



HAL
open science

Geo-historical analysis of flood impacts in Alpine catchments (HIFAVa database, Arve River, France, 1850–2015)

Eva Boisson, Bruno Wilhelm, Emmanuel Garnier, Alain Mélo, Sandrine Anquetin, Isabelle Ruin

► To cite this version:

Eva Boisson, Bruno Wilhelm, Emmanuel Garnier, Alain Mélo, Sandrine Anquetin, et al.. Geo-historical analysis of flood impacts in Alpine catchments (HIFAVa database, Arve River, France, 1850–2015). EGU (European Geosciences Union), Apr 2021, Online, Austria. 10.5194/nhess-2021-169 . hal-03306885

HAL Id: hal-03306885

<https://hal.science/hal-03306885v1>

Submitted on 29 Jul 2021

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.



1 Geo-historical analysis of flood impacts in Alpine catchments
2 (HIFAVa database, Arve River, France, 1850 – 2015).

3
4 Eva Boisson¹, Bruno Wilhelm¹, Emmanuel Garnier², Alain Mélo³, Sandrine Anquetin¹, Isabelle
5 Ruin¹.

6
7 ¹ University Grenoble Alpes, CNRS, Institut des Géosciences de l'Environnement (IGE),
8 Grenoble, France.

9 ² University Franche-Comté, CNRS, Laboratoire Chrono-environnement (LCE), Besançon,
10 France.

11 ³ AXALP, Annecy, France; associate member at University Savoie Mont-Blanc, CNRS,
12 EDYTEM - UMR 5204, Le Bourget du Lac, France.

13
14 Correspondance to : Eva Boisson (eva.boisson@univ-grenoble-alpes.fr)

15
16
17 **Abstract**

18 In France, flooding is the most common and damaging natural hazard. Due to global warming,
19 it is expected to globally exacerbate, and it could be even more pronounced in the European
20 Alps that warm at a rate twice as high in the Northern Hemisphere. The Alps are densely
21 populated, increasing exposure and vulnerability to flood hazard. To approach long-term
22 evolutions of past flood occurrence and related socio-economic impacts in relation to changes
23 in the flood risk components (i.e. hazard, exposure and vulnerability), the study of historical
24 records is highly relevant.

25 To this aim we analyze the newly constituted database of *Historical Impacts of Floods in the*
26 *Arve Valley* (HIFAVa) located in French Northern Alps and starting in 1850. This database
27 reports for the first-time flood occurrences and impacts in a well-documented Alpine catchment
28 that encompasses both a hydrological and societal diversity.

29 We analyze past impacts in regard to their characteristics and evolution in both time and space.
30 Our results show an increasing occurrence of impacts from 1920 onwards, which is more likely
31 related to indirect source effect and/or increasing exposure of goods and people rather than
32 hydrological changes. The analysis reveals that small mountain streams and particularly
33 glacial streams caused more impacts (67%) than the main river. While increase in heavy
34 rainfall and ice melt are expected to enhance flood hazard in small Alpine catchments, this
35 finding calls to pay a particular attention to flood risk assessment and management in small
36 catchments.

37
38
39 **Keywords** : flood risk, exposure, vulnerability, history, socio-economic impacts, French Alps.

40
41
42
43



44 1. Introduction.

45

46 On the mainland French territory flood is the most common and damaging natural
47 hazard in terms of economic cost and number of municipalities concerned (Ministère de la
48 Transition écologique, 2020). In highland regions, these events can be caused, among others,
49 by summer thunderstorms, rain on thaw saturated soils, rain on snow or glacial lake outburst
50 (Merz and Blöschl, 2003). The topography induces flood events with highly contrasted
51 dynamics; from sudden events with large sediment transport in the upstream small catchments
52 to multi-day events flooding large parts of the valley floor. This diversity of hydrological
53 dynamics adds to the complexity in flood risk management. Furthermore, climate change is
54 expected to increase extreme precipitation (Min et al., 2011) that could in turn increase flooding
55 (Gobiet et al., 2014; Blöschl et al., 2020). This is especially the case for the European Alps
56 where an increase in summer heavy rainfalls (Giorgi et al., 2016; Ménégoz et al., 2020) may
57 threaten densely populated mountainous valley especially exposed and vulnerable to climate
58 extremes (IPCC, 2019). With its long history of flooding, the densely populated Arve valley
59 located in the Northern French Alps is indeed prone to experience the latter effects of global
60 warming in the future.

61 Historical records constitute a source of reliable data to characterize past hydrological
62 events because they contribute to give a comprehensive representation of these events and
63 of their changes over long time scales in spite of the lack of instrumental data (Garnier and
64 Desarthe, 2013; Barriendos et al., 2014; Wetter, 2017; Wilhelm et al., 2019). Impacts are
65 considered as all types of outcomes for humans, society and ecosystems occurring in the
66 aftermath of a physical phenomenon (IPCC, 2012).

67 The historical analysis of past events is useful for the study of catastrophe as we can
68 hypothesize that these remarkable events are etched in the community's memory
69 (Papagiannaki et al., 2013). Indeed, it is because these events have impacted the society that
70 they are recorded in the historical records, i.e. have left a "social signature". Those high impact
71 events can come close to the notion of a catastrophe as they can lead to a societal upheaval
72 (Soanes and Stevenson, 2009) sometimes deleterious but also beneficial (behavioral change
73 promoting prevention) (Garnier, 2017). High impact events are by nature rare, often resulting
74 in a lack of available data (e.g. description of the event, time, extent, damages caused etc.).
75 However, historical approach allows a social and spatio-temporal contextualization of the data
76 (Giacona et al., 2017), making the reconstruction (date, impacts) of major flood events possible
77 (Barriendos et al., 2003, 2019) and attesting the social apprehension of the phenomenon (Gil-
78 Guirado et al., 2016).

79 Numerous historical databases were built to document past flood occurrence and
80 magnitude, such as the Prediflood database (Barriendos et al., 2014), and some, as the
81 database from Thoumas (2019), allow to analyze the climatic fluctuations. In contrast to these
82 latter databases focusing on hydrological events, some databases collected the
83 socioeconomic impacts of floods such as the APAT database (Lastoria et al., 2006), the press
84 database on natural hazards and climate change from Llasat et al. (2009), the database of
85 high-impact weather events in Greece from Papagiannaki et al. (2013), the EUFF database
86 (Petrucci et al., 2019) and the SMC-Flood database (Gil-Guirado et al., 2019). Some
87 databases stand out as the participative flood database ORRION (Giacona et al., 2019) or the
88 database built by the RISC-KIT project (Garnier et al., 2018) which aim to develop methods
89 and management tools and discuss the trajectories of vulnerability.

90 Floods, as natural hazards, are physical phenomena naturally occurring and can, when
91 certain conditions are met, cause harm to societies. They can be interpreted as a social
92 construction (Beck, 1992) since exposure of human activities and social vulnerability play a
93 large role in the severity of the impacts. Flood impacts databases, constituted from historical
94 records, can be considered as the expression of society's concerns, risk perceptions (fear,



95 habit) and values (based on reported impacts). The recording of flood impacts, or the failure
96 to record them, provides a subjective measure of the events that were considered worth
97 reporting for various reasons across historical periods. Flood impacts result from the
98 interaction between the natural phenomenon and the dynamics of exposure and vulnerability.
99 As vulnerability we understand the inclination to damage of various exposed goods, activities
100 or people constituting a given territory (Leone and Vinet, 2006). We consider the vulnerability
101 as a dynamic system articulated to numerous physical and societal factors (Antoine, 2011).
102 This system can evolve in time and space (Cutter, 2003). Major natural disasters, such as
103 floods, are often displayed as unforeseeable events whereas the historical facts give evidence
104 of the contrary (Garnier, 2016, 2019). Yet the society's vulnerability may increase as the past
105 disasters are forgotten, leading to a "society of risk" (Garnier, 2019). Historical approach allows
106 to explore the trajectories of hazard and vulnerability in response to changes in climate, land
107 use and flood risk management (Gil-Guirado et al., 2016).

108

109 The present paper introduces a newly constituted database of flood impacts of the Arve
110 River and its tributaries (Northern French Alps). The database called "*Historical Impacts of*
111 *Floods in the Arve Valley*" (HIFAVa) covers all impacts caused by hydrological events that
112 occurred since 1850.

113 The study of this database, the first one documenting a mountainous catchment, ultimately
114 aims at analyzing the interactions between social and natural dynamics engendering flood
115 impacts. In this paper we analyse the impacts with respect to their nature and evolution in both
116 time and space.

117

118

119 2. Study area: the Arve River.

