but also to key historical information about water property rights. Finally, Sociés refers several times to droughts and the lack of water supply experienced several times in the city during the study period.

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In addition to our analysis of the Book of Fountains, a review of the secondary literature on urban history has identified valuable works that refer to measures approved by the city government during the 17th century to cope with drought and diminishing water flows (Voltes Bou, 1967; Perelló Ferrer, 1996). We have also reviewed the leaflets published by the city government during our period of study and found several connected to water management. In first place, we located a pamphlet in defence of a channel project to bring waters from the Llobregat River to Barcelona (AS3, published in 1627). Despite this project was not carried out, we have traced references to it in city chronicles and meeting records during the following years (AS4 and AS5). Our review has also identified four leaflets connected to a legal conflict concerning water rights, which in 1634 brought face to face the Barcelona city government and the water officer Francesc Sociés with the Cathedral’s Chapter (AS6, AS7, AS8, see Figure 3, and AS9).



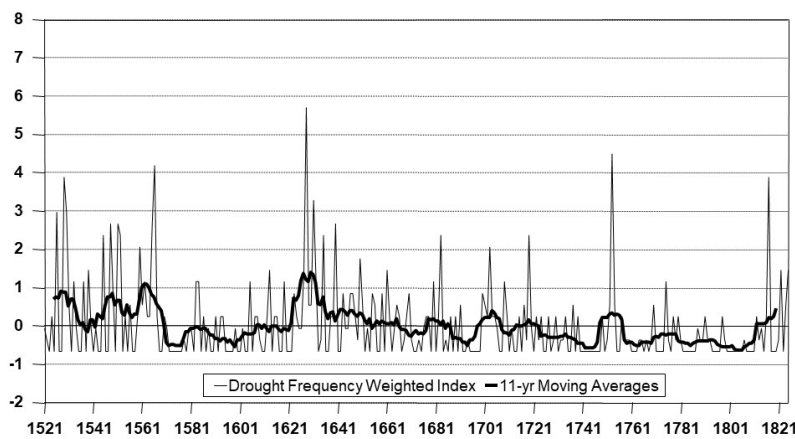
Figure 3. First page of leaflet “Por la ciudad de Barcelona y Francisco Sossies, maestro de las fuentes, con el Cabildo de la Iglesia Maior acerca de las censuras declaradas contra el dicho Sossies”, 1634 (AS8).
Source: F.Bon. 10964, Biblioteca de Catalunya.

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378 **3. Results**

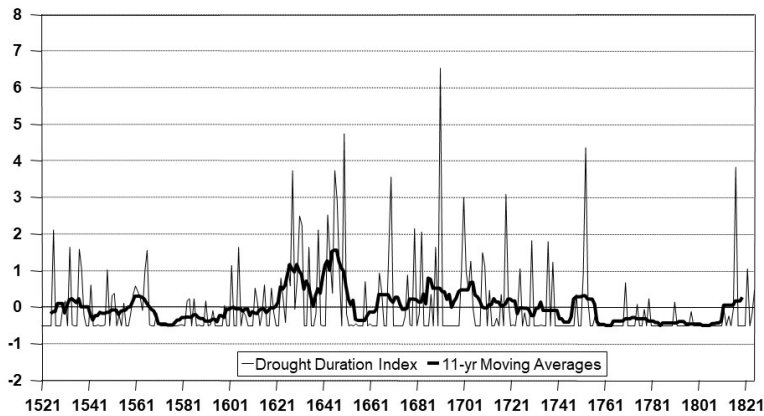
379
380 *3.1 Drought reconstruction*

381 Drawing on *pro pluvia* rogations, Figure 4 shows a distribution of drought frequency in
382 Barcelona between 1521 and 1825 with different degrees of intensity. By using yearly
383 weighted indexes, we identify the decades of 1560s and 1625-1635 as the two most
384 significant drought events of these three centuries in the city. The latter, however, stands
385 out for its extreme severity. Moreover, there was no similar experience with drought in
386 the previous 50 years (approximately 1570-1620).

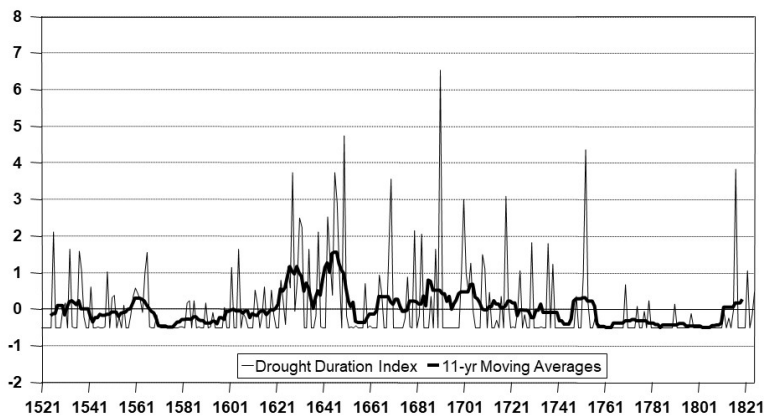


387
388 Figure 4. Drought Frequency Weighted Index. Standardised values. City of Barcelona (1521-1825).
389 Data improved from Martín-Vide and Barriendos, 1995.

390
391 Through the development of an index of drought duration, Figure 5 shows relevant
392 results (Figure 3). Figure 3 illustrates that the drought experienced in Barcelona during
393 the late 1620s drought and its successive episodes were was perceived as longer than
394 any other registered until ~~the~~that time. While it is difficult to extract more details with
395 these historical records, it is evident that the drought registered had an extraordinary
396 magnitude. However, the long duration of the rain rogations may also be related to the
397 perception of an extreme anomaly by the city authorities, since almost no drought
398 conditions had been experienced in the previous 50 years.



399



400

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Figure 35. Drought Duration Index. Standardised values. City of Barcelona (1521-1825).

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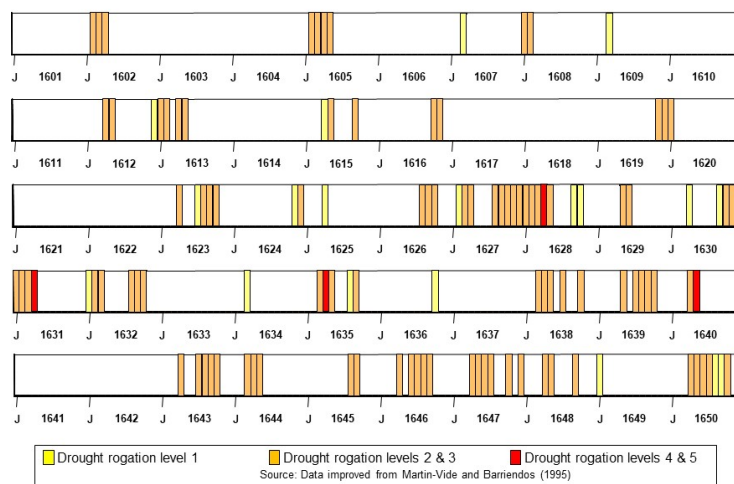
413

414

The analysis of drought duration presented in Figure 35 reveals another significant detail. After the severe 1620s drought, which extends into the first part of the 1630s, there was a less intense episode of drought, but, very close in time, around the 1640s. Perhaps impressed by the previous drought, in this occasion the duration of rain rotations of level 2 – involving the exhibition of Santa Madrona – was as long or even longer than in the previous episode (Figure 35). These results do not allow to analyse in detail the development of the drought episode as a natural episode but provide an entry point to the human response to an extraordinary climate event. The first drought episode of the period of study (1620s to the first half of 1630s) had such a social impact that the almost consecutive episode of the 1640s generates a proportional response. In frontview of the impact of drought on water resources and due to the limited references available after two generations without

415 ~~experiencing~~ similar events, the duration of the ~~religious responses~~rain rogations may
 416 have been extended as a response against a challenging situation for local authorities.