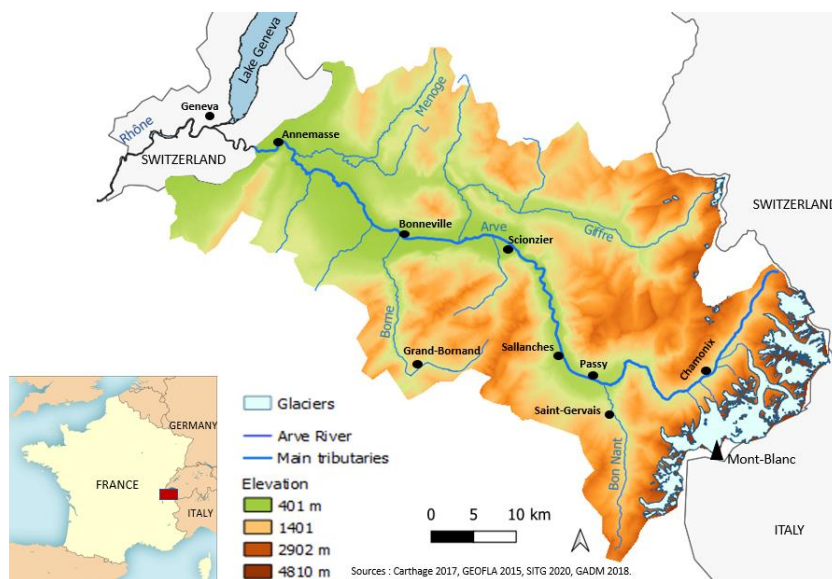
120

121 2.1. Description of the physical setting of the Arve River.

122 The Arve River is located in the Northern French Alps (Figure 1), flowing from the high
123 elevations of the Mont-Blanc summit (4810m a.s.l.) to the Swiss lowlands (330m a.s.l.), where
124 it flows into the Rhône River. The surface area of its catchment is 2164 km² with the largest
125 part higher than 1000m a.s.l.. The main tributaries of the Arve River are the Giffre, the Borne,
126 the Menoge and the Foron Rivers. Since 1850, i.e. the start date of the studied period, the
127 Arve River is already almost completely embanked (Mougin, 1914; Gex, 1924; Peiry and
128 Bravard, 1989).

129 Due to large difference of altitude between high and lowlands, the Arve flows can be defined
130 by two hydrological regimes following an upstream to downstream continuum:

- 131 - The upstream part of the catchment (down to the city of Sallanches; Figure 1), has a
132 glacio-nival regime due to the numerous glacial tributaries flowing from the Mont Blanc
133 massif (Viani et al., 2018). Low flows occur in winter and early spring (December to
134 March) and the high flows in summer (maximum in July and August) because of the
135 strong contribution of ice melting (Bernard, 1900). Floods mainly occur in summer due
136 to the synchronicity of both ice melt and intense subdaily rain storms. In this part of the
137 catchment, the flood plain is narrow and the slope inclination is high.
- 138 - At lower elevations (i.e. downstream Sallanches) the regime becomes more and more
139 nival downward. Low waters mainly occur in winter and reach the highest levels
140 between late spring and early summer with the snowmelt. Between Sallanches and
141 Bonneville, floods mainly occur in summer and autumn due to the conjunction of
142 intense daily rain storm, snow melt and, in a lesser extent, ice melt contribution.
143 Downstream Bonneville, floods occur at any time of the year due to even more various
144 hydro-meteorological interplays. The valley floor is here wide and may be affected by
145 extended flooding.



146

147

Figure 1. The Arve catchment with its location in the Northern French Alps, its topography, its main hydrological network and the main cities.

148

149

150

151

2.2. Socioeconomic setting and land use.

152

There are 106 municipalities located in the Arve catchment, globally facing a major population growth since 1850. For instance, the population has been multiplied by a factor of three in about 170 years at Chamonix (2 304 to 8 611 inhabitants between 1848 and 2016) and by a factor of thirty-four in Annemasse (1 047 to 35 712 inhabitants between 1848 and 2017) (INSEE, 2019). These numbers also hide large seasonal variations related to tourism activities. This is particularly the case in Chamonix where the number of residents increases up to ten times in high season. Most inhabitants live in the valley floor and the foothills that also welcome most of the farming, industrial and tourism activities as well as the main transportation routes and urban areas. Since 1965 and the opening of the Mont-Blanc Tunnel Highway the Arve valley is a major trans-Alpine route connecting France and Italy.

162

The socioeconomic setting of the valley follows an upstream-downstream distribution pattern. The period from 1850 to 1913 experienced a great touristic development (thermal bath of Saint-Gervais and mountaineering in Chamonix). The economy around Chamonix is essentially based on mountain tourism. In 1921, 250000 tourists were visiting Chamonix each year (Gex, 1924). In 2015 the lodging capacity in the valley reached around 416400 equivalent touristic beds. This part of the valley has undergone a rapid urbanization. In 1804, the discovery and exploitation of spring water for hydrotherapy in Saint-Gervais (Gex, 1924) fostered the construction of touristic accommodations. Around Bonneville, the valley is a densely populated corridor characterized by an old bar turning industry, born from the watch manufacture and nearby hydropower resources. The small valleys of the Arve tributaries are sparsely populated and the economy is based on tourism and farming. Due to the attractiveness of the city of Geneva, the valley from Bonneville to the Rhône River confluence is characterized from the 1960's by a major population growth, extended industrial areas and strong urbanization. Between the town of Cluses and Geneva the valley floor is almost continuously built-up.

176

177



178
179
180
181
182
183
184
185
186
187
188
189
190
191
192
193
194
195
196
197
198
199
200
201
202
203
204
205
206
207
208
209
210
211
212
213
214
215
216
217
218
219
220
221
222
223
224
225
226
227

3. Material and methods of the HIFAVa database.

3.1. Collecting data from historical archives.

A first historical study has been carried out to draw a flood chronicle of the Arve valley between the 18th and the 21th century, with a particular focus on the hydro-meteorological circumstances of the flood events (Mélo et al., 2015). As sources are more abundant over the last 165 years (1850-2015), this period was defined as the studied time frame of the HIFAVa database. Only events mentioned in at least two sources were integrated in the database. Since 2015, data have been further collected to complete the preliminary dataset from Mélo et al. (2015).

Information on floods and related impacts has been collected from various sources. Primary sources range from handwritten archives like municipal acts to departmental archives (e.g. reports of the *Préfecture* and of town councils). Secondary and tertiary sources are respectively made of published documents (newspapers, reports, books) and pre-existing databases. The database of historical records providing a chronological and synthetic layout of the data is composed of (Table A1):

Manuscript materials:

- Most of the manuscripts are kept in the departemental archives (*Archives Départementales de Haute-Savoie*: ADHS) (Conseil départemental de la Haute-Savoie, n.d.) or in the municipal archives (*Archives municipales*: AM) of the towns of Chamonix, Cluses and Bonneville. The departmental and municipal archives also contain records older than the Savoy annexation by France in 1860. The records can be private or from a public institution.

Printed materials:

- Articles of scientific journal and books used in this study have been published since 1914. They mostly correspond to analyses of the regional hydrology (Mougin, 1914; Rousset-Mestrallet, 1986) but they can also focus on single hydrological events (Pardé 1931; Rougier 2002; Goy 2002) and risk assessment (Douvinet et al., 2011).
- Open-access online municipal risk prevention plans (*Plan de Prévention des Risques*: PPR; and *Plan de Prévention du Risque Inondation*: PPRi) (Préfecture de la Haute-Savoie, n.d.) as preventive regulatory documents used to delineate risk areas, often compile historical flood events that affected municipalities.

Newspapers:

- Most of the newspapers used are regional, but one is published at national level (*Le Figaro*) and another is printed in Geneva, Switzerland (*Le Journal de Genève*). Most of the newspapers can be found online or are kept in the departmental or municipal archives. Newspapers describe the causes and consequences of the event and sometimes provide instrumental data and illustrations. They also inform about the public authority response and the past ongoing discussion.

Other records:

- The national database of historical flooding (*Base de Données Historiques sur les Inondations*: BDHI) that gathers floods events considered as “remarkable” in the French territory (Ministère de la Transition Ecologique, n.d.; Boudou, 2015) has been used.
- The database created by the department of Restoration of Mountainous Areas (*Restauration des Terrains en Montagne*: RTM) from the public institution managing the French public forests (*Office National des Forêts*: ONF). The ONF-RTM database gathers transcriptions of observations of the RTM officials as well as information collected from diverse primary sources. These data (labelled RTM in the HIFAVa



228 database) are freely available through the open-access and online ONF-RTM database
229 (RTM and ONF, 2012). Some specific ONF-RTM reports are also included in the
230 HIFAVa. The RTM database was built to assist the management of small tributaries.
231 - A movie realized in 1990 by the RTM is also mentioned as a source.
232 - Some records are from the *Syndicat Mixte d'Aménagement de l'Arve et de ses*
233 *Affluents* (SM3A), which is the institution in charge of the management of the Arve River
234 and its tributaries since 1994.