417 ~~After describing the recurrence of drought during these years, the following sections~~
 418 ~~examine how Barcelona, an urban human community of nearly 40,000 people,~~
 419 ~~experienced the years 1620-1650. We interpret several events of the period of study in~~
 420 ~~relation to drought, from institutional efforts to build water infrastructure to the~~
 421 ~~elaboration of the Book of Fountains. In order to better integrate the role of rain~~
 422 ~~rogations as proxy data for drought with the events discussed in the following sections,~~
 423 ~~Figure 4 presents drought rogations in Barcelona month by month, from 1601 to 1650.~~



424 Finally, Figure 6 delves into the first half of the 17th century, the period when the most
 425 significant and long episodes of drought have been identified in the previous figures.
 426 Figure 6 visualises rain rogation levels at a monthly resolution for the first time in our
 427 geographical context. This timeline allows to analyse if drought appeared either
 428 sporadically and irregularly, or as a persistent anomaly for longer periods. In the case of
 429 prolonged drought during the rainy seasons in the region (spring and autumn), the
 430 impacts in agriculture and water supply may have been particularly severe. The results
 431 shown in Figure 6 allow to identify the years 1626-1627 as the beginning of the 1620-
 432 1630s drought episode shown in Figures 4 and 5. During the 1640s, the specific period
 433 identified spans from 1643 to 1648.
 434

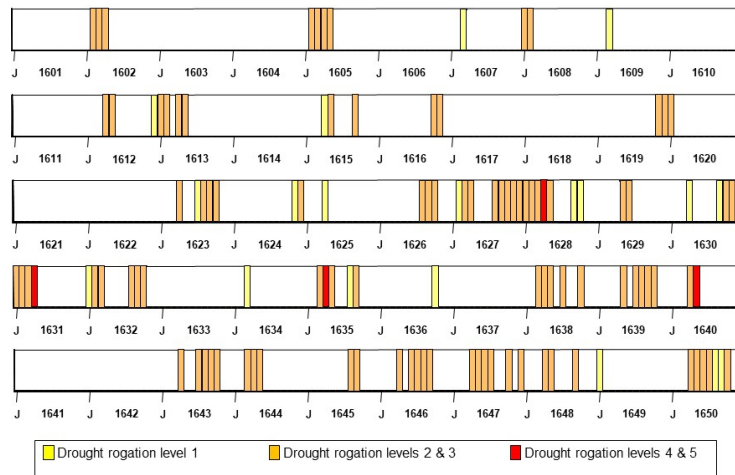


Figure 6: Monthly drought rogations levels in Barcelona, 1601-1650.

3.2 Institutional response

Throughout the period 1620 to 1650 the city government implemented a diverse range of institutional strategies to respond to drought. In the following paragraphs, we summarise these strategies, which we have identified in our review of primary and secondary sources. Figures 7 and 8 synthesise these responses in relation to the two periods of drought identified (1620s-1630s and 1640s).

One of the main strategies developed by the city council to cope with the diminishing water flows caused by drought was the improvement and expansion of the urban water supply sources. During the 17th century,

Figure 4: Monthly drought rogations levels in Barcelona, 1601-1650. Data improved from Martín Vide and Barriendos, 1995.

3. Struggling for water supply in Barcelona

The years 1626-1627 were a turning point for the water supply of the city of Barcelona. During the first two decades of the 17th century there had been a great abundance of water, even accompanied with extreme rain episodes such as the catastrophic floods of 1617 (Thorndycraft *et al.*, 2006). In line with these years of abundance, during the early 1620s the city government supported the expansion of the water distribution system, ongoing in the first quarter of the 17th century, and gave water concessions to several aristocratic houses and monasteries, as well as completing a pipe to supply the city harbour (AS1, chapters 65, 69, 79 and 98). This perception of abundance came to an end between 1626 and 1627. In the words of Francese Sociés, responsible for the management of water supply in the city, “the abundance of waters lasted until the year

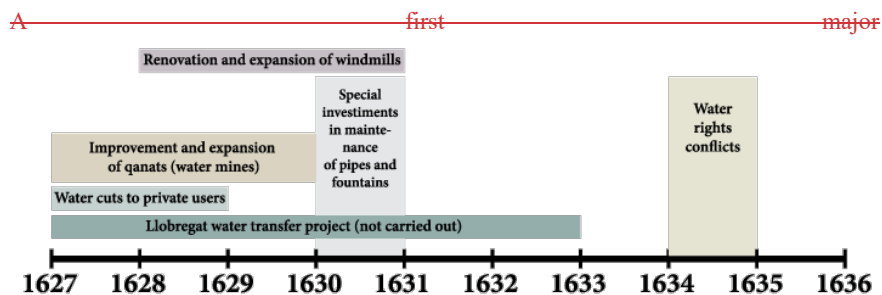
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Con formato: Francés (Francia)

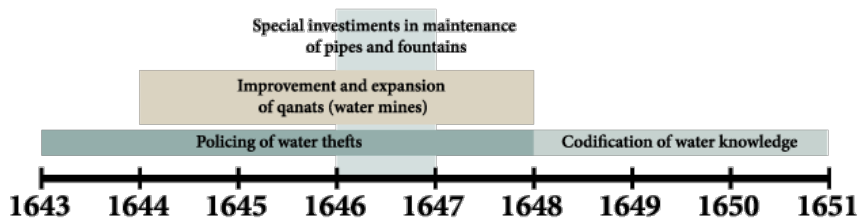
462 1626 (...). Already in the year 1627 came a great drought and in the fountains of the
 463 city there was a great lack of water" (AS1, chapter 65). ~~Socias account concurs with the~~
 464 ~~available information from rain rogations, which points to the second half of 1626 as the~~
 465 ~~beginning of six years of recurrent droughts (1626-1632, see Figure 4).~~

466 ~~During these years,~~ the water supplied to Barcelona's fountains came from several
 467 underground drainage channels originating in the hills surrounding the city. These
 468 structures, known as *mines d'aigua* ("water mines") in Catalan and as *vijajes de agua*
 469 ("water journeys") in Spanish, were common in all the Mediterranean and originated in
 470 the medieval *qanats* established by Muslim settlers (Guàrdia, 2011; Custodio, 2012).
 471 ~~On several occasions during our period of study water flows coming from these sources~~
 472 ~~decreased significantly, triggering efforts from the Consell de Cent to improve and~~
 473 ~~expand old qanats and to open new ones. Between 1627 and 1629, the city water officer~~
 474 ~~built a new qanat that provided a significant increase in the waters delivered to~~
 475 ~~Barcelona (Perelló Ferrer 1996: 126-127). The recurrent dry years starting in 1626-1627~~
 476 ~~seriously reduced the amount of water coming from these sources and prompted serious~~
 477 ~~efforts from the Consell de Cent to diversify the water supply sources of the city. In~~
 478 ~~addition, the reduction in water flows in irrigation channels near Barcelona sometimes~~
 479 ~~compromised the use of watermills to mill the grain, and therefore put in danger the~~
 480 ~~supply of flour. To confront these problems, the city government developed a wide~~
 481 ~~array of responses, from ambitious water transfer projects to the improvement of the~~
 482 ~~existing water supply or the shift from mills relying on waterpower to windmills. In this~~
 483 ~~section, we discuss these initiatives and argue that recurrent drought and limited water~~
 484 ~~supply during the years 1626-1650 heightened micro and macropolitical tensions in~~
 485 ~~Barcelona. During the second half of the 1640s the Consell de Cent approved the~~
 486 ~~construction of a new qanat in Pedralbes (Perelló Ferrer 1996:129).~~



488
 489 **Figure 7:** Strategies of institutional response by to drought (1627-1636). Source: Own elaboration.

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492 Figure 8: Strategies of institutional response to drought (1643-1650). Source: Own elaboration.

493
494 Other attempts to diversify the Barcelona water sources of the city were more ambitious.
495 In 1627 the city government came already in 1627 in the form of an ambitious proposal:
496 a project for proposed to build an open water canal (approximately 12 km long)
497 connecting the river Llobregat to the city. The Consell de Cent regarded the Llobregat
498 waters as the “universal solution” to the recurrent problem of water supply, and
499 published a pamphlet detailing the many advantages of the project. According to this, if
500 the project was completed, water would be secured even in dry years, new fountains
501 would be built, water concessions given to more buildings, cleaning of the supply
502 network would be improved and, perhaps most importantly, agriculture based in
503 irrigation could be developed. The city government invited several Several experts in
504 water supply infrastructure from outside came to Barcelona, who joined Francese Socies
505 and set out to examine the best possible itinerary for the canal. These experts drafted
506 and worked together with the water city officer to draft a detailed proposal which
507 accounted for significant funds required to compensate landowners and also included
508 details about bridges to be built (AS2). Still in 1627, while the consequences of drought
509 extended throughout Catalonia, the city government presented a petition to support the
510 project was submitted to the Viceroy, who redirected it to and eventually to the Spanish
511 King (AS3). King Philip IV. The Spanish king showed interest in the project, but also
512 concerns about the landowners affected by it (Voltes Bou 1967: 58-59). Moreover, the
513 petition arrived in the aftermath of Philip IV meeting with the representative body of
514 Catalonia (Corts), held in 1626, where the King’s proposal to raise an economic and
515 human contribution from Catalonia to support the Spanish army had utterly failed
516 (Elliott, 1984). In 1633 the project made a comeback, when the city officers called
517 water supply experts to resume the work on the canal and even started marking it on the
518 ground (AS4). However, the Royal Privilege needed was not obtained (AS5: 137, 154-
519 155) and the project did not go ahead (Voltes Bou, 1967:59-60; Perelló Ferrer,
520 1996:127-128).