235

236

3.2. Characteristics of the HIFAVa database.

237

238

239

240

241

242

243

244

245

246

247

248

249

250

251

252

253

254

255

256

257

258

259

260

261

262

263

3.3. Text mining.

264

265

266

267

268

269

270

271

272

273

274

275

276

277

278

The flood impacts of the HIFAVa were categorized through a text quantitative content analysis with the KH Coder software (Higuchi, 2015). The description of the impacts comes from comments contained in the records. The most frequent words have been gathered in order to determine representative categories of the database content. A category is made of several words assigned to a coding rule. Categories have been inspired by the flash flood impact severity scale of Diakakis (2020). This analysis has led to the following seven categories with example of the assigned words:

- Transport network: e.g. "road", "bridge", "railway", "street".
- Urbanized areas and residential buildings: e.g. "house", "town", "basement".
- Natural environment: e.g. "forest", "field", "yield", "sediment transport".
- Protection infrastructures and dams: "dikes" and "dam".
- Industrial, commercial and recreational facilities: e.g. "mill", "factories", "golf", "camping", "hotel", "school".
- Critical installations: "drain", "power transformer".
- Victims: "dead", "injured", "missing", "evacuee".



279
 280
 281
 282
 283
 284

A more in-depth analysis will be conducted later on to define severity classes based on the nature of the impacts. This future analysis will be based on the work of Barriendos et al., (2003), Llasat et al (2005, 2013) and Boudou et al. (2015).

ID	Event	Sources	Start_day	Start_month	Start_year
140	58	Payot 1951 / Goy 2002 / RTM / BDHI	12	7	1892
670	263	RTM / Dauphiné libéré : 26/07/1996, 27/07/1996, 30/07/1996 and 02/08/1996	24	7	1996

Start_date	Time_unc	Hour	River	Impacts	Municipality
12/07/1892	D		Bon Nant	Thermal Bath, victims	Saint-Gervais-les-Bains
24/07/1996	H	11 pm	Arve	City center	Chamonix-Mont-Blanc

Impact_latitude	Impact_longitude	Space_unc	Count	Hydrometeo_descript	Water_level
45.8965	6.70596	A	175	No entry	
45.9257	6.87057	A	0	No entry	0,4m

Flood_description	Impacts_decription
Debris flow. 30 minutes to flow from the Tête Rousse glacier to the Arve confluence.	More than 175 victims, destruction of most of Thermal Bath, mud over the first floor.
Debris flow, logjam under bridges.	Numerous houses and the city center are under water. Fuel oil pollution due to basement flooding.

285
 286
 287
 288
 289
 290
 291
 292
 293
 294
 295
 296
 297
 298

Table 1. Extract of the HIFAVa database showing its structure. Refer to the Online Resource 2 for details about the column contents.

4. Results and discussion.

4.1. Evolving sources over time.

During the studied period, the diversity and the quantity of sources in which mentions of impacts have been found fluctuate (Figure 2). Among the existing databases used, the BDHI database for instance continuously covers the studied period but was sporadically informative since it only contains two mentions of flood impacts in the Arve catchment, respectively in 1892 and in 1987. By contrast, the SM3A database appears later (1979) in the studied time frame.

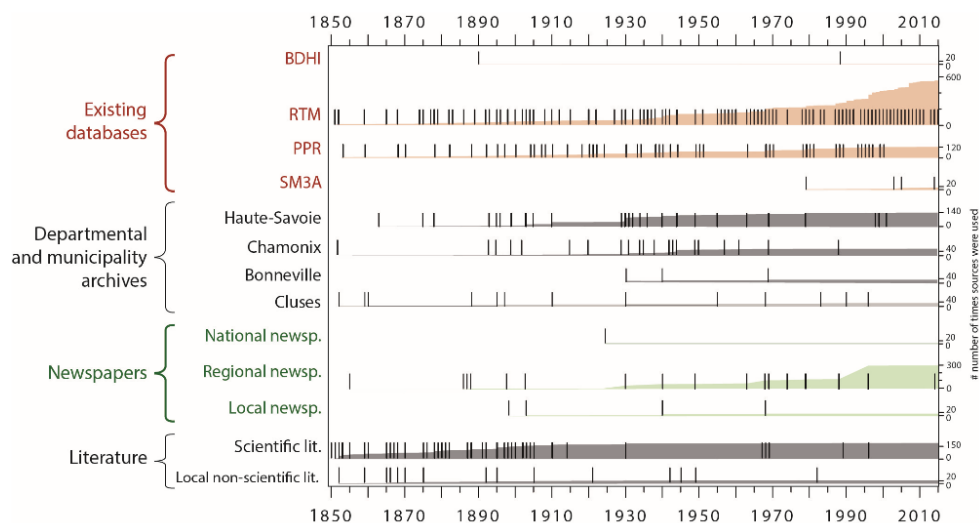


Figure 2. Number and diversity of studied sources to document flood impacts.

299

300

301

302 RTM (38% of the sources), regional newspapers (20%) and scientific literature (13%)
 303 constitute the main sources of information on past flood impacts throughout the studied time
 304 period. Sources from the literature are particularly useful (54%) to document the period
 305 between 1850 and 1910. Then, materials from the departmental and municipality archives are
 306 abundant between 1900 and 1970, especially those from Haute-Savoie (20% of the total
 307 registered sources for this period) and Chamonix (7%). Between 1940 to 2015, the RTM
 308 represents 58% of the sources describing the impacts.

309 One of the evolutions of the sources is the increase in the newspaper articles mentioning flood
 310 impacts. Following the 1881 press freedom French law, the 1880-1889 decade marks the
 311 emergence of articles recording natural hazards, such as flood impacts (Ferenczi, 1996).
 312 However, the 1855 flood in Bonneville was already reported by the swiss newspaper, *Le*
 313 *Journal de Genève*.

314 Although a few sources (e.g. the municipal archives of Sallanches) remain to be examined,
 315 most of them have been analyzed in order to constitute the database. Hence, we consider that
 316 we have a comprehensive view of past flood impacts since 1850 over the whole Arve
 317 catchment.

318

319

4.2. Changes in impacts over time and space.

320

321

322

323

324

325

326

327

328

329

330

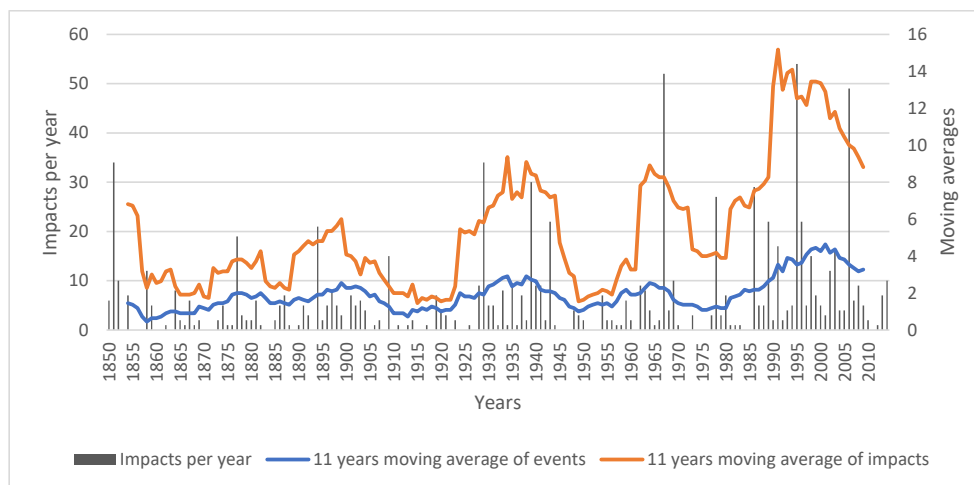
331

From 1850 to 1920, the number of impacts fluctuates and only four years are remarkable with more than 15 impacts (1852, 1878, 1895 and 1910). From 1920, years with such a large number of impacts become more frequent (1930, 1940, 1944, 1968, 1979, 1987, 1990, 1996, 1997 and 2007) and the total amount of impacts per year reaches 54 in 1996 (Figure 3). The decennial moving average of the impacts' number highlights an overall increase over the 165 years, punctuated by periods with less frequent impacts (in 1910-1923, 1950-1960 and 1975-1980).