521 While the Consell de Cent promoted this massive water infrastructure, the situation of
522 water supply kept worsening. The acute dry conditions experienced during 1627 and
523 early 1628 (see Figure 4) forced to cut off water supply to almost all private users in the
524 city and stimulated an urgent search for nearer water sources. Aware that the Llobregat
525 canal would only be available in the best scenario in the medium term, the city
526 government resolved to expand the network of the so-called “water mines” (ganats). As
527 a result, Francese Socies started working on a new ganat draining the Sant Gervasi
528 torrent. This was a far less costly option, easier to connect with the rest of the water
529 catch of the city, and works progressed rapidly between 1627 and 1629, eventually
530 providing Along with the investments devoted to expanding the sources of water supply,
531 the city government attempted to improve the efficiency of the existent system. In 1630-
532 1631 it devoted substantial efforts to the conservation and upkeeping of the city pipes,
533 fixing broken sections, and cleaning those that were clogged by earth and trees. During
534 the second half of the 1640s it also invested in the improvement of the city fountains
535 (Voltes Bou, 1967:60; Perelló Ferrer, 1996:127-129). But in moments of great scarcity,
536 the city government would actively police any possible theft of water from the urban
537 supply system and, if needed, impose restrictions to private users. The acute dry
538 conditions experienced during 1627 and early 1628, for instance, forced to cut off water
539 supply to almost all private users in the city (Perelló Ferrer, 1996:126). After suspecting
540 water thefts during the 1640s, in 1644 the city government went as far as approving a

541 search into all the houses close to the main pipe to find where the water leak was or who
542 had illegally drilled into the pipe and set a tap (AS1, chapter 22; Perelló Ferrer
543 1996:128) (see Figures 7 and 8).

544 The proactive attitude of the city government to regulate water use by the institutions
545 and private actors who had access to it created acute tensions with some of them. In
546 1634, the city government's decision to cut water supply to the Cathedral triggered a
547 remarkable confrontation. The Cathedral's Chapter immediately excommunicated the
548 city water officer and the members of the Consell de Cent for offending the property of
549 the Church, causing a great scandal in the city (AS5). The Cathedral proved that its right
550 to water was granted by an agreement with the Consell dated in 1355. The
551 excommunications were lifted the very same year, but despite accepting the Cathedral
552 Chapter's rights, the city government reasserted itself as the "master and owner of the
553 waters that flow to [Barcelona's] fountains" (AS7).

554 Extreme drought did not only cause problems in the city fountains, but also in a
555 significant increase in the waters delivered to Barcelona (Perelló Ferrer 1996: 126-127).
556 According to Sociés, the rich *ganat* of Sant Gervasi was key to keep the supply of the
557 city running during the driest years between 1627 and 1650 (AS1, chapter 65). The city
558 government complemented this intervention with substantial efforts, both in 1630 and
559 1631, for the conservation and upkeep of the city pipes, fixing broken sections and
560 cleaning other clogged by earth and trees (Perelló Ferrer 1996: 127). Lacking support
561 and resources for a major infrastructural work like the Llobregat canal, local authorities
562 focused in improving the efficiency of the existing system.

563 Extreme drought did not only mean an immediate problem for the city fountains, but
564 also for the water mills that milled the grain and produced flour.
565 During dry years, the water level in the irrigation channels was not high enough for the
566 watermills to function. This situation forced the city government to transport the
567 grain to locations farther from the city, thus increasing the associated costs and
568 occasionally jeopardizing the city's flour supply (Simon i Tarrés 1992: 165-169). The
569 unreliability of watermills in dry years was invoked by the city government in their plea
570 to bring the waters of Llobregat river to Barcelona via a water canal. As explained in
571 this document, this in fact, it was the reason why the city government owned two
572 windmills outside the city walls since earlier times (AS2AS3). However, due to the
573 almost absence of dry years since the 1570s, these windmills had been little used and
574 fell into disrepair. In 1628, the Consell de Cent had to request its renovation
575 due to its poor condition. Two along with two new windmills were commissioned the
576 same year, and five more would follow in 1629. Therefore, the Consell city
577 government addressed the unreliability of watermills during dry years with a great
578 expansion of the city windmills, which grew from two to nine (450%) between 1628
579 and 1631 (Perelló Ferrer 1996: 286-288).

580 However, Finally, towards the real challenge was end of the study period (July 8, 1648)
581 the Consell de Cent asked the water city officer to write a book about the city's water
582 supply and the operation of the city's fountains. The Book of Fountains, written during
583 the very lack of grain to be milled dry year of 1650, provides a detailed description of
584 the main pipe supplying the city, each of its branches and sections, along with the
585 buildings receiving water supply and the location of the water conduits and fountains
586 (see Figure 9). The value of the knowledge compiled in the book was regarded as
587 critical, and according to the city government's instructions, it could not leave the city
588 government's grounds (AS2:325-326, 400).



589
590 **Figure 9:** The urban water supply network of Barcelona as described in the *Llibre de les Fonts*. Source:
591 Modified from Guàrdia, 2011.

592
593 The Book of Fountains did not only provide readers with a geography of the water
594 network elements, but also with a calendar for the system's maintenance and key
595 historical information about water property rights and concessions to specific buildings.
596 Moreover, it includes useful information for the reconstruction of the climate of the past.
597 Sociés' account points out the years 1626 and 1627 as the beginning of a long dry
598 period in Barcelona. The first two decades of the 17th century had been a time of water
599 abundance, when the city government supported the expansion of the water distribution
600 system and granted water concessions to several aristocratic houses and monasteries
601 (AS1, chapters 65, 69, 79 and 98). All this came to an end between in 1626-1627. In
602 Sociés own words, "the abundance of waters lasted until the year 1626 (...). Already in
603 the year 1627 came a great drought and in the fountains of the city there was a great
604 lack of water" (AS1, chapter 65). ~~face of the drought impacts~~When writing the book in
605 the summer of 1650, Sociés visited the *qanats* of Nostra Senyora del Coll and pointed
606 out that it was the first time in his life that he saw them dry. After 30 years on his post,
607 Sociés wrote that as years passed by, the flow of water in the city had been decreasing.
608 He underlined the importance of the *qanat* construction he had led in the late 1627-1629
609 to keep water running in Barcelona's fountains during the driest years (AS1, chapter 65).
610

611 **4. Discussion**

612
613 *4.1 Drought stress and political tensions*

614 ~~In this section, we discuss how the unprecedented drought pulse started in 1626-1627~~
615 ~~heightened micro and macropolitical tensions in Barcelona. By looking at three ways in~~
616 ~~which the institutional responses to drought intertwined with urban and political~~
617 ~~conflicts, we shed light on the complex interlinkages between drought, water scarcity,~~
618 ~~food supply and politics at the local and regional agriculture. In a context of diminishing~~
619 ~~grain supplies, the development of an alternative infrastructure to secure the~~
620 ~~transformation of grain into flour avoiding the reliance on water was futile. The scale.~~

621 ~~The impacts of the severe drought of 1627 extended throughout the following years and~~
622 ~~dry period started in 1627 went beyond Barcelona. A very cold winter, with snowstorms~~
623 ~~that killed many fruit trees, was followed by a very dry summer, and critically disrupted~~
624 ~~food supply during the following years. By 1628, a contemporary witness stated; that~~
625 ~~“the dioceses of Barcelona, Tarragona and the plain of Urgell cry of thirst” (Simon i~~
626 ~~Tarrés 1992: 161-162). Between 1628 and 1631, dry years and extreme climate events~~
627 ~~critically affected agriculture in Catalonia, resulting in bad crops and adding new~~
628 ~~tensions to both local and regional conflicts (Simon i Tarrés 1992:158-161). An~~
629 ~~international conjuncture of The diminishing grain supplies could have been~~
630 ~~compensated with imports from southern France and Milan, but war and plague in~~
631 ~~Milan and southern France prevented grain imports from these regions, which could~~
632 ~~have compensated for the local losses. As a result, prices in cities like Girona and~~
633 ~~prevented it. The Barcelona went skyrocketing, and by the beginning of 1631 the supply~~
634 ~~of bread in Barcelona was in a critical situation. city government had boosted the~~
635 ~~construction of windmills to secure the transformation~~
636 ~~in this context, some profited from selling bread that did not comply with the legal~~
637 ~~weight or mixed different types of grain. In into flour when water flows were too little~~
638 ~~(see Figure 7), but often there was simply no grain to be milled. During the spring of~~
639 ~~1631, the protests for the price, scarcity, and bad quality of bread in Barcelona ended up~~
640 ~~in violent riots that directly threatened the very lives of the city government members of~~
641 ~~the city government. In response to this subsistence crisis, the Consell de Cent decided~~
642 ~~to assume assumed full control of bread production, strictly banning any production or~~
643 ~~distribution of bread by other authorities. In an attempt to secure the distribution of~~
644 ~~bread to the population, the Consell de Cent organized institutions, and putting in place~~
645 ~~a centralized, street-by-street rationing system. In the end, a wheat cargo coming from~~
646 ~~Mallorca in May 1631 alleviated the shortage (Simon i Tarrés, 1992). However, the~~
647 ~~strategy of enforcing a centralized rationing system during scenarios of scarcity —or~~
648 ~~whenever these scenarios seemed feasible— remained in use during the following years.~~

649 ~~During 1632 Barcelona experienced again several months without rain (Figure 4).~~
650 ~~Despite the efforts devoted to improve urban water supply sources and take care of the~~
651 ~~maintenance of the infrastructure, this year Barcelona received less than a third of its~~
652 ~~usual water supply (Voltes Bou 1967: 59). This critical situation contributed to a brief~~
653 ~~comeback of the project of a canal from the Llobregat River proposed to the Spanish~~
654 ~~king five years earlier (Perelló Ferrer 1996: 128). The city officers called water supply~~
655 ~~experts to resume the work on the canal and even started marking it on the ground~~
656 ~~(AS3). In 1633 the Consell de Cent decided to go ahead with the project. However, it~~
657 ~~required the permission and Royal Privilege from King Philip IV. This could not come~~
658 ~~at a worse moment, for the 1632 meeting of the king with Catalan representative body,~~

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659 the *Corts*, had repeated the 1626 fiasco. The tensions between the Catalan *Corts* and the
660 King in the years 1626-1632 certainly did not help to bring the Llobregat canal project
661 any closer to fruition. After the city petition, Philip IV consulted the Viceroy of
662 Catalonia as he had done in 1627 (AS4: 137, 154-155). There is no trace of the
663 Viceroy's reply, but some of the aristocratic landowners of the territories where the
664 canal had to be built consistently opposed the project (Voltes Bou 1967: 59-60). After
665 1633 we find few more references to it. Three centuries were still to pass until the
666 waters of Llobregat were channelled to Barcelona (Burgueño, 2008; Sauri, March and
667 Gorostiza, 2014).

668 The very mechanisms established to cope with the subsistence crisis of 1627-1631 in
669 Barcelona intertwined with ongoing power struggles, setting the scene for new conflicts.
670 During 1633 the city government attempted to enforce its control of bread production
671 and distribution, put into practice two years earlier. ~~During 1633 the city government~~
672 ~~attempted to enforce its control of bread production and distribution, put into practice~~
673 ~~two years earlier.~~ The insistent public calls issued to the monasteries and the Cathedral
674 to prevent them from producing and circulating/distributing bread suggest that these
675 regulations were far from followed, ~~and bread was distributed in several stalls in the city~~
676 ~~—not only in those depending from the city government.~~ In this context, on the 4th of
677 January 1634, a representative from the Consell de Cent confiscated a piece of bread
678 that had been produced by the Cathedral. This proved, confirming that this institution
679 was disobeying the city government calls. ~~When the member of the Consell de Cent~~
680 ~~who had confiscated the bread refused to hand in the proof to the Cathedral, this~~
681 ~~institution arrested him and imprisoned him on ecclesiastical grounds from the city~~
682 ~~government (AS5).~~ ~~The~~ The accusations escalated rapidly, and among the reprisals from
683 ~~the city government came immediately in the form of arrests of several persons~~
684 ~~connected to the Cathedral, but also with a different action. The Consell de Cent~~
685 approved, the city government ordered the water officer, Francese Socies, to cut off the
686 water supply to the Cathedral. This decision triggered a dramatic confrontation
687 between scandal which soon went beyond the walls of the city government and the
688 ecclesiastical powers.

689 As previously explained, during of Barcelona. On the first quarter of the 17th century the
690 Consell de Cent basis that they had pursued/offended the property of the Church by
691 cutting the expansion of the urban water network and gave water concessions to
692 different aristocrats and monasteries, while at the same time retaining the right to cut off
693 the water supply if needed. The Cathedral, however, was no ordinary monastery. When
694 Francese Socies carried out the city's orders and water stopped flowing to the
695 ecclesiastical grounds of the Cathedral, the conflict immediately escalated. The water
696 cut lasted only a couple of hours and supply was restored, for the city government
697 seems to have confirmed that an agreement dating back to 1355 granted the Cathedral
698 with the right of water provision. But even if the precious liquid was soon flowing again
699 in the Cathedral's cloister, the offense was not without results. The Cathedral's Chapter
700 immediately excommunicated Francese Socies and flow, the members of the Consell de
701 Cent for offending the property of the Church, causing a great scandal in the city
702 (AS5) and Francese Socies were excommunicated. While it was bread production and
703 distribution, and not water, what had originally been the cause of the dispute, legal
704 rights about water supply and its value in time of drought were at stake. The conflict
705 cannot be interpreted as caused by water scarcity, but the recent experience on the
706 critical value of water in times of severe drought helps explaining the reprisal chosen by
707 the Consell and the virulent response of the Cathedral. By questioning access to water, a

708 quarrel over bread distribution rights transformed into a major legal case leading to the
709 excommunication of the city government officials – including the city water officer.

710 ~~Moreover, the reaction of the city’s government aggravated the offence against the~~
711 ~~Cathedral. Far from accepting the Cathedral’s authority, the Consell de Cent called~~
712 ~~dozens of church doctors and theologians from several monasteries of the city and asked~~
713 ~~them if the excommunication was legal and valid. After deliberating on the matter, these~~
714 ~~experts concluded that the excommunication could be considered invalid due to errors~~
715 ~~in the way it had been carried out – a written statement that the city hastened to make~~
716 ~~public, printing a pamphlet and distributing it widely (AS6).~~

717 ~~The Consell de Cent, even if acknowledging the Cathedral’s rights to water,~~
718 ~~publicly~~The Cathedral’s Chapter soon proved that, unlike many monasteries in the city,
719 its right to receive waters went back as far as 1355, as demonstrated by the documents
720 kept in its archive (AS6 and AS7). Water supply to the Cathedral was restored in a
721 matter of hours. In the legal conflict that followed, even if the Consell acknowledged
722 the Cathedral’s rights to water, it also reasserted its own role as the institution
723 responsible of maintaining and overseeing urban water supply. ~~As put in one of the~~
724 ~~pamphlets published in 1634, the city declared itself “master and owner of the waters~~
725 ~~that flow to its fountains” (AS7). In order to justify the water cut-off, they the city~~
726 ~~government~~ argued that they had not been aware that the Cathedral hold old rights to
727 these waters, ~~and that they immediately restored the service when they realised their~~
728 ~~mistake. Accordingly, the lawyers of the Consell de Cent pointed out that committing a~~
729 ~~sin by ignorance could not justify a punishment as severe as an excommunication (AS7).~~
730 (AS6 and AS7). The Cathedral’s Chapter, on the other side, considered that both the
731 city government and the city water officer had been perfectly aware that waters
732 belonged to the Cathedral, and therefore underlined that the water cut-off had to be
733 considered an aggravated crime against the Church properties –one that was punished
734 with excommunication (AS8).

735 The legal case fell in the hands of the Archbishop of Tarragona, ~~and mutual and was~~
736 discussed in Madrid and Rome. Mutual accusations between the Cathedral and the
737 Consell continued for months, even if the excommunications were provisionally lifted
738 after a few weeks (AS4:205-206). ~~Soon afterwards, major events seem to have taken~~
739 ~~over this quarrel. War broke out between Spain and France in 1635, and Catalan~~
740 ~~territories immediately became a space in dispute. Moreover, the Catalan revolt of 1640~~
741 ~~split the region from the Spanish crown until 1652. Beyond these grand changes,~~
742 ~~however, the daily work to keep the water running to Barcelona remained a challenge –~~
743 ~~and Francesc Socies remained in charge.~~

744 **4. Codifying knowledge about water supply: The Book of Fountains (1650)**

746 ~~The scandal of the excommunication of the Consell de Cent and the city water officer~~
747 ~~came after some of the driest years remembered in Barcelona (1626-1632). The city~~
748 ~~government emerged from the conflict with renovated sensibility about the importance~~
749 ~~of enforcing control over water supply, but also over the very knowledge about water~~
750 ~~concessions, which could help avoiding similar conflicts in the future. In line with the~~
751 ~~declaration that the city was “master and owner of the waters that flow to its fountains”,~~
752 ~~during the following years the city government devoted more and more attention to~~
753 ~~watch out its water resources and remained wary of any violation of its water rights. At~~
754 ~~the same time, it launched an initiative to take over the water knowledge embodied by~~
755 ~~the city water officer.~~

756
757 *4.1 The origins of the Book of Fountains*

758 In 1641 the Barcelona water officer, Francesc Socies, completed his 21st year in his
759 post. It was not without surprises. In December, water stopped flowing to the fountain
760 of Sant Joan. Despite all efforts, it was impossible to determine the cause, and when the
761 water flow resumed after two months, it left Socies puzzled. When this repeated next
762 year around the same dates, the water officer was convinced that someone was illegally
763 tapping into the network. During the following years, the water loss in the fountain of
764 Sant Joan became one of Socies' main headaches. His inability to find the reason behind
765 it compromised his authority in front of the Consell. This problem may have been not so
766 serious had it not been accompanied by another long repetition of dry years. But the
767 extreme weather suffered throughout Spain in 1640-1643 (Parker 2013: 289), followed
768 in Barcelona by several dry years in a row (1643 to 1651, see Figure 4), made it more
769 pressing.