Besides, the number of recorded flood events stays relatively stable between 1.5 and 3 events per year on average until 1990, then it rises up to 4.5 events per year. Therefore, the overall increase in recorded impacts seems partly disconnected to changes in flood occurrence. Only the latest period (1990-2015) of increasing impacts may be partially due to a rise in flood occurrence. In particular, the increase in flood impacts starting in the 1920's and well-marked



332 since the 1960's, especially by repeated years with very high numbers of impacts, may be
333 explained by other processes as discussed in the next section.
334

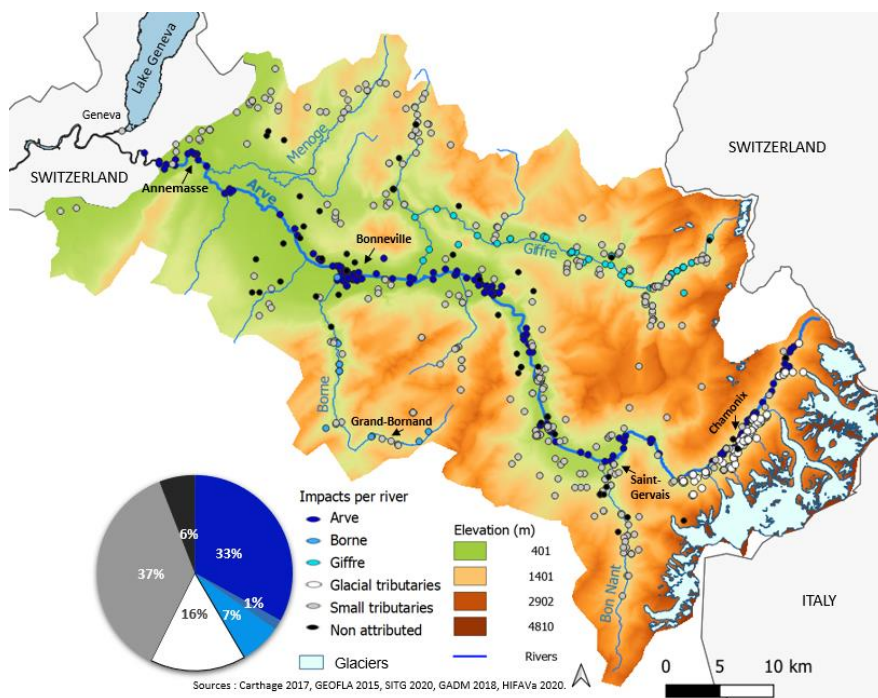


335
336 **Figure 3. Occurrence of impacts and moving averages of impacts and associated flood events.**
337

338 When analyzing the spatial distribution of the flood impacts, we can see that they are
339 spread over the entire catchment (Figure 4). They are, however, mainly gathered in the Arve
340 valley around Chamonix and Bonneville (24 and 12,5% of total impacts recorded in the Arve
341 catchment). These high numbers may be due to the fact that these towns are both among the
342 most densely populated and the closest towns to the Arve River. The impacts caused by the
343 Arve River floods represent 33% of all recorded impacts, and its two main tributaries, the Giffre
344 and the Borne Rivers, have only caused 8% of the recorded impacts. In fact, most impacts are
345 due to small torrential streams (53%). Among them, almost a third is related to glacial
346 tributaries, while these tributaries are localized only in the uppermost part of the catchment
347 near Chamonix. For instance, small torrential tributaries such as the Arveyron, the Grépon (left
348 bank tributary close to Chamonix) or the Bon Nant have caused alone more impacts than the
349 Borne River itself.



350



351

352 Figure 4. Location and distribution of flood impacts caused by the Arve and its tributaries. The
353 category “non attributed” corresponds to the part of impacts for which it was not possible to
354 attribute a river, either because events are related to overland flows or because of the location
355 between two or more rivers.

356

357 The Arve tributaries produced disasters characterized by numerous and major flood damage.
358 Among them, the 1987 Borne River flooding in its uppermost part washed away the municipal
359 campsite of the village of the Grand-Bornand causing 23 casualties and heavy economic
360 losses (Meunier, 1990). In addition, the 1892 glacial lake outburst from the Tête Rousse glacier
361 in the Bon Nant River (which literally translated means “Good Stream”) swept away the thermal
362 bath of Saint-Gervais (Figure A1) and 33 houses causing at least 175 casualties. The glacier
363 was drained in 2010 and is today closely monitored to avoid such a brutal and disastrous
364 natural event (Garambois et al., 2016).

365 All these high impacts events are due to sudden, highly-dynamic summer floods of tributaries,
366 often aggravated by large sediment transport. Some towns located along the Arve River – such
367 as Sallanches – are more prone to tributary’s floods because embankments have been built
368 and efficiently prevent impacts from the Arve flooding. In contrast, there are very few impacts
369 recorded in high altitude, probably due to the sparse human settlements.

370

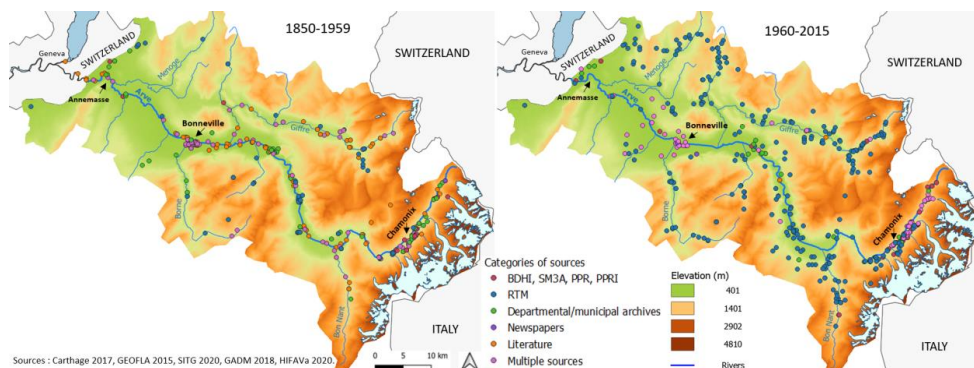
371 4.3. Potential drivers of changes in the number and spatial distribution 372 of impacts.

373

374 The increase in the number of impacts starting in the 1920’s and well-marked from the
375 1960’s can be explained by multiple factors such as indirect source effect, increasing flood
376 activity and/or increasing exposure of goods and people. However, the flood occurrence did
377 not change significantly before the 1990’s (Figure 3). Therefore, the increase in impacts cannot
be explained by changes in flood occurrence, at least prior to 1990.



378 To decipher the potential source effect in the increase in impacts since 1960, maps of
379 the impacts by sources have been drawn for the periods before and after 1960 (Figure 5). For
380 the first period (1850-1959), three main sources describe 64% of the impacts (literary records
381 28%, RTM 18% and departmental and municipal archives 18%) and for 29% the information
382 comes from more than one source. The impacts are mainly gathered along the Arve and the
383 Giffre Rivers, especially in the valley of Chamonix and between the towns of Cluses and
384 Bonneville.
385 For the second period (1960-2015), the RTM reports 65% of the impacts, and 20% come from
386 multiple sources while departmental and municipal archives and the PPR/PPRI describe 5%
387 each. Information coming only from literature decreases substantially (122 described impacts
388 in the first period to 3 impacts in the second), SM3A records start in 1979 and only document
389 the Giffre and the Bon Nant Rivers. The distribution of the impacts is much more scattered
390 across the whole catchment than during the first period. The impacts are not anymore gathered
391 along the Arve River, since most of them result from small tributaries. Impacts described by
392 more than one source are located in the valley of Chamonix and around Bonneville, probably
393 because these economic and touristic centers arouse interest of many sources (newspapers,
394 departmental and municipal archives and RTM). The touristic specificity of valley and its
395 international stature can explain the media coverage. We can assume that, floods are more
396 likely to be reported in newspapers as when they happen in a location known by the reader. In
397 addition, the strong emergence of the RTM since 1940 (Figure 2) can explain the rise in
398 impacts caused by small tributaries illustrates by the Figure 5. Following the floods of the
399 Rhône, the Loire and the Garonne in 1854, the 1858 law against urban flooding places flood
400 control at the heart of the national legislation for the first time. In the following, the RTM
401 department was formed for the reforestation of mountains slope in order to prevent the
402 reproduction of major floods. The department became quickly efficient and since 1860
403 collected numerous reports. Built for the study and management of small tributaries, the RTM
404 database became the main source of information since 1930 for the HIFAVa database.
405



406 Sources : Carthage 2017, GEOFLA 2015, SITG 2020, GADM 2018, HIFAVa 2020
407 Figure 5. Distribution of the sources describing the recorded flood impacts in the Ave
408 catchment during two periods: 1850-1959 and 1960-2015.
409

410 The rise in the number of impacts per flood may be partly explained by the fact that distinct
411 impact types in the same location were reported and therefore referenced under distinct impact
412 ID while they were not differentiated in previous periods. Recent sources seem to provide more
413 accurate information on the impacts and their locations. In older sources, impacts are most of
414 the time documented at the city scale (21% of the impacts for the first period, and 10% for the
415 second period). Thereby, all these impacts are stored in the database in a single line with an
416 uncertainty code for the impact location corresponding to the municipal level. In most recent

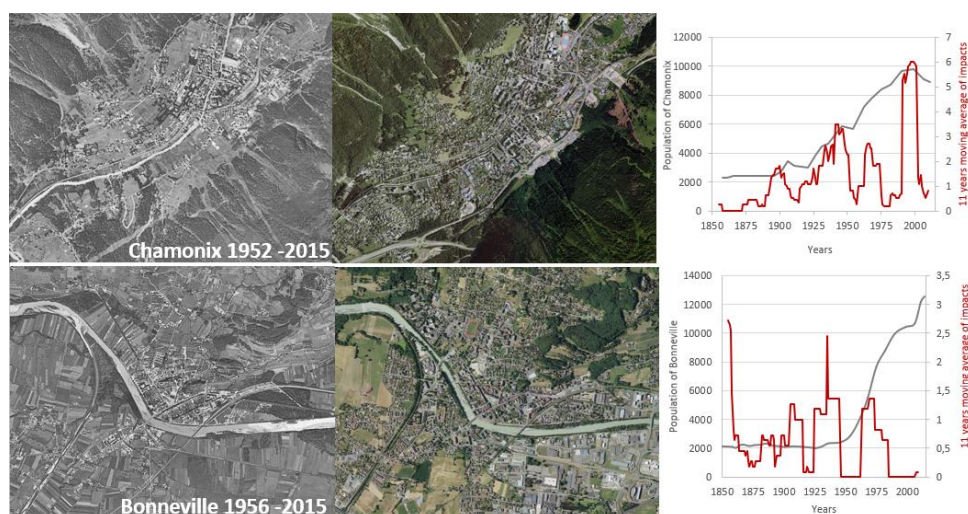


417 sources, impacts' locations are described more accurately allowing to record them at a
418 resolution up to the building scale. As a result, impacts are stored in as many lines as impacts
419 locations can be identified, with an uncertainty code for the impact's location corresponding to
420 the building or neighborhood level (85% of the impacts for the second period). For example, in
421 1996 fifty-three impacts were recorded for a same event and fifty of them were located in
422 distinct places in Chamonix. The rise in impacts can also be due to numerous impacts in
423 different locations, as the flood of 1990 which impacted six towns in two different sub-
424 catchments (the Arve and the Giffre catchments). However, in order to overcome the bias
425 induced by the recording of impacts according to their location, we have aggregated the
426 impacts at the municipality level. That is to say, all the impacts reported for a given municipality
427 that were caused by the same event (thus the same day) are recorded under the same line in
428 the database. This results in 562 "aggregated" impacts instead of 917 impacts initially. From
429 these data, we have redrawn Figure 3 (Figure A2) comparing the moving average of impacts
430 and associated events. We can see that the trends are significantly the same. There is an
431 increase of impacts (here starting soon as 1890s) and a late increase of events (1990s). Thus,
432 the way the impacts are stored in the database (by location or by municipality) does not affect
433 the observed temporal changes in impacts.

434

435 Changes in exposure and vulnerability related to land use is another potential
436 explanation of the rise in the number of impacts (Magnan et al., 2012; Garnier and Desarthe,
437 2013; Camuffo et al., 2020). A major population growth happened, especially in Bonneville and
438 Chamonix, leading to a strong and fast urban sprawl in the flood plain between the 1950's and
439 the 2010's as shown by aerial photographs (Figure 6). They also show the vanishing of the
440 alluvial forest (Dufour and Piégay, 2006) and cultivated fields to the benefit of urbanization in
441 both towns. The population growth in the Arve Valley varies according to the towns. Upstream,
442 in Chamonix, the demographic expansion dates back to the early 20th century with the flourish
443 of mountain tourism. In downstream towns – e.g. Bonneville and Annemasse – the expansion
444 starts in the 1950's because of the economic attractiveness of Geneva.

445



446

447 Figure 6. Land use evolution and expansion demographic associated with impacts of
448 Chamonix and Bonneville from 1848 to 2011 (© IGN).

449

450 Besides these numbers, the urban expansion and the growth in tourism come with the arrival
451 of new residents in the valley (Haute-Savoie : la plus forte croissance démographique de



452 métropole, 2020), unaware of the local hazard history. The valley narrowness, the demand for
453 land and the loss of memory of past events have led to build in historical flood-prone area,
454 resulting in an increased exposure. For instance, in 1944 recently built houses in Chamonix
455 were washed away by the Grépon River. The same situation also happened during the 1968
456 flood that destroyed a new residential area in Bonneville. In Chamonix, the number of impacts
457 punctually increase from year to year, somehow mirroring the population growth (Figure 6).
458 Increasing exposure due to population growth and urbanization may then explain the
459 increasing number of impacts. One can, however, notice the decrease in impacts after the
460 disastrous 1996 flood event. This is due to the heightening of the dikes after the 1996 flood. In
461 Bonneville, the link between the number of impacts and the population growth is not clear.

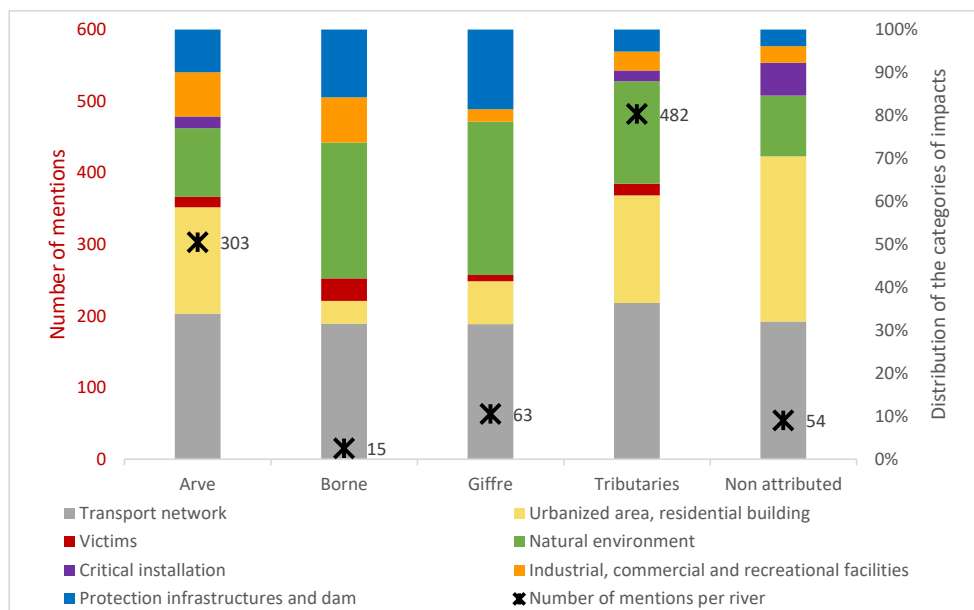
462
463
464

4.4. Nature of the flood impacts.

465 The quantitative analysis of text content reveals the distribution of the impact categories
466 by river and illustrates the diversity of the catchment in terms of land use and economic
467 development (Figure 7). This analysis of text content is particularly relevant because it allows
468 to overcome the database scarcity of quantitative information on the severity of the flood.
469 Indeed, it is difficult to estimate the severity of the flood event as the flow rate and the water
470 height are only exceptionally mentioned. However, a link can be made between the impact
471 nature and the severity of the event (Barriendos et al., 2019).
472 The number of occurrences of the words determining the category is here named as the
473 number of mentions. For the overall Arve catchment, damage to the transport network is the
474 most frequent (406 mentions), followed by damage to urbanized areas (286) and natural
475 environment (253). Impacts on transport network are in proportion equally distributed among
476 river types (all around 30%). Impacts on industrial facilities are mainly caused by the Arve
477 and the Giffre Rivers as their wider valleys allow the installation of these facilities. The Giffre
478 and the Borne Rivers have caused the least impacts specifically on urban areas, probably
479 because of less dense population and of an economy based on farming and tourism activities.



480



481

482 **Figure 7. Distribution of flood impacts according to the river types. The class “non attributed”**
 483 **correspond to all impact with no assigned river (e.g. overland flows).**

484

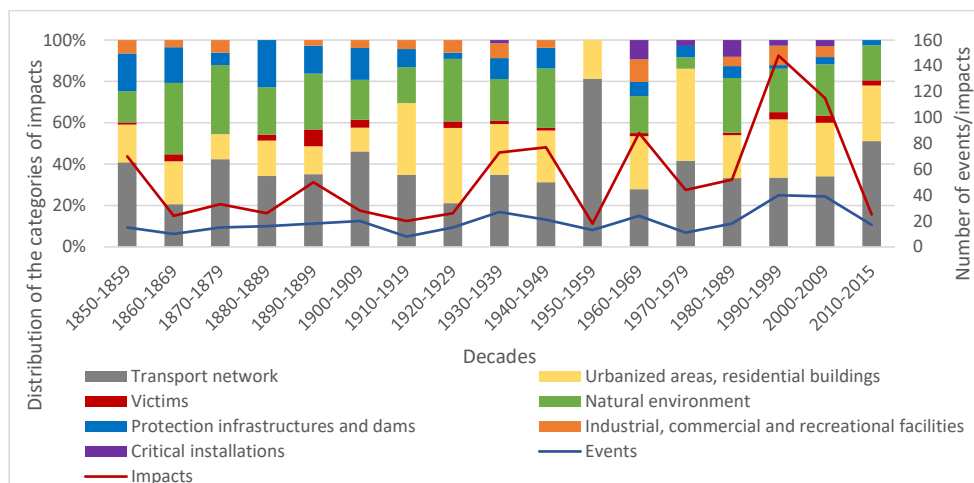
485 Most of the mentions of victims refer to impacts caused by tributaries (20 out of 28). They have
 486 caused 80% of the deadly impacts registered since 1850 in the whole catchment, e.g. the 1892
 487 glacial lake outburst and the 1987 flood of Grand-Bornand. The mentions of victims of the
 488 Borne River should belong to the small tributaries class as the impacts occurred in the
 489 uppermost part of the catchment. This high mortality may be due to sudden and strong floods
 490 and to less developed infrastructure of flood protection on the tributaries.