770 In 1644, the city government went as far as approving a search into all the houses close
771 to the main pipe to find where the water leak was or who had illegally drilled into the
772 pipe and set a tap. It even offered rewards in exchange for information, but all attempts
773 to find out the cause of water loss proved fruitless. Eventually, in 1647, Socies was
774 ordered to remake the whole sector of the pipeline that supplied the fountain, connecting
775 it to another branch of the distribution system (AS1, chapter 22; Perelló Ferrer
776 1996:128). These efforts to enforce control of water distribution came hand in hand
777 with initiatives to expand the water sources of the city supply system. During the second
778 half of the 1640s the Consell de Cent approved the construction of a new *ganat* in
779 Pedralbes, while also devoting funds to the improvement of the city fountains (Perelló
780 Ferrer 1996:129). Crucially, however, the Consell lacked a detailed knowledge of the
781 water system and therefore depended on the city water officer for carrying out almost
782 any change or improvement to the water supply and distribution infrastructure. The
783 persistent droughts of these years only made this circumstance more evident. Francesc
784 Socies was aging with no successor in sight. In this context, during the summer of 1648
785 the city government decided to put forward a proposal to him:

786 Traditionally, when approaching retirement, it was the city water officer who would ask
787 the city government to perform his duties accompanied with an assistant—usually his
788 son or son-in-law. After working together several years—receiving only one salary—
789 the apprentice would then replace the city water officer in his post (Perelló Ferrer
790 1996:77). This father-to-son tradition kept knowledge in the hands of city water officers'
791 families and away from the Consell de Cent, which therefore remained fully dependant
792 on him. Francesc Socies, however, had no direct relatives to work with. His son was a
793 monk in Montserrat monastery, and his two sons-in-law already had their own
794 profession.

795 Perhaps taking advantage of Socies' situation and his questioned authority after the
796 unresolved water thefts, this time it was the Consell de Cent that took the initiative. On
797 July 8, 1648, after a significantly dry spring (see Figure 4), it formally required Socies
798 to write a book about the city water supply and the operation of the city's fountains.
799 According to the Consell's instructions, the book would remain perpetually in the city
800 government's grounds, "for the clarity of [the officer's] successors in his post";
801 therefore showing an explicit intention of appropriating the knowledge inherently
802 associated to the water officer's job post and codifying it for future uses, always under
803 the Consell's control. The manifest objective of keeping the proposed book in the

804 ~~Consell's grounds also made clear another aim of the city government: to reinforce its~~
805 ~~position as the only institution managing and owning water in the city, and therefore to~~
806 ~~reaffirm its capacity to use water as a tool to control urban space (AS9:325-326). The~~
807 ~~writing of a book about the city waters, kept by the Consell de Cent, was fully in line~~
808 ~~with the statement made in 1634. In terms of water property and rights, writing was an~~
809 ~~instrumental juridical tool for the city government to reassert itself as the "master and~~
810 ~~owner of the waters that flow to [Barcelona] fountains".~~

811 ~~Moreover, from the perspective of the Consell, water knowledge was also key to attain a~~
812 ~~more efficient and less costly daily management of water supply. The proposed book,~~
813 ~~according to the Consell's proposal, should result in great benefit of the fountains and~~
814 ~~would reduce the expenditure they required, since it would facilitate finding out about~~
815 ~~any problem they could suffer (AS9:325-326). After all, aside from his regular salary to~~
816 ~~maintain the water distribution system, the city water officer had to be paid for each~~
817 ~~specific work he carried out. Considering the troubled decades of 1620-1650, the~~
818 ~~Consell's attempt to appropriate the city water officer's knowledge can also be~~
819 ~~interpreted as an attempt to anticipate future difficulties by codifying the knowledge of~~
820 ~~the past—in other words, by developing tools for future generations to cope with the~~
821 ~~variability of the climate and its impact into the water supply and distribution network~~
822 ~~of the city.~~

823 ~~Francese Socies took two years to provide a formal answer. In September 1650, amid a~~
824 ~~very severe drought (see Figure 4), he finally offered to write the proposed book, under~~
825 ~~one condition. In exchange for it, he demanded to receive a salary until the end of his~~
826 ~~life, whether he was working or not. On September 6, 1650, the Consell accepted Socies'~~
827 ~~offer, highlighting that the water officer had been more than three decades at the service~~
828 ~~of the city and stating that payments would start as soon as the book was delivered~~
829 ~~(AS9:325-326). In fact, Socies had started to write what would later be known as the~~
830 ~~*Llibre de les Fonts* ("Book of Fountains") at least two months earlier, in July 1650. In~~
831 ~~his writing, Francese Socies went over the water geography of the city, but also~~
832 ~~revisited more than thirty years of Barcelona's water supply history.~~

834 *4.2 Structure and contents of the Book of Fountains*

835 ~~The Book of Fountains adopts the form of a manual about urban water supply, a text~~
836 ~~where Socies provides instructions that codify both the knowledge of his profession and~~
837 ~~the experience of his job position, aimed at guiding future interventions in the supply~~
838 ~~system and communicating what new workers will need to know. Its elaboration~~
839 ~~Finally, among the diverse range of strategies launched by the city government in these years~~
840 ~~(see Figure 7) one stands out for its ambition and scale: the project to build a canal~~
841 ~~bringing the waters of Llobregat river to Barcelona. Launched as soon as 1627, the~~
842 ~~project harmed the interests of aristocratic landowners, who opposed it consistently. The~~
843 ~~petition reached King Philip IV in the aftermath of his meeting with the representative~~
844 ~~body of Catalonia (*Corts*), held in 1626, where the King's proposal to raise an economic~~
845 ~~and human contribution from Catalonia to support the Spanish army had failed (Elliott,~~
846 ~~1984). The situation repeated a few years later, in 1632, when the impact of drought in~~
847 ~~food supply had been felt and Barcelona received less than a third of its usual water~~
848 ~~supply (Voltes Bou 1967:59). The conversation about the project was resumed around~~
849 ~~the time of a new fiasco at the meeting of the Catalan *Corts* with the King. The~~
850 ~~permission and Royal Privilege from King Philip IV were never obtained, and the~~
851 ~~project came to nothing despite the advanced preparations carried out by the Consell de~~

852 Cent (Perelló Ferrer, 1996:127-128). Three centuries were still to pass until the waters
853 of Llobregat were channelled to Barcelona (Burgueño, 2008; Tello and Ostos, 2012;
854 Saurí, March and Gorostiza, 2014). Lacking the political support and the resources
855 needed for a major infrastructural work like the Llobregat canal, local authorities
856 focused in alternative, less expensive options, such as improving the efficiency of the
857 water supply system and expanding the already existing network of *qanats*, among other
858 (see Figure 7). While these works increased urban water flows, they provided a
859 precarious equilibrium in time of recurrent drought.

860 861 *4.2 Knowledge transmission and adaptation*

862 Under the light of the troubled decades of 1620-1650 for water supply, we interpret the
863 efforts of the city government to codify water knowledge into a book as an attempt to
864 anticipate future difficulties by collecting the knowledge of the past. In other words, the
865 Book of Fountains represents an effort to develop tools for future generations to cope
866 with the impact of water stress into the urban water supply infrastructure.

867 The city government's petition to Sociés took place during the summer of 1648, after a
868 significantly dry spring and five years of recurrent droughts (see Figure 6). During these
869 years, the water stress suffered in the city made any suspected water theft a critical
870 matter. The aggressive attitude demonstrated by the city authorities in policing water
871 thefts between 1643 and 1648 (see Figure 8) marks an increased awareness of the
872 importance of controlling urban water infrastructure (see the following section). The
873 need to expand urban water flows also involved investments in new *qanats* and
874 extraordinary funds for the maintenance of the supply network (see Figure 8). All these
875 works required additional expenditures, since the salary paid to the water city officer
876 included only maintenance tasks. Accordingly, the city government considered that with
877 the assistance of a book compiling urban water knowledge the expenditure related to
878 city fountains would be lowered, therefore improving urban water management. The
879 economic reasons to write the Book of Fountains were explicitly mentioned in the
880 petition directed to Francesc Sociés (AS2:325-326).

881 The city government lacked knowledge about urban water infrastructure and fully
882 depended on the water city officer. The severe impact of droughts during the 1630s and
883 1640s only made these circumstances more evident. By the late 1640s, the city water
884 officer was aging with no successor in sight. His precious knowledge, involving almost
885 three decades of working with urban water infrastructure, risked being lost. In this
886 context, the city government saw an opportunity to intervene in the process of
887 knowledge transmission by putting forward a proposal to write a book. Only during the
888 dry year of 1650 did Francesc Sociés accept this demand, in exchange of receiving a
889 salary until the end of his life (AS9:325-326). The Book of Fountains was written
890 during the continuously dry months of 1650 (see Figure 6) which caused the loss of the
891 harvest and made the year be known as "the year of misery" (Guàrdia, Pladevall i Font
892 and Simon i Tarrés, 1986:105). Perhaps key to his decision to accept writing the Book
893 of Fountains, the water officer had no direct relatives to whom pass on his knowledge
894 and job post.

895 Traditionally, when approaching retirement, it was the city water officer who would ask
896 the city government for permission to perform his duties accompanied with an assistant
897 – usually his son or son-in-law. After working together several years – receiving only
898 one salary – the apprentice would then replace the city water officer in his post (Perelló
899 Ferrer 1996:77). This father-to-son tradition of knowledge transmission was common

900 within guilds' structures, where family and the family house were units of production
901 (for the Catalan context, see for instance Creixell i Cabeza, 2008; Solá, 2008). Within
902 this context, knowledge about professions was transmitted to direct family and to
903 apprentices. Therefore, knowledge transmission combined a type of oblique
904 transmission (teacher to pupil) with a vertical type (father to son, uncle to nephew)
905 (Leonti, 2011). This mechanism of transmission could sometimes involve the creation
906 of dynasties of the same families in the same job post, keeping knowledge away from
907 the city government (Montaner i Martorell, 1990:177).

908 By requiring Sociés to write a book compiling his knowledge, the city government
909 aimed at interceding in the circuit of knowledge transmission and appropriating the
910 water city officer knowledge. In other words, it aimed at putting oblique knowledge
911 transmission under institutional control. The elaboration of the Book of Fountains shall
912 be contextualised within the emergence of technical and practical manuals to transmit
913 knowledge (Eamon, 1994; Long, 2001; Cifuentes i Comamala, 2006). The water
914 distribution system is described as an interconnected network, from the drainage
915 underground channels in the hills of Barcelona known as "water mines" (*ganats*) to the
916 city fountains. Water supply is conceived as part of a human system, where urban
917 elements are interdependent (if water is cut in one section, other sections will be left
918 unsupplied). This network is examined and described both technologically and socially.
919 The knowledge that the city water officer pours into the book is a thorough technical
920 description of the journey followed by water through the city, indicating with high
921 precision where each element is located, both for those visible and those hidden from
922 view, underground or behind walls (water taps, pipes, water tanks or wells).The
923 knowledge recorded in these manuals, however, was not meant to be made "public" in
924 the modern sense. In the case of the Book of Fountains, water knowledge could not be
925 disseminated for the sake of the institutions' own interests and for security reasons. The
926 process of knowledge transmission revealed critical details about the location of water
927 infrastructure, potentially subject to attack or disruption. Secrecy around infrastructure
928 was strategic for the survival of the city, both for external circumstances – the 1630s
929 and 1640s were marked by war and the threat of siege – and internal struggles with
930 other city institutions such as the Cathedral's Chapter. The strategic value of this
931 knowledge explains the city government's instructions, which established that the book
932 should remain perpetually in the city government's premises. This also showed an
933 explicit intention of appropriating the knowledge inherently associated to the water
934 officer's job post, restricting the access to it to those authorised by the city government.

935 The Book of Fountains is a knowledge manual but was also conceived as a tool to be
936 used. When referring to specific places in the city, the author often establishes
937 the Book of Fountains was about compiling the knowledge of the past, but also about
938 creating an object that could collect future information. Francesc Sociés demanded the
939 involvement of his readers –future water city officers– to ensure that the book remained
940 a useful tool. He required them to record at the margins of the text any intervention in
941 the water network, thus keeping knowledge to date for future generations (AS1:262).
942 By involving future water officers into the authorship, the book aimed at becoming a
943 transgenerational endeavour, a collective heritage under the control of the city
944 government. In this way it became useful for the present as a physical object, but also a
945 perdurable, vital tool for the city's future. By obtaining a book that transmitted
946 knowledge to future managers, the city government aimed at improving the institutional
947 capacity for adaptation to future environmental stress.

949 4.3 Enforcing control over water infrastructure

950 The scandal of the excommunication of the Consell de Cent and the city water officer
951 after the water cut-off to the Cathedral in 1634 came after some of the driest years
952 remembered in Barcelona (see Figures 4, 5 and 6). The city government emerged from
953 the conflict with renewed awareness about the importance of enforcing control over
954 water supply, but also of monitoring information about water concessions and water
955 rights, which could help avoiding similar conflicts in the future. In line with the
956 declaration that the city was “master and owner of the waters that flow to its fountains”,
957 during the following years the city government devoted more and more attention to
958 watch out its water resources and remained wary of any violation of its water rights.

959 The production of the Book of Fountains was in line with this behaviour. The ambition
960 to elaborate a book containing urban water knowledge and the explicit requirement that
961 it should be kept in the city government’s grounds made clear the Consell’s
962 determination to reinforce its position as the institution responsible for water
963 management in the city, and therefore to reaffirm its capacity to use water as a tool to
964 control urban space (AS2:325-326). In other words, enhancing the city government’s
965 control over water flows was also one of the goals behind the codification of water
966 knowledge. Elaborating the Book of Fountains meant creating a valuable tool to enforce
967 control over urban water flows and infrastructure. In terms of water property and rights,
968 writing was an instrumental juridical tool for the city government to reassert itself as the
969 “master and owner of the waters that flow to [Barcelona] fountains”, fully in line with
970 the statement made during the conflict with the Cathedral’s Chapter in 1634 (AS7).

971 With his writing the water city officer established the water’s urban journey from source
972 to tap, defining who the proprietor of this knowledge was and institutionalizing who had
973 the power to control it. When referring to specific places in the city, he often established
974 a symbolic relation between the written text and the urban fabric. Text and territory
975 become inseparable, and as a connector, the author ~~uses~~ used a figure —the cross—
976 sometimes in the text but more often in its margins, making its location faster to readers.
977 These crosses written in the ~~text~~book refer to crosses chiselled in the stone walls of the
978 street buildings, indicating specific elements of water infrastructure hidden from view
979 and thus binding the book pages with the urban fabric of the city. In other words: the
980 author ~~inscribes~~ inscribed water urban geography into the pages of the Book of
981 Fountains— (see Figure 10).

982 As both a manual and a tool, the Book of Fountains does not only provide readers with
983 a geography of the water network elements, but also with a calendar for the system’s
984 maintenance. Instructions are provided within a particular urban space and time.

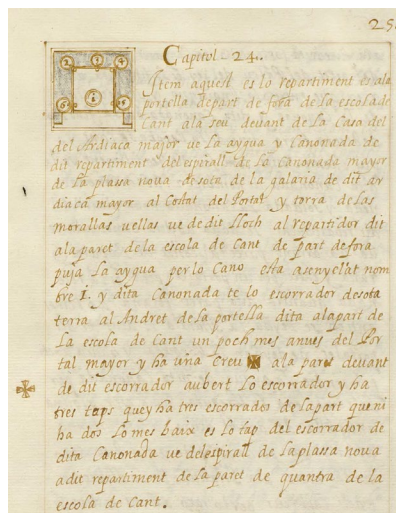


Figure 10: Book of Fountains, chapter 24. On the lower left side, a cross marks a reference for the reader. The text refers to the location of the same cross in the urban fabric. Source: *Llibre de les Fonts*, Manuscrits, L-15, Arxiu Històric de la Ciutat de Barcelona (AHCB).