491

492 To track potential changes in the nature of impacts since 1850, they are scrutinized by
 493 decades over the last 165 years (Figure 8). Impacts on transportation networks are present in
 494 every decade since 1850 but they increase after 1930 as well as impacts on urbanized area
 495 and natural environment categories. It was not until 1960 that impacts on the industrial,
 496 commercial and recreational facilities category increased. Mentions about critical installation
 497 (sewers and water pipes) are recorded for the first time in the 1960’s. Mentions of victims
 498 are present in almost every decade. Two decades (1950 and 1970) stand out in terms of category’s
 499 distribution.

500 Nevertheless, no major evolution of the impacts categories can be seen, except the
 501 emergence of mentions of critical installations in the 1930’s. The categories used for the
 502 analyze have been inspired by a recent paper from Diakakis (2020) but in order to deepen our
 503 analysis of the historical evolution of the impacts’ nature some other and more precise
 504 classifications should be tested in the future as well as the evolution of the assigned words.

505



506

507 **Figure 8. Decennial histogram of the evolution of the categories of impacts divided by the**
508 **number of events.**

509

510 This analysis of proportions, however, hinders changes in absolute values. For instance, at
511 the catchment scale there is a slight increase in the number of mentions of the victims category
512 since 1980 (16 out of 28) (Figure 8). This increase is not easily noticeable when looking at
513 proportions of impacts categories because of the strong augmentation in the total number of
514 mentions since 1930. Yet, apart from the disaster in the Grand-Bornand in 1987, since 1931
515 all the mentions of victims refer to evacuations, recues or injuries.

516 The number of impacts has been almost multiplied by two since 1920. Hence, the mentions of
517 impacts on natural environment for the period 1850-1930 were multiplied by more than two
518 compared to the period 1960-2015. During the first period, mentions of impacts on natural
519 environment refer mainly to forest, field and crops, while after 1960 there is no mention of field
520 or crops and most of the mentions are about gullying, deposition of sediments and banks. This
521 is in agreement with the evolution of the land use due to the demographic growth, i.e. the
522 observed vanishing of forest areas and cultivated land to the benefit of urbanization (Figure 6).
523 Yet, mentions of impacts on urbanized areas during 1960-2015 has been multiplied almost by
524 four compared to the 1850-1930 period. This agrees with observed changes in land use
525 characterized by urban sprawl.

526

527 **5. Conclusions.**

528 We collected historical information from 1850 onwards to document flood impacts in
529 the Arve valley, an Alpine catchment characterized by a high hydrological and socioeconomic
530 diversity. The analysis of the HIFAVa database led to acknowledge the rise in the number of
531 impacts starting in 1920 and well-marked from 1960. This rise does not seem to be related to
532 increased flood hazard since it does not follow changes in flood occurrence, except partially
533 for the latest period (1990-2015). Instead, more frequent impact could be explained by
534 increased exposure related to the demographic growth (tourism and economic attractiveness
535 of Geneva) and/or by the evolution of the sources, in particular the emergence of the RTM.

536 There are two main types of flood events causing impacts in the catchment, e.g. floods related
537 to the main river and those related to the smaller mountain streams. Floods from these small
538 streams are characterized by sudden and fast hydrological responses and large sediment
539 transport, making hazard management difficult. They caused two third of the 916 recorded
540 impacts with numerous casualties and gathered impacts, such as the 1892 Bon Nant and the



541 1987 Borne rivers floods. In contrast, slow rising floods of the Arve River last in general several
542 days, affect a large area and trigger mainly economics consequences and no casualties. The
543 1968 flood affecting a large part of the Arve catchment is an exemplary case of this flood type.
544 The analysis of the nature of the impacts does not reveal a clear evolution over the last 165
545 years. However, further work is required to define more detailed categories allowing to
546 question the evolution of the assigned words since 1850. Additional investigations of the
547 municipal archives and interviews of local flood risk managers should also be undertaken to
548 allow answering some key questions, such as the definition of high-impacts events in this very
549 valley. The processes of risk memory transmission and the evolution of the local political risk
550 management will be queried for the purpose of understanding the evolution of the social
551 vulnerability. The following study of this database aim to better understand how hazard,
552 exposure and vulnerability combines to trigger high impacts events across the recent history
553 of the Arve catchment.
554
555
556



557 **Appendixes**

558

559 Table A1. List of the historical records – or their origin – used to provide information about flood events
 560 and impacts collected in the HIFAVa database. The date mentions the year of publication for books
 561 and period covered by the newspapers.

Manuscript materials	Printed materials	Newspapers	Other records
ADHS	AM Cluses	ADHS	BDHI
AM Bonneville	Conard 1931	Le Messager (1965-1968)	RTM (movie 1990)
AM Chamonix	Douvinet 2011	Le Dauphiné libéré (1963-2014)	SM3A
AM Cluses	Goy 2002	Journal de Genève (1855-1978)	
	Mestrallet 1986	La Croix 74 (1898)	
	Mougin 1914	L'Allobroge (1903-1940)	
	Parde 1931	Le Faucigny (1968)	
	Payot 1951	Le Figaro (1924)	
	PPR	Le Messager (1940)	
	PPRI	Le Mont-Blanc républicain (1903)	
	Rannaud 1916	Le Progrès (1898)	
	Rougier	L'Industriel Savoisien (1910)	
	RTM	La Revue Savoissienne (1887-1889)	

562

563

564

565 Table A2. Presentation of the HIFAVa database showing its structure with each data entry.

id	[PK] serial	Primary key. ID number of an impact.
event	integer	Number of the event that triggers the impact. In case of an hydro-meteorological event, several impacts located at different places on different river are associated to the same event.
sources	integer	The different sources that provide information.
start_day	integer	Start day of event.
start_mont	integer	Start month of event.
start_year	integer	Start year of event.
start_date	date	Start date of event.
hour	text	Start hour of event.
time_unc	text	Uncertainty of the start date. H means that the start date is known at the hour scale, D at the day scale, M at the month scale and Y at the year scale. By default, when the day and/or the month is not known, "1" is attributed to start_day and/or start_month.
duration	real	Duration of event
river	text	River that trigger the flood (the cell may be empty if the impacts are not related to river flooding).
impact	text	Nature of impact.
municipality	text	Municipality where the impact is located.
imp_lat	real	Latitude of the impact in decimal degrees.



imp_long	real	Longitude of the impact in decimal degrees.
Space_unc		Describe the spatial scale of impact location. A means that the impact is located at the scale of a point on a map, B at the scale of a part of a city, C at the scale of a city, D at a coarser scale than the one of a city.
count	integer	Number of victims
hydrometeo_descript	text	Description of the hydrometeorological event according to the sources.
precipitation	real	Precipitation rate given in the sources (mm).
flood_descript	text	Description of the flood from the sources
river_water_level	real	Water level of the river (m).
water_level	real	Water level of flooded area (m).
discharge	real	Discharge of the river (m3/s)
impact_descript	text	Description of the impacts according to the sources.

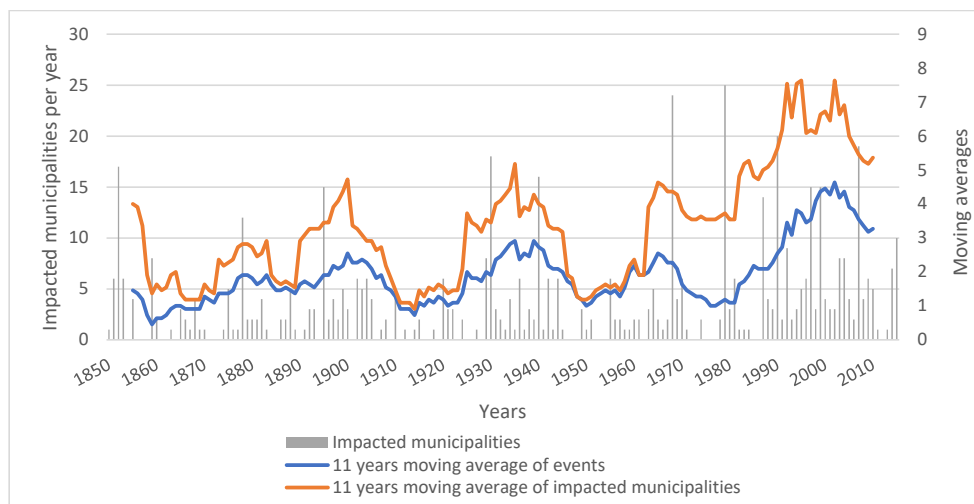
566
 567

568 Figure A1. The wiped-out thermal bath of Saint-Gervais after the debris flow of the 12th of July 1892
 569 (Thermes de Saint-Gervais Mont-Blanc, 2021).



570
 571
 572
 573
 574

Figure A2. Occurrence of impacts and moving averages of impacted municipalities and associated flood events (one line = one municipality impacted by a flood event).



575
576
577
578
579
580
581
582
583
584
585
586
587
588

Acknowledgments: We would like to thank the *Syndicat Mixte d'Aménagement de l'Arve et de ses Affluents* who shared its database of events and impacts. The HIFAVa database was partly fed thanks to the funding of the projects Labex ITEM CrHistAI and OSUG2020 RHAAP. This study was developed in the framework of *CDP-Trajectories* of the Grenoble-Alpes University (France) funded by the *Agence Nationale de la Recherche* through the project "*Investissements d'avenir*" (ANR-15-IDEX-02).



589 **Bibliography:**

590

591 Antoine, J.-M.: Vulnérabilité et adaptation des sociétés montagnardes à la torrentialité au cours du
592 Petit Âge Glaciaire dans les Pyrénées, *soe*, 53–66, <https://doi.org/10.4000/soe.685>, 2011.

593 Barriendos, M., Coeur, D., Lang, M., Llasat, M. C., Naulet, R., Lemaitre, F., and Barrera, A.: Stationarity
594 analysis of historical flood series in France and Spain (14th–20th centuries), *Nat. Hazards Earth Syst.*
595 *Sci.*, 3, 583–592, <https://doi.org/10.5194/nhess-3-583-2003>, 2003.

596 Barriendos, M., Ruiz-Bellet, J. L., Tuset, J., Mazón, J., Balasch, J. C., Pino, D., and Ayala, J. L.: The
597 “Prediflood” database of historical floods in Catalonia (NE Iberian Peninsula) AD 1035–2013, and its
598 potential applications in flood analysis, *Hydrol. Earth Syst. Sci.*, 18, 4807–4823,
599 <https://doi.org/10.5194/hess-18-4807-2014>, 2014.

600 Barriendos, M., Gil-Guirado, S., Pino, D., Tuset, J., Pérez-Morales, A., Alberola, A., Costa, J., Balasch, J.
601 C., Castellort, X., Mazón, J., and Ruiz-Bellet, J. L.: Climatic and social factors behind the Spanish
602 Mediterranean flood event chronologies from documentary sources (14th–20th centuries), *Global and*
603 *Planetary Change*, 182, 102997, <https://doi.org/10.1016/j.gloplacha.2019.102997>, 2019.

604 Beck, U.: *Risk Society : Towards a New Modernity*, Sage., London, 1992.

605 Bernard, C.: *Restauration et conservation des terrains en montagne : les terrains et les paysages*
606 *torrentiels (Haute-Savoie)*, Impr. nationale (Paris), 60 pp., 1900.

607 Blöschl, G., Kiss, A., Viglione, A., Barriendos, M., Böhm, O., Brázdil, R., Coeur, D., Demarée, G., Llasat,
608 M. C., Macdonald, N., Retsö, D., Roald, L., Schmocker-Fackel, P., Amorim, I., Bělinová, M., Benito, G.,
609 Bertolin, C., Camuffo, D., Cornel, D., Doktor, R., Elleder, L., Enzi, S., Garcia, J. C., Glaser, R., Hall, J.,
610 Haslinger, K., Hofstätter, M., Komma, J., Limanówka, D., Lun, D., Panin, A., Parajka, J., Petrić, H.,
611 Rodrigo, F. S., Rohr, C., Schönbein, J., Schulte, L., Silva, L. P., Toonen, W. H. J., Valent, P., Waser, J., and
612 Wetter, O.: Current European flood-rich period exceptional compared with past 500 years, *Nature*,
613 583, 560–566, <https://doi.org/10.1038/s41586-020-2478-3>, 2020.

614 Boudou, M.: *Approche multidisciplinaire pour la caractérisation d’inondations remarquables :*
615 *enseignements tirés de neuf évènements en France (1910–2010)*, *Geography*, Université Paul Valéry -
616 Montpellier I, Lyon, 462 pp., 2015.

617 Boudou, M., Denis, C., Michel, L., and Freddy, V.: Grille de lecture pour la caractérisation d’évènements
618 remarquables d’inondations en France: Exemple d’application pour la crue de mars 1930 dans le bassin
619 de la Garonne et du Tarn, 22, 2015.

620 Camuffo, D., della Valle, A., and Becherini, F.: A critical analysis of the definitions of climate and
621 hydrological extreme events, *Quaternary International*, 538, 5–13,
622 <https://doi.org/10.1016/j.quaint.2018.10.008>, 2020.

623 Conseil départemental de la Haute-Savoie: *Archives départementales de Haute-Savoie*, n.d.

624 Cutter, S. L.: The Vulnerability of Science and the Science of Vulnerability, *Annals of the Association of*
625 *American Geographers*, 93, 1–12, <https://doi.org/10.1111/1467-8306.93101>, 2003.

626 Diakakis, M., Deligiannakis, G., Antoniadis, Z., Melaki, M., Katsetsiadou, N. K., Andreadakis, E., Spyrou,
627 N. I., and Gogou, M.: Proposal of a Flash Flood Impact Severity Scale for the classification and mapping
628 of flash flood impacts., 2020.



- 629 Douvinet, J., Defossez, S., Anselme, A., and Denolle, A.-S.: Les maires face aux plans de prévention du
630 risque inondation (PPRI), 40, 31, <https://doi.org/10.3917/eg.401.0031>, 2011.
- 631 Dufour, S. and Piégay, H.: Forêts riveraines des cours d'eau et ripisylves : spécificités, fonctions et
632 gestion, *Rev. For. Fr.*, <https://doi.org/10.4267/2042/6704>, 2006.
- 633 Ferenczi, T.: L'invention du journalisme en France, Naissance de la presse moderne à la fin du XIXème
634 siècle, Payot., Paris, 274 pp., 1996.
- 635 Garambois, S., Legchenko, A., Vincent, C., and Thibert, E.: Ground-penetrating radar and surface
636 nuclear magnetic resonance monitoring of an englacial water-filled cavity in the polythermal glacier of
637 Tête Rousse, 81, 2016.
- 638 Garnier, E.: Genève face à la catastrophe 1350-1950. Un retour d'expérience pour une meilleure
639 résilience urbaine., Slatkine, Genève, Suisse, 195 pp., 2016.
- 640 Garnier, E.: Xynthia, February 2010: Autopsy of a Foreseeable Catastrophe, in: Management of the
641 Effects of Coastal Storms: Policy, Scientific and Historical Perspectives, Quevauviller, P., 111–148, 2017.
- 642 Garnier, E.: Lessons learned from the past for a better resilience to contemporary risks, 28, 778–794,
643 2019.
- 644 Garnier, E. and Desarthe, J.: Cyclones and Societies in the Mascarene Islands 17th-20th Centuries,
645 *AJCC*, 1–13, <https://doi.org/10.4236/ajcc.2013.21001>, 2013.
- 646 Garnier, E., Ciavola, P., Spencer, T., Ferreira, O., Armaroli, C., and Mclvor, A.: Historical analysis of storm
647 events: Case studies in France, England, Portugal and Italy, 134, 10–23, 2018.
- 648 Gex, F.: La Haute-Savoie aujourd'hui et il y a 100 ans avec un tableau de la population par commune
649 de 1801 à 1921., Librairie M. Dardel, Chambéry, 1924.
- 650 Giacona, F., Eckert, N., and Martin, B.: A 240-year history of avalanche risk in the Vosges Mountains
651 based on non-conventional (re)sources, 17, 887–904, <https://doi.org/10.5194/nhess-17-887-2017>,
652 2017.
- 653 Giacona, F., Martin, B., Furst, B., Glaser, R., Eckert, N., Himmelsbach, I., and Edelblutte, C.: Improving
654 the understanding of flood risk in the Alsatian region by knowledge capitalization: the ORRION
655 participative observatory, *Nat. Hazards Earth Syst. Sci.*, 19, 1653–1683, <https://doi.org/10.5194/nhess-19-1653-2019>, 2019.
- 657 Gil-Guirado, S., Espín-Sánchez, J.-A., and Del Rosario Prieto, M.: Can we learn from the past? Four
658 hundred years of changes in adaptation to floods and droughts. Measuring the vulnerability in two
659 Hispanic cities, *Climatic Change*, 139, 183–200, <https://doi.org/10.1007/s10584-016-1768-0>, 2016.
- 660 Gil-Guirado, S., Pérez-Morales, A., and Lopez-Martinez, F.: SMC-Flood database: a high-resolution
661 press database on flood cases for the Spanish Mediterranean coast (1960–2015), *Nat. Hazards Earth
662 Syst. Sci.*, 19, 1955–1971, <https://doi.org/10.5194/nhess-19-1955-2019>, 2019.
- 663 Giorgi, F., Zsolt Torma, C., Coppola, E., and Ban, N.: Enhanced summer convective rainfall at Alpine high
664 elevations in response to climate warming, 9, 2016.