This intention of controlling urban space, based on the need of preserving water supply, was also explicit. Socies specifies where to intervene and how often, for instance in relation to the cleaning of pipes and curtailing the growth of trees' roots that can disrupt sections of the system (e.g. every two, four or five years). Nevertheless, Socies' temporal specifications do not only apply to maintenance, but also to key historical information about water property rights. While writing the book, Socies visited the city archive and consulted the Consell's meeting proceedings in order to record the water right concessions to several monasteries, dating from 1611. He left a clear reference to where these legal documents could be found. Similarly, he visited the archive of the Cathedral's Chapter, providing detailed information about the old pipes underground the building and reminding future readers about the agreement between the Cathedral and the city government, dating from 1355, which granted the Cathedral the ownership of the waters flowing to it (AS1, chapters 26 and 56). In other words, he recorded this information for the future city water managers, setting the basis to prevent conflicts such as the one occurred in 1634.

Additionally, in order to ensure that the Book of Fountains remained a useful tool, Socies demanded the involvement of his readers — the future city water officers. Socies asked them to use the book, recording any intervention in the water network in the margins of the text, and therefore keeping knowledge to date for future generations (AS1:262). By involving future water officers into the authorship in a transgenerational endeavour, the book aimed at becoming collective heritage. In this way it became useful for the present as a physical object, but more than that, a perdurable, indispensable tool for the city's future. The transmission of knowledge to the future became a tool to manage risks affecting the city water supply.

Starting at the main water tank distributor of Barcelona, outside the city walls, the Book of Fountains provides a detailed description of the main pipe supplying the city, each of its branches and sections, along with the buildings receiving water supply and the

Con formato: Espacio Después: 0 pto, Interlineado: sencillo

1017 location of the very water conduits. Later in the text, Socies turns his attention to the
1018 “water mines” (*ganats*) in the hills of the city. Therefore, with his writing the water city
1019 officer establishes the water’s urban journey from source to tap, fixing and at the same
1020 time defining who the proprietor of this knowledge is, and institutionalizing who has the
1021 power to control it. This intention of controlling urban space, based on the need of
1022 preserving water supply, it is well apparent in Socies’ instructions to future managers.
1023 In order to keep a regular water flow running in the city’s fountains, the city
1024 government ~~needs~~needed to be able to detect and solve any incident rapidly, particularly
1025 in relation to water thefts. To this end, Socies ~~narrates~~explained how he ~~has~~had been
1026 remaking the water network that ~~runs~~run through internal parts of buildings, moving it
1027 to their external sections, in order to hinder any attempt to illegally tap into the water
1028 network. He ~~recommends~~recommended continuing with these reforms in ~~order~~the future,
1029 to put the network as ~~close~~much as possible ~~to the~~under control of the water city officer
1030 and ~~the city government~~make surveillance simpler (AS1, chapters 26, 78 and 79).

Con formato: Fuente: Negrita

1031 ~~Among the detailed knowledge demonstrated, Socies also provided his testimony on the~~
1032 ~~state of water supply during the summer of 1650, when he was writing the Book of~~
1033 ~~Fountains. In July 1650, when he started the book, the dry spell in Barcelona was~~
1034 ~~already ongoing, with *pro pluvia* rogations in the streets since April (see Figure 4).~~
1035 ~~Exploring the *ganats* of Nostra Senyora del Coll, Socies pointed out that it was the first~~
1036 ~~time in his life that he saw them dry, and commented that as years passed by, the flow~~
1037 ~~of water in the city had been decreasing. He specifically pointed to the years 1626–1627~~
1038 ~~as the moment when this “lack of waters” had started, and underlined the importance of~~
1039 ~~the Sant Gervasi *ganat*, whose construction he had led in the late 1620s, to keep~~
1040 ~~Barcelona supplied in these dry years (AS1, chapter 65).~~

1041 ~~Likewise, throughout the book Francese Socies reminded readers of the many works~~
1042 ~~and improvements he carried out in the water network and the date when they took~~
1043 ~~place. Writing provided social and historical prestige, and the Book of Fountains not~~
1044 ~~only institutionalized the control of the city government over water, but also qualified~~
1045 ~~Francese Socies as the water expert of his epoch. In this regard, the book has a similar~~
1046 ~~function to that which institutional chronicles had at the time, authored by the political~~
1047 ~~institutions of Catalonia (Simon i Tarrés, 2005). Moreover, in relation to the water~~
1048 ~~officer, the prestige associated with authorship of the Book of Fountains could~~
1049 ~~overshadow his compromised position in relation to the unresolved 1640s water thefts~~
1050 ~~and perhaps the scandalous 1634 excommunication.~~

1051 ~~The dry summer of 1650 eventually caused the loss of the harvest and made the year~~
1052 ~~known as “the year of misery” (Guardia, Pladevall i Font and Simon i Tarrés, 1986:105).~~
1053 ~~However, rains finally arrived in mid-October, a few days after the Consell organized a~~
1054 ~~major *pro pluvia* rogation. A week of rain saved the sowing and was celebrated with a~~
1055 ~~*Te Deum Laudamus* at the Cathedral on October 23. Socies probably finished the Book~~
1056 ~~of Fountains around the time. On November 14, 1650, he walked into the meeting of the~~
1057 ~~Consell de Cent and made a ceremonious presentation of the Book of Fountains~~
1058 ~~(AS9:400).~~

1059 1060 **5. Conclusions**

1061 This article has examined the human response to drought in the city of Barcelona
1062 (Western Mediterranean) during the years 1620–1650. After establishing the regional
1063 significance of drought in the Western Mediterranean during 1620–1640 with literature
1064 on climate history relying on ecological proxies (Nicault *et al.*, 2008), in the first part of

1065 the article we analysed the historical climatology of Catalonia and Barcelona drawing
1066 on *pro pluvia* rogations as documentary proxy data. This analysis has identified two
1067 main periods of drought in the city (1625–1635 and the 1640s) as the most significant
1068 drought events of the period 1521–1825 (highest Drought Frequency Weighted Index of
1069 the series).

1070 Building on this, the main part of the paper has explored the institutional strategies
1071 deployed by the city government in response to severe drought between 1626 to 1650.
1072 A key determinant to this analysis is the long period without significant droughts
1073 immediately before these years (1570–1620). Several sources point to an expansion of
1074 the urban water supply and the water concessions granted by the Barcelona city
1075 government during the first quarter of the 17th century. Both rain rogations, the
1076 testimony of the city water officer and printed sources confirm that these times of
1077 abundance finished in 1626–1627. During the following five years, drought and general
1078 climate variability, combined with the international context of war and plague in Milan
1079 contributed to produce a supply crisis in Barcelona, where riots for bread took place in
1080 1631. During these years, water scarcity was felt both in the city fountains and the
1081 watermills, which in some occasions could not mill the grain. The city government
1082 launched several initiatives to alleviate the problems caused by water scarcity. Large
1083 infrastructural projects such as the Llobregat water canal failed due to the lack of
1084 financial and political support. This failure privileged other, softer measures of
1085 adaptation: the expansion of water supply sources in the hills near Barcelona, the
1086 investments to maintain and clean the city pipes, or a great expansion of windmills as an
1087 alternative to mill grain not depending on water.

1088 In this context of water scarcity, tensions around water availability increased. One of the
1089 loudest public conflicts of the period was related to water and confronted the city
1090 government and the Barcelona Cathedral in early 1634. As proven by drought
1091 reconstruction, the conflict broke out after several dry years (1627–1632), but no direct
1092 causality can be established between drought and social conflict. After the 1626–1627
1093 drought and the climate variability that contributed to the supply crisis and the 1631
1094 riots in Barcelona, the city government had introduced a centralized rationing system
1095 for the distribution of bread. Even if the shortage was over by 1633, the system
1096 remained in use and the city government continued to enforce it. It is the power to
1097 produce and distribute bread that originally sparked the conflict with the Cathedral.
1098 Cutting off water supply was one of the reprisals carried out by the Consell against the
1099 Cathedral—and certainly one that had scandalous consequences and developed its own
1100 course. But it was not the cause of the conflict. Nonetheless, the severe drought
1101 experienced the previous years and the diminished flow of water available in the city's
1102 pipes made water a handy weapon to use. So while we cannot interpret the 1634
1103 confrontation as caused by water scarcity, the impact of drought in water supply
1104 certainly helps explaining how the precious liquid became a weapon, transforming a
1105 quarrel over bread distribution rights into a major legal case leading to the
1106 excommunication of the city government officials—including the city water officer.