- 665 Gobiet, A., Kotlarski, S., Beniston, M., Heinrich, G., Rajczak, J., and Stoffel, M.: 21st century climate
666 change in the European Alps—A review, *Science of The Total Environment*, 493, 1138–1151,
667 <https://doi.org/10.1016/j.scitotenv.2013.07.050>, 2014.
- 668 Goy, J.: *Autour de la catastrophe de l'établissement thermal de Saint-Gervais-les-Bains en 1892 :
669 problèmes d'histoire des catastrophes naturelles., Les pouvoirs publics face aux risques naturels dans
670 l'histoire., Grenoble, 39–49, 2002.*
- 671 Higuchi, K.: KH Coder, 2015.
- 672 Haute-Savoie : la plus forte croissance démographique de métropole:
673 <https://www.insee.fr/fr/statistiques/3689656>, last access: 1 August 2020.
- 674 INSEE: *Populations légales communales depuis 1968, 2019.*
- 675 IPCC: *Managing the risks of extreme events and disasters to advance climate change adaptation,
676 Intergovernmental Panel on Climate Change, 2012.*
- 677 IPCC: *The Ocean and Cryosphere in a Changing Climate, Intergovernmental Panel on Climate Change,
678 Genève, Suisse, 2019.*
- 679 Lastoria, B., Simonetti, M. R., Casaioli, M., Mariani, S., and Monacelli, G.: *Socio-economic impacts of
680 major floods in Italy from 1951 to 2003, Adv. Geosci., 7, 223–229, [https://doi.org/10.5194/adgeo-7-
681 223-2006](https://doi.org/10.5194/adgeo-7-223-2006), 2006.*
- 682 Leone, F. and Vinet, F.: *La vulnérabilité, un concept fondamental au cœur des méthodes d'évaluation
683 des risques naturels, in: La vulnérabilité des sociétés et des territoires face aux menaces naturelles,
684 GESTER, 2006.*
- 685 Llasat, M. C., Llasat-Botija, M., and López, L.: *A press database on natural risks and its application in
686 the study of floods in Northeastern Spain, Nat. Hazards Earth Syst. Sci., 9, 2049–2061,
687 <https://doi.org/10.5194/nhess-9-2049-2009>, 2009.*
- 688 Llasat, M. C., Llasat-Botija, M., Petrucci, O., Pasqua, A. A., Rosselló, J., Vinet, F., and Boissier, L.: *Towards
689 a database on societal impact of Mediterranean floods within the framework of the HYMEX project,
690 Nat. Hazards Earth Syst. Sci., 13, 1337–1350, <https://doi.org/10.5194/nhess-13-1337-2013>, 2013.*
- 691 Llasat, M.-C., Barriendos, M., Barrera, A., and Rigo, T.: *Floods in Catalonia (NE Spain) since the 14th
692 century. Climatological and meteorological aspects from historical documentary sources and old
693 instrumental records, Journal of Hydrology, 313, 32–47,
694 <https://doi.org/10.1016/j.jhydrol.2005.02.004>, 2005.*
- 695 Magnan, A., Duvat, V., and Garnier, E.: *Reconstituer les « trajectoires de vulnérabilité » pour penser
696 différemment l'adaptation au changement climatique, Nat. Sci. Soc., 20, 82–91,
697 <https://doi.org/10.1051/nss/2012008>, 2012.*
- 698 Mélo, A., Wilhelm, B., Giguët-Covex, C., and Arnaud, F.: *Construire une chronique d'inondations :
699 événements hydrologiques et histoire climatique dans le bassin de l'Arve (Alpes du Nord, France) entre
700 les XVIIIe et XXIe siècles., 40, 411–419, 2015.*
- 701 Ménégos, M., Valla, E., Jourdain, N. C., Blanchet, J., Beaumet, J., Wilhelm, B., Gallée, H., Fettweis, X.,
702 Morin, S., and Anquetin, S.: *Contrasting seasonal changes in total and intense precipitation in the
703 European Alps from 1903 to 2010, 1–37, <https://doi.org/10.5194/nhess-2019-690>, 2020.*



- 704 Merz, R. and Blöschl, G.: Regional flood risk—what are the driving processes?, 40–58, 2003.
- 705 Meunier, M.: La catastrophe du Grand Bornand : crue torrentielle du Borne le 14 juillet 1987, 78, 103–
706 114, 1990.
- 707 Min, S.-K., Zhang, X., Zwiers, F. W., and Hegerl, G. C.: Human contribution to more-intense precipitation
708 extremes, *Nature*, 470, 378–381, <https://doi.org/10.1038/nature09763>, 2011.
- 709 Ministère de la Transition écologique: Prévention des risques naturels, 2020.
- 710 Ministère de la Transition Ecologique: Base de Données Historiques sur les Inondations, n.d.
- 711 Mougin, P.: Les torrents de la Savoie, Société d'histoire de la Savoie, Grenoble, 1914.
- 712 Papagiannaki, K., Lagouvardos, K., and Kotroni, V.: A database of high-impact weather events in
713 Greece: a descriptive impact analysis for the period 2001–2011, *Nat. Hazards Earth Syst. Sci.*, 13, 727–
714 736, <https://doi.org/10.5194/nhess-13-727-2013>, 2013.
- 715 Pardé, M.: Les crues de l'Arve en octobre 1930, *rga*, 19, 495–497,
716 <https://doi.org/10.3406/rga.1931.4782>, 1931.
- 717 Peiry, J. L. and Bravard, J. P.: Evolution naturelle d'un remplissage sédimentaire intramontagnard et
718 impacts des aménagements contemporains : L'exemple de la vallée de l'Arve (74), *La Houille Blanche*,
719 221–225, <https://doi.org/10.1051/lhb/1989018>, 1989.
- 720 Petrucci, O., Aceto, L., Bianchi, C., Bigot, V., Brázdil, R., Pereira, S., Kahraman, A., Kılıç, Ö., Kotroni, V.,
721 Llasat, M. C., Llasat-Botija, M., Papagiannaki, K., Pasqua, A. A., Řehoř, J., Rossello Geli, J., Salvati, P.,
722 Vinet, F., and Zêzere, J. L.: Flood Fatalities in Europe, 1980–2018: Variability, Features, and Lessons to
723 Learn, *Water*, 11, 1682, <https://doi.org/10.3390/w11081682>, 2019.
- 724 Préfecture de la Haute-Savoie: Données communales : plans de prévention des risques naturels
725 (PPRN), Les services de l'Etat en Haute-Savoie, n.d.
- 726 Rougier, H.: Les inondations du 24 juillet dans la haute vallée de l'Arve : faits et conséquences à tirer
727 pour l'aménagement du territoire., *Les pouvoirs publics face aux risques naturels dans l'histoire.*,
728 Grenoble, 51–64, 2001.
- 729 Rousset-Mestrallet, M.: Des torrents et des hommes. Trois siècles d'histoire à Samoëns., *Imprim'off 7*,
730 Marignier, 150 pp., 1986.
- 731 RTM and ONF: Base de Données RTM, 2012.
- 732 Soanes, C. and Stevenson, A.: Catastrophe, *Concise Oxford English Dictionary*, 11 (revised), 2009.
- 733 Thermes de Saint-Gervais Mont-Blanc: The wiped-out thermal bath of Saint-Gervais after the debris
734 flow of the 12th of July 1892., [https://www.thermes-saint-gervais.com/wp-](https://www.thermes-saint-gervais.com/wp-content/uploads/2018/07/STGMB-7.jpg)
735 [content/uploads/2018/07/STGMB-7.jpg](https://www.thermes-saint-gervais.com/wp-content/uploads/2018/07/STGMB-7.jpg), 30 March 2021.
- 736 Thoumas, P.: Histoire des crues du Roubion (Drôme, France) depuis 1501 AD, une approche
737 hydrologique des fluctuations climatiques sur cinq siècles, *physio-geo*, 14, 87–111,
738 <https://doi.org/10.4000/physio-geo.8984>, 2019.



- 739 Viani, A., Condom, T., Sicart, J.-E., Rabatel, A., Gascoin, S., Ranzi, R., and Wimez, M.: Impact of the
740 glacier retreat and snow melt on the seasonal cycle of streamflow of the Arve catchment since the
741 1960s (Northern French Alps), EGU General Assembly, Vienna, Austria, 1, 2018.
- 742 Wetter, O.: The potential of historical hydrology in Switzerland, *Hydrol. Earth Syst. Sci.*, 21, 5781–5803,
743 <https://doi.org/10.5194/hess-21-5781-2017>, 2017.
- 744 Wilhelm, B., Ballesteros Canovas, J. A., Macdonald, N., Toonen, W., Baker, V., Barriendos, M., Benito,
745 G., Brauer, A., Corella, J. P., Denniston, R., Glaser, R., Ionita, M., Kahle, M., Liu, T., Luetscher, M.,
746 Macklin, M., Mudelsee, M., Munoz, S., Schulte, L., St. George, S., Stoffel, M., and Wetter, O.:
747 Interpreting historical, botanical, and geological evidence to aid preparations for future floods, 6,
748 <https://doi.org/10.1002/wat2.1318>, 2019.
- 749