1107 Beyond this, the relevance of the 1634 conflict for water management during the
1108 following years is twofold. First, it illustrated the ambiguities and difficulties of the city
1109 government when dealing with water concessions. The Consell de Cent rapidly
1110 acknowledged it had committed a mistake when cutting off water supply, because the
1111 agreement between both institutions to guarantee the water flows to the Cathedral dated
1112 back to 1355. Regardless of the political intentions of the city government, the existence
1113 of diverse agreements, contracts and water concessions between the city and other

1114 ~~institutions—signed in past times, when water supply was more abundant—justified the~~
1115 ~~codification of water knowledge into a unique book/tool. This article examined past~~
1116 ~~climate variability in the city of Barcelona (Western Mediterranean) engaging both in~~
1117 ~~drought reconstruction and institutional responses to it. First, drawing on *pro pluvia*~~
1118 ~~rogations as documentary proxy data, we have provided a detailed reconstruction of~~
1119 ~~drought frequency and duration between the years 1521 and 1825. The years 1625-1635~~
1120 ~~register the highest drought frequency weighted index of the series (Figure 4), while the~~
1121 ~~1640s stand out in the drought duration index (Figure 5). Second, we have examined the~~
1122 ~~institutional strategies launched by the city government in response to drought during~~
1123 ~~the period identified as most relevant (1626 to 1650). Among other, these involved new~~
1124 ~~water supply infrastructure, enhanced efforts in system maintenance, and the elaboration~~
1125 ~~of a book compiling urban water knowledge. We discussed these measures taking into~~
1126 ~~account the complex interlinkages of drought with food supply and political conflict.~~

1127 ~~By focusing on the historical analysis of drought in Barcelona, our research~~
1128 ~~corroborates and expands previous work about that had identified a dry period in the~~
1129 ~~Western Mediterranean between 1620-1640 (Martín-Vide and Barriendos, 1995;~~
1130 ~~Nicault *et al.*, 2008). Moreover, by providing insights about the strategies implemented~~
1131 ~~by a major city of 40,000 inhabitants to confront a severely dry period, we expand the~~
1132 ~~work on human response and adaptation to drought (Grau-Satorras *et al.*, 2018). Among~~
1133 ~~these strategies, the codification of urban water knowledge stands out for its novelty.~~
1134 ~~Finally, by showing how the information collected in the Book of Fountains can be used~~
1135 ~~both for reconstructing past drought events and examining institutional adaptation, we~~
1136 ~~argue that manuals of urban water management are rare but valuable documentary~~
1137 ~~sources to be considered in the field of historical climatology.~~

1138 ~~Written in 1650, right at the end of the most significant drought period identified in~~
1139 ~~Barcelona between 1521 and 1825, the Book of Fountains offers an authoritative voice~~
1140 ~~on the perception of urban water flows: that of the city officer in charge and his thirty~~
1141 ~~years of experience. His assessments of the severity of drought during the years 1626-~~
1142 ~~1627 or the summer of 1650 correspond with the results of the analysis of *pro pluvia*~~
1143 ~~rogations. This cross-check reinforces the authority of both documentary sources used~~
1144 ~~in our research. In essence, the Book of Fountains constitutes a mechanism to transmit~~
1145 ~~and preserve key knowledge to cope better with environmental stress. In a context~~
1146 ~~marked by drought and diminishing urban water flows, the Book of Fountains was a~~
1147 ~~complex form of adaptation directed at improving the efficiency of urban water~~
1148 ~~management systematising historical information about repairs and maintenance,~~
1149 ~~reducing expenditure and preventing conflicts about water rights. In order to prepare for~~
1150 ~~an uncertain future, water knowledge had to be taken from a specific family line or~~
1151 ~~profession and codified into a book under the control of the city government.~~

1152 ~~From this perspective, the Book of Fountains can be interpreted as an outcome of the~~
1153 ~~institutional learning of the most severe drought period experienced in Barcelona~~
1154 ~~between 1521 and 1825, and as a tool to prevent similar conflicts such as the one~~
1155 ~~sustained with the Cathedral. In addition, from a political perspective, the 1634 conflict~~
1156 ~~only three decades of coping with severe water stress. Years of local and regional~~
1157 ~~tensions reinforced the city government’s legal claims over the management of urban~~
1158 ~~water supply. In a coherent step to reassert the legal discussion following the~~
1159 ~~conflict, position of the Consell de Cent declared itself as the “master and owner of the~~
1160 ~~waters that flow to [Barcelona] fountains”. A coherent step to reassert these claims” was~~
1161 ~~to codify knowledge about urban water rights, water distribution and maintenance into a~~
1162 ~~book. On top of this, as previously discussed, the contract to produce the Book of~~

1163 ~~Fountains underlined its critical value and banned the removal of the book from the city~~
1164 ~~government's premises. On its own, the Book of Fountains is a technical manual~~
1165 ~~describing urban water supply. But its contextualisation within the social conflicts and~~
1166 ~~historical climatology of the period points to its unequivocal political character.~~
1167 ~~Crucially, this is only possible by combining several documentary sources, since the~~
1168 ~~author of the Book of Fountains follows a descriptive pattern with a neutral tone,~~
1169 ~~making no explicit political claims on water.~~

1170 ~~In conclusion, the appropriation of the city water officer's knowledge by the Consell de~~
1171 ~~Cent, legally binding the resulting Book of Fountains and the knowledge it embodies to~~
1172 ~~the city's premises, can be interpreted as an adaptation strategy and an attempt to make~~
1173 ~~the water supply system more efficient in a context of frequent and severe drought.~~
1174 ~~Anticipating the future is required in order to adapt to variability, and the codification of~~
1175 ~~knowledge aims at taking it from a specific family line or profession, to use it for the~~
1176 ~~common good of the city. It is a "public" effort to overcome the private transmission of~~
1177 ~~information from father to son and use it for the common future good, but also a~~
1178 ~~reinforcement of the authority of the city government in relation to a precious resource~~
1179 ~~in times of drought: water. The, more than ever, the knowledge collected in the Book of~~
1180 ~~Fountains has the potential to make the functioning of the urban water supply more~~
1181 ~~efficient, avoiding conflicts and reducing expenditure. Hence the key call to involve~~
1182 ~~future water city officers in updating the Book of Fountains, aiming at the creation of a~~
1183 ~~transgenerational tool to cope with future risks associated with urban water supply.~~

1184 ~~Last but not least, the Book of Fountains is also useful as a source for historical~~
1185 ~~climatology. Not only it originates during the most significant drought period identified~~
1186 ~~in Barcelona between 1521-1825, but it provides access to the perception of water flows~~
1187 ~~from a very authoritative voice: about the old qanats, pipes, deposits and fountains that~~
1188 ~~formed the water supply network, together with the centenary water rights that of the~~
1189 ~~local expert on water supply, in office for three decades (1620-1650). Writing in the~~
1190 ~~summer of 1650, during an extreme episode of drought, Francesc Sociés testimony~~
1191 ~~depicts the years 1626-1627 as the beginning of a period of water scarcity in Barcelona.~~
1192 ~~Both references are coherent with the analysis of drought presented in the first part of~~
1193 ~~this article (figures 2, 3 and 4), drawing on pro pluvia rogations as documentary proxy~~
1194 ~~data. Considering the regional extent of the dry period of 1620-1640 in the Western~~
1195 ~~Mediterranean (Nicault et al., 2008), our case study shows the potential of examining~~
1196 ~~human response to drought and water stress from the institutional perspective~~
1197 ~~it, was key to the exercise of political power. A book containing all this information was~~
1198 ~~a treasure that had to be carefully kept for future generations.~~

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1199

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1200 **Author contribution**

1201 Santiago Gorostiza conceived this research with Maria Antònia Martí Escayol and
1202 wrote the introduction, conclusion, and section 3 of the text. He made significant
1203 contributions to the rest of the text. In addition, he handled the coordination, integration,
1204 translation, and revision of texts.

1205 Maria Antònia Martí Escayol conceived this research with Santiago Gorostiza and
1206 wrote section 4 of the text. Martí Escayol transcribed the *Llibre de les Fonts de la*
1207 *Ciutat de Barcelona* and made significant contributions to the introduction, section 3
1208 and conclusions of the text.

1209 Mariano Barriendos prepared the drought series for Catalonia and Barcelona, handled
1210 the database organization, statistical treatment, graphic production, and preparation of
1211 the tables and figures. Barriendos wrote the section 2 of the text.

1212

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1222

1223 **Competing interests**

1224 The authors declare no competing interests.

1225

1226 **Archival sources**

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1228 [AS1] *Llibre de les Fonts*, Manuscrits, L-15, Arxiu Històric de la Ciutat de Barcelona
1229 (AHCB).

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1231 ~~[AS2]~~ [AS2] AHCB, *Deliberacions, Consell de Cent II-159, 1650*.

1232
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Interlineado: sencillo

Con formato: Título 1, Izquierda, Espacio Después: 0 pto,
Interlineado: sencillo

Con formato: Catalán

Con formato: Título 1

1247
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1249 hauido sobre sí los que concurrieron en quitar el agua que sale en las fuentes de los
